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A GENERAL APPROACH TO DESCRIBING THE DRIVER-VEHICLE INTERACTION

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Abstract. The aim of this study was to demonstrate that the theory of functional systems is appropriate for describing interaction of the driver with the vehicle and environment. Well-known driver behaviour models describe the different stages of the human cognitive process, but do not describe how humans control their actions. Description of the cognitive process of drivers in terms of the results of their actions, will make it possible to explore various aspects of the human factors in different road situations. We employed the methods of the P. K. Anokhin's theory of functional systems to create a conceptual model of the «driver – automated vehicle» system. The proposed conceptual model allows to describe the driver's cognitive process gradually, stage by stage based on a dynamic coupling mechanism that evaluates the deviations of the actual values of the result parameters of the driver's actions from the expected values. The theory of functional systems is promising and has the potential for describing the driver-vehicle interaction. The proposed conceptual model can be used as a framework to develop computational models of the driver-vehicle interaction for understanding how driver-vehicle interface must be designed for comfort and safety.

Keywords: vehicle automation, driver behaviour, driver state, human–machine interaction, human factors.

Introduction.

Currently, a gradual transition from human-driven vehicles to autonomous vehicles is taking place in the world [1-3]. This process is characterized by increasingly complex electronic systems to improve the safety, efficiency and comfort of the driving [4-6]. On the one hand, such trend makes it easier for the drivers to work, but on the other hand, poses new issues associated with their complacency, lack of attention to the road, loss of situation awareness, sudden changes in workload, and degradation of driving skills and abilities due to the fact that the highly automated vehicles allow the drivers to be out of the control loop for extended periods but don't exclude resuming of the manual control at any time [2, 4, 7 – 9]. The aforementioned factors can affect driver's performance negatively during transitions between an automated and manual vehicle control and therefore need to be carefully studied for providing the safety and efficiency of the automated vehicles [1, 2, 9 – 13]. For this objective, it is important to develop an appropriate conceptual model of the interactions between the driver and the automated vehicle that could serve as a theoretical basis for developing computational models to investigate different aspects of driver behaviour in different traffic situations.

Traditionally, the driver is treated as an information processing unit (figure 1) that receives data from its sensory systems, processes them to gain situation awareness for decision-making, and executes appropriate control responses [14-17]. Herewith, it is assumed that driver errors occur because of the limitations in the human abilities to allocate attention and process information. Such approach to the modelling and analysis of the interactions between the driver and the automated vehicle allows to investigate the influence of different stages of the cognitive process of drivers and their functional abilities on driving performance. But well-known driver behaviour models [14-19] do not take into account the dynamic coupling mechanism between the decision making of a driver to perform a particular action and changes of road conditions which evaluates the deviations of the actual values of the driver's actions result parameters from the expected values. A more complete description of the cognitive process of drivers, including the evaluation of the results of their actions, will allows developing new mathematical and simulation models of driving an automated vehicle to examine different aspects of human factor in transitions between driver and automated driving. The practical application of large-scale simulation models for these purposes will require the use of cloud technologies, since the highly automated vehicles are not only consuming but also generating a huge amount and heterogeneous types of data, which is referred to as Big Data [20].

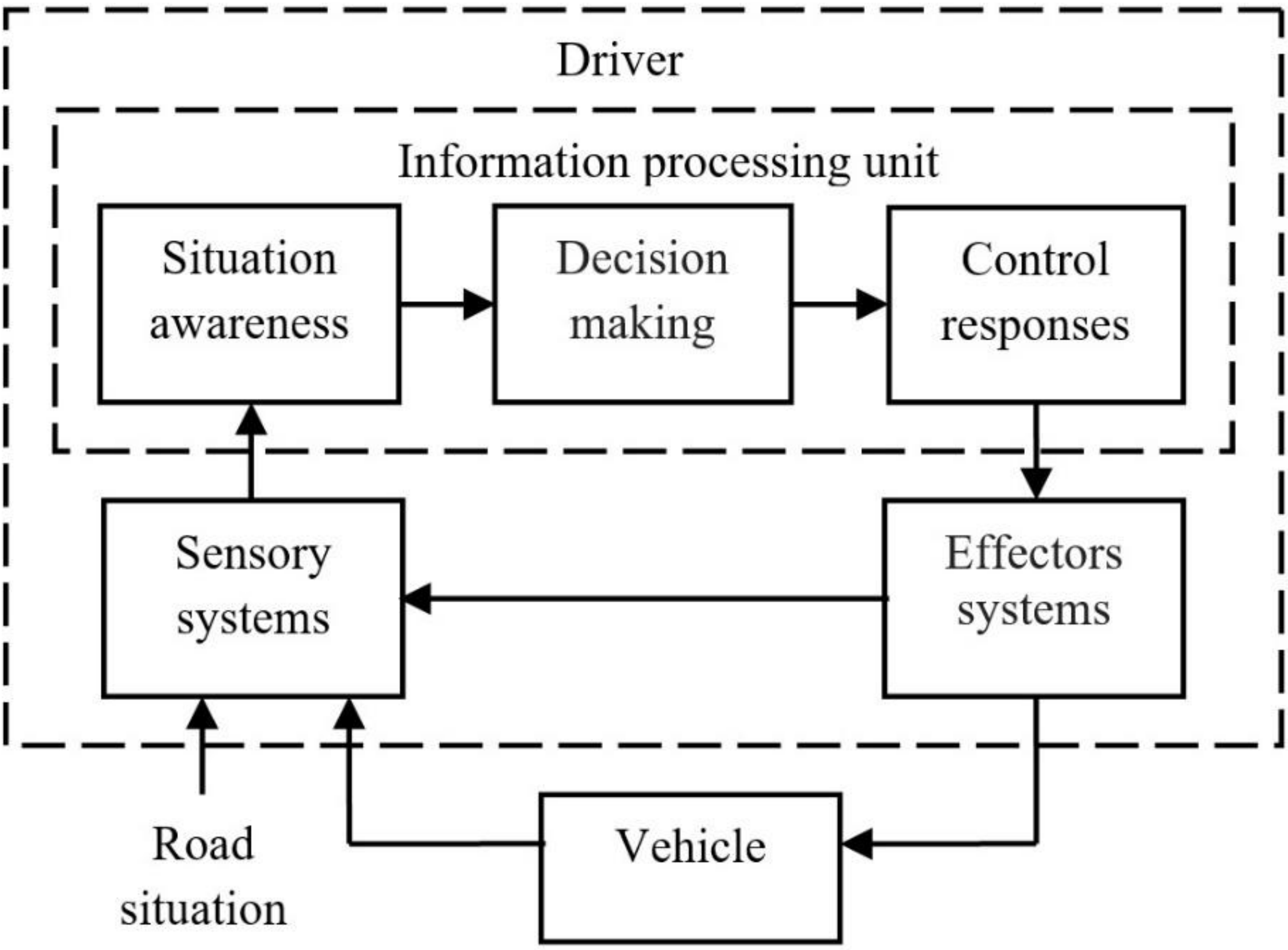

Figure 1. A basic diagram of the vehicle driver as an information processing unit

The aim of this article is to propose a conceptual model of the «driver – automated vehicle» system based on the theory of functional systems according to which the future result model is the primary factor that controls the activity of all living systems.

Theory of functional systems.

The theory of functional systems was proposed by P. K. Anokhin as a theoretical framework for describing internal structures and processes of the purposeful systems. According to this theory the functional system is a mechanism of self-regulation that dynamically and adequately adapts the purposeful system's behaviour to changes in external environment [21]. A basic diagram of the functional system as a mechanism of self-regulation in humans is depicted in figure 2. This self-regulation process is a dynamic and cyclical process comprising four main stages (1) afferent synthesis (2) decision making (3) action execution (4) result analysis.

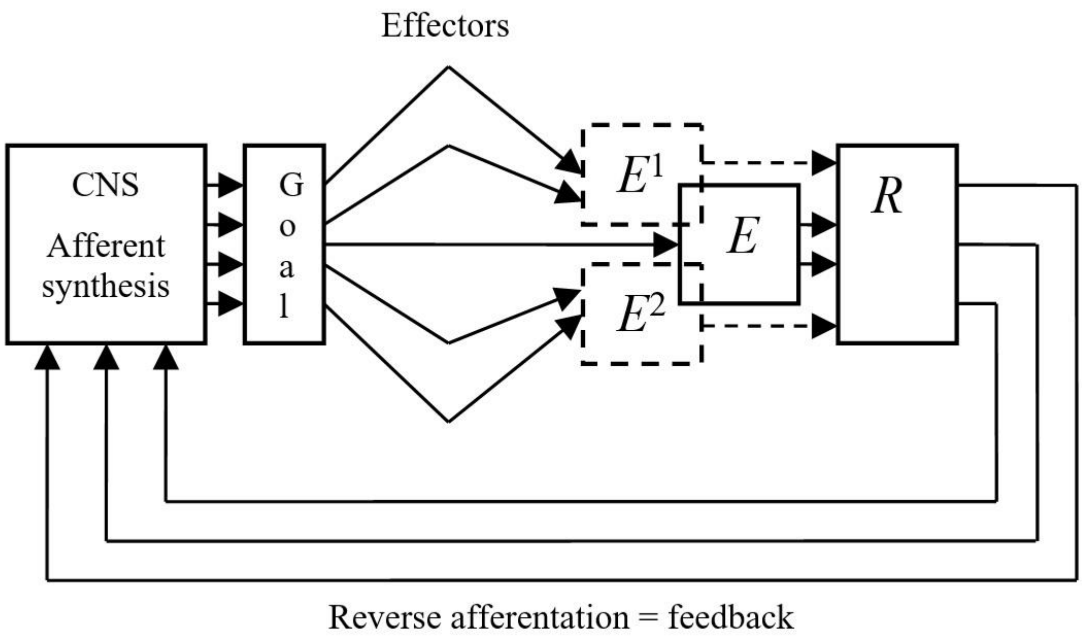

Figure 2. A basic diagram of the functional system as a mechanism of self-regulation. E is the beneficial end effect of the functional system; E1 and E2 are the deviations from E due to various influences; R is the receptor of the functional system precisely adapted to the characteristics of the beneficial or adaptive effect; CNS is the central nervous system which effects the afferent synthesis of all the information from the receptors of the system [21]

The afferent synthesis is the initial stage of the behavioural act at which the central nervous system (CNS) processes information from internal and external environment (situational and triggering afferentation) taking into account motivational excitation and memory (previous experience). This stage is essential to set a goal of the behavioural act and define a desired effect (result) of its attainment.

Then at the stage of decision making the CNS generates the program of action (complex of efferent impulses) that is only one particular form of behaviour appropriate to achieve the desired goal and generates a model of the expected result of action that contains various parameters of the desired result. The decision making stage is a critical point of the functional system at which there occurs the organization of a complex of efferent impulses capable of producing a quite specific action. After the decision making stage all combinations of impulses assume an executive, efferent character.

The next step is the action program execution during which the CNS receives feedback information about the current result (beneficial end effect E) of the action from the receptor R (figure 2). Then at the stage of result analysis the current result parameters are compared with the required parameters in the previously created model. Based on this comparison of the actual result with its model, the behaviour is corrected or the action is terminated.Thus, the theory of functional systems can be used as a method for analyzing self-regulating adaptations and resistance of an organism under different normal and extreme conditions [22].

A conceptual model of the «driver – automated vehicle» system.

In general, the «man-machine» system can be represented as a set of interacting biological and technical components combined into a single system with goal-directed behaviour. From the point of view of the theory of functional systems the driver of a vehicle is a multilevel functional system for performing the tasks related to driving. The structure and behaviour of such a functional system at each current point in time are determined by deviations of the actual driver's actions result parameters from the desired ones.In the proposed conceptual model, the automated vehicle is represented by its mechanical components and assemblies, driving controls, vehicle and environment state sensors, automated driving system, control mode switch, driver functional state (DFS) estimation system, central display, and driver/vehicle/environment state analyzer (figure 3).

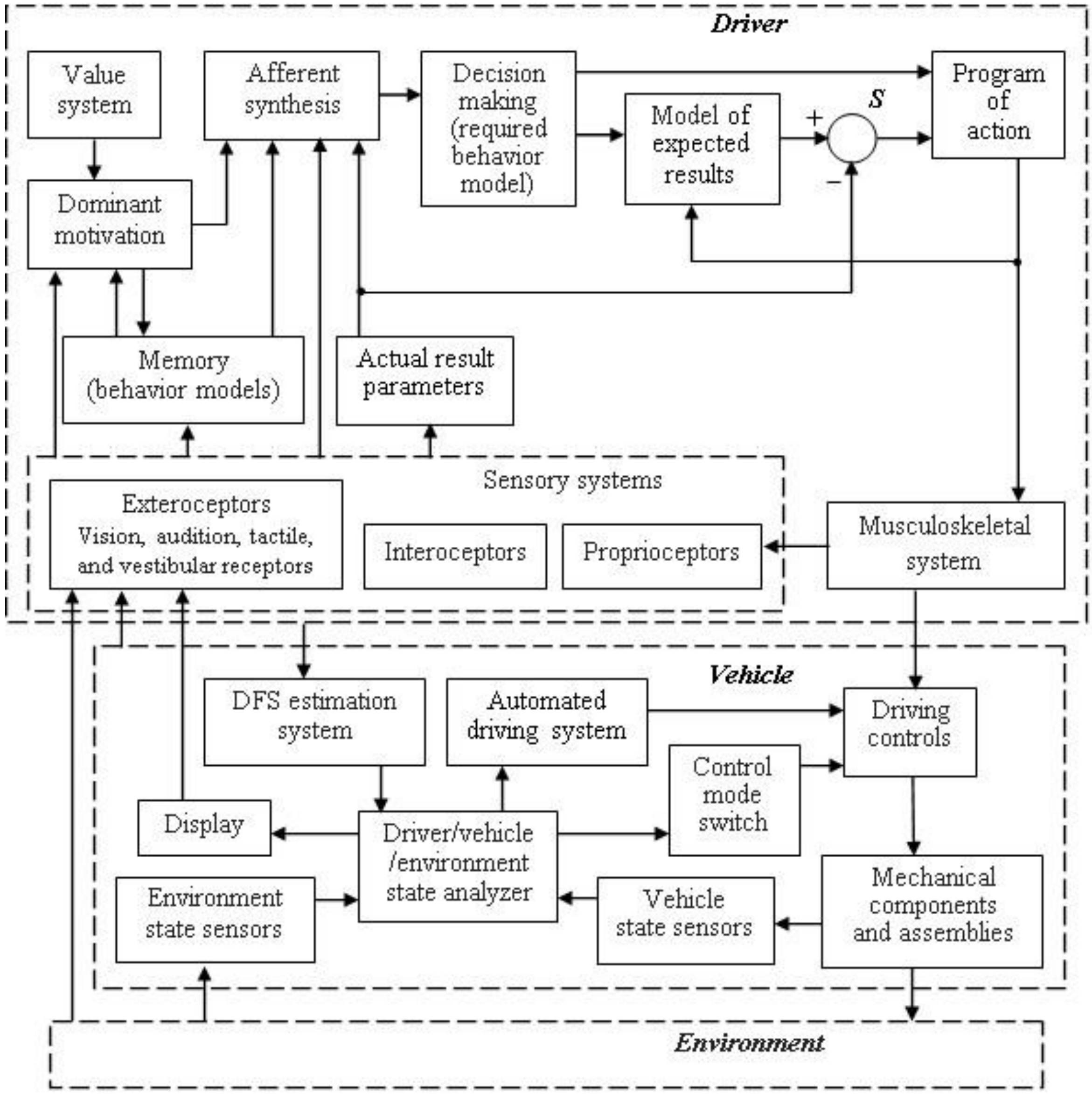

Figure 3. A conceptual model of the «Driver – automated vehicle» system. S is the summation block

The vehicle state sensors provide information about the current vehicle operation, motion, and position. The environment state sensors provide information about the current location and motion of other vehicles and pedestrians, road and lane information, information about the road infrastructure facilities, and weather conditions. The driver state sensors provide information about the current psychophysiological and behavioural characteristics such as, for example, heart rate, heart rate variability, skin conductance, electroencephalography, and distraction from the road. The DFS can be estimated based on these characteristics.

The overall functional structure of the automated vehicle in the proposed conceptual model includes a driver/vehicle/environment state analyzer to control the interaction between driver and vehicle that is necessary, for example, to organize transitions between automated and manual control. The information about the driver, vehicle, and environment states is presented to the driver through the display.

For practical applications of the proposed conceptual model the driver, vehicle, and environment states can be represented by vectors of their significant parameters (such as DFS, vehicle's position, velocity and acceleration, number of lanes on the road, other vehicle position, velocity, and acceleration, visibility, temperature and other essential weather conditions).

The interaction between the driver and the vehicle occurs as follows. During driving, the CNS of the driver continuously receives multimodal information about the driver psychophysiological and behavioural characteristics, the vehicle's state, and the traffic situation through the sensory receptors (interoceptors, proprioceptors and exteroceptors). All this information undergoes an afferent synthesis process to gain situation awareness for decision making under the influence of the current dominant motivation and the memory representation of the suitable prior experience (behaviour models) of the driver. The information about the actual result of the driver's actions is also involved in the afferent synthesis, but this will be discussed later. The current dominant motivation is determined by the driver's current needs that are formed by the internal and external afferentation, life experience extracted from the memory, and a personal value system. The afferent synthesis is carried out continuously, and is the basis for decision-making on the current behaviour model.

The decision-making process produces a final choice of what action program (the program of interaction with the vehicle) to use in the current traffic situation, and at the same time creates a corresponding model of expected results. The model of expected results anticipates the afferent properties of the various multimodal features of the result that should be obtained in accordance with the decision taken, and therefore is ahead of the events in the interaction between the driver, the vehicle and the environment.

Further, the action program's implementation is carried out step by step. During the program execution the driver on each of these steps acts on the vehicle controls, receiving feedback information about the current traffic situation as also a result of own actions both directly from the environment and through the central display. If the values of the current traffic situation parameters match those in the model of expected results the implementation of the planned program continues. If not, then the program and model of expected results are corrected or replaced by another at the decision-making stage based on the current afferent synthesis that also includes the information about the actual result of driver's actions. The comparison of the current traffic situation parameters with those in the model of expected results is performed in the summation block S (figure 3).

As can be seen from the figure 3, the aggregate of such components as the decision-making, model of expected results, summation block S and action program represents a dynamic mechanism which is a key mechanism of the proposed model. This mechanism is a dynamic coupling mechanism between the decision making of a driver to perform a particular action and changes of road conditions due to the driver's actions. It is based on the step by step evaluation of the deviations of the actual values of the driver's actions result parameters from the expected values, what allows to examine the driver's performance during numerical simulation of transitions between an automated and manual vehicle control. If the current result of the driver's actions is acceptable, then the output signal from the program of action activates the next one in the model of expected results, and so on. If not, the program of action and model of expected results are changed in accordance with the change of the current road situation. When the current program of action is finished, its output signal will give the command to switch to the next action program (with the relevant model of expected results) and/or to a higher level program of action (for example general plan of trip). In the latter case, a higher level expected results model will be activated. Thus, the structure of such dynamic coupling mechanism shown in the figure 3 can be used to describe the transitions between different levels in the multilevel functional systems for performing the tasks related to driving. In this case, both the program of action and the model of expected results should have a hierarchical structure.

Conclusion.

The objective of this work was to build a conceptual model of the «driver – automated vehicle» system based on the P. K. Anokhin's theory of functional systems. The key mechanism of the proposed model is a dynamic coupling mechanism between the decision making of a driver to perform a particular action and changes of road conditions. This mechanism is based on the stage by stage evaluation of the deviations of the actual values of the driver's actions result parameters from the expected values. The structure of such dynamic coupling mechanism can be used to describe the transitions between different levels in the multilevel functional systems for performing the tasks related to driving. This conceptual model can be used to develop appropriate computational models of driving an automated vehicle to examine different aspects of human factor in transitions between driver and automated driving. Such computational models can be also used to develop and investigate new methods for optimization of the interaction between driver and automated vehicle.

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ОБЩИЙ ПОДХОД К ОПИСАНИЮ ВЗАИМОДЕЙСТВИЯ ВОДИТЕЛЯ И ТРАНСПОРТНОГО СРЕДСТВА

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Аннотация. Данное исследование проведено с целью продемонстрировать возможности теории функциональных систем П. К. Анохина для описания взаимодействия водителя с транспортным средством. Хорошо известные модели поведения водителей описывают различные стадии когнитивного процесса человека, но не описывают, как водитель управляет своими действиями. Описание когнитивного процесса водителей с точки зрения результатов их действий, позволит исследовать различные аспекты человеческого фактора в различных дорожных ситуациях. На основе методов теории функциональных систем создана концептуальная модель системы «водитель - автоматизированное транспортное средство». Предложенная концептуальная модель позволяет описывать когнитивный процесс водителя на основе механизма динамически связующего принятие решения водителем и изменение дорожной ситуации. Данный механизм основан на пошаговой оценке отклонений параметров текущего результата действий водителя от параметров ожидаемого им результата. Показано, что теория функциональных систем является перспективной для описания взаимодействия водителя и транспортного средства. Предлагаемая концептуальная модель может служить в качестве основы для разработки вычислительных моделей взаимодействия водителя с транспортным средством, исследования которых позволили бы разработать требования к интерфейсу взаимодействия водителя с транспортным средством для обеспечения комфорта и безопасности.

Ключевые слова: автоматизация транспортных средств, состояние водителя, взаимодействие человека с машиной, человеческий фактор.