Cooperative Human-Machine Interfaces for Safety of Intelligent Transport Systems: Requirements, Development and Assessment

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Abstract: In this work, the analysis into the available solutions regarding the cooperative intelligent transport systems (ITS) and their human-machine interfaces (HMI) has been conducted. The standards and recommendations in the area of transport systems interfaces design have been analysed. Profiling of the requirements to cooperative human-machine interface (CHMI) for such systems including requirements to usability and safety is based on a set of standards for ITSs. An approach and a design technique of human-machine interfaces for ITSs are suggested. This approach is based on designing the cooperative human-machine interfaces for intelligent transport systems. The architecture of cloud-based CHMI for intelligent transport systems has been developed. The system consists of three main parts: client end, server end, and core-project that includes data models for the communication protocol and the common utility functions. The prototype of software system for CHMI for ITS is described. The prototype has been examined in the laboratory conditions. The assessment using the GOMS method has allowed to calculate the efficiency to execute the task of user interaction with the system.

Key-Words: cooperative human-machine interfaces, green human-machine interfaces, intelligent transport systems, cloud computing, GOMS method, GPS, safety, assessment.

1 Introduction

1.1 Motivation and work related analysis

Different vendors on IT market offer the advanced driver assistance systems [1, 2]. Such systems as a collision warning system, parking assistant, aredesigned for improvement of safety during the driving and reducing the driver's strain [3].

One of the development lines of such systems is the improvement of the interaction between the driver and the vehicle control system "human-machine" (Human-Machine Interaction) and the provision of the information about the current situation on the road in real time for a driver (Real-Time Traffic and Travel Information (RTTI).

The provision this sort of information leads to an increase of situational awareness of vehicle driver. Awareness implies the existence of operational information about the vehicle state and road conditions. Sufficient level of situational awareness is required for risk assessment and hazard analysis, planning, goal-setting, etc.

Situational awareness includes levels:

– the level of perception of the situation, which is provided by monitoring the status of various objects around the vehicle;

– the level of conclusions, which determines the ability of vehicles to integrate various sources of information and to make assessments of situations on this basis (this level is provided by the decision-making about the current dangers and risks for the vehicle);

– the level of prediction, on which the forecast of dangerous situation risks is carried out.

Increasing of situational awareness leads to overall risk lowering (collisions, overturning, etc.), since it is possible to detect and predict hazardous situations, determine precautions for their reducing in real time.

Issues for construction of secure dynamic human-machine interfaces (HMI) are greatly important for enhancing of situational awareness [4–8].

At the same time, the point is that there are two sides of the safe HMI:

– firstly, the development and evaluation of interfaces according to the requirements of the normative documents and safety standards;

– secondly, reporting succinct information about objects in the area of the vehicle movement to the driver, which can threat him (area of a potential hazard (APH)).

It is also necessary to take into account the ability of a HMI to adapt to the situation on the road, to take into account the state of the driver, its features, driving experience, behavior peculiarities in critical situations, habits, etc., i.e. increasing of its adaptability.

The high amount of data used in the intelligent transportation system leads to the necessity to improve the information access for all traffic participants.

Improvement of situational awareness, risk assessment in the real-life improvement requires the use of large computing facilities for the storage, processing and analysis of data [9, 10].

It is very importantly that these facilities are not always available, even for modern on-board computing equipment of vehicle.

One of today's challenges in the HMI creation domain is a development of green (or ecological) human-machine interfaces (GHMI). In contrast to the traditional HMIs they have such properties as environmental friendliness, adaptability, safety, reliability, etc. Scalable and flexible interfaces of the operator's panels allow integrating into the different monitoring GHMI systems and control functions.

GHMI for the automobile informational systems improves the traffic safety by decreasing the driver's informational overload, and thus minimizing the distractions.

Reliability of on-board software is also an additional safety factor in the ITS. It is necessary to consider additional precautions to enhance safety, including the possibility of using modern cloud computing for information processing in the framework of the ITS [11, 12].

1.2 Goal of the paper

The goal of the paper is to raise the awareness of vehicle drivers about the road situation through the development and implementation of the cooperative human-machine interfaces for the intelligent transport systems based on the cloud computing. The paper is structuring by the following way. The second section describes requirements to the HMI for ITS and forms requirement profile. The third section is dedicated to development of cooperative HMI and cloud-based architecture. The fourth section presents some safety assessment results for CHMI. The last section concludes and discusses the future steps.

2 Requirements to HMI for ITSs

The international standardization process is an essential mean of ensuring the compatibility of the separate transport telematics systems [13, 14].

The standards for ITSs are as follows:

– ISO/TR 10992:2011 Intelligent transport systems - Use of nomadic and portable devices to support ITS service and multimedia provision in vehicles;

– ISO/TR 12859:2009 Intelligent transport systems - System architecture - Privacy aspects in ITS standards and systems;

– ISO/TS 17419:2014 Intelligent transport systems - Cooperative systems - Classification and management of ITS applications in a global context;

– ISO/TS 17423:2014 Intelligent transport systems - Cooperative systems - ITS application requirements and objectives for selection of communication profiles;

– ISO/TS 17427:2014 Intelligent transport systems - Cooperative systems - Roles and responsibilities in the context of cooperative ITS based on architecture(s) for cooperative systems;

– ISO/TS 19321:2015 Intelligent transport systems - Cooperative ITS - Dictionary of in-vehicle information (IVI) data structures;

– ISO 24978:2009 Intelligent transport systems - ITS Safety and emergency messages using any available wireless media - Data registry procedures.

The parameters and requirements for the CHMI for the ITSs identified as a result of the analysis into the standards, recommendations and the context of the use are given in table 1.

Table 1. Requirements for the HMI for the ITSs.

Parameter	Requirement description
Usability	The feedback between the system and the driver should be timely and recognizable. The driver should be given the information about the current state of the system and any system malfunction. Visual information should be displayed in a way that the driver can assess special details within few sights. The driver should anytime have the possibility to keep at least one hand on the steering wheel when interacting with the system.
Safety	The system should help the driver and should prevent the possible dangerous behavior of the driver or other road users. The system

	should not distract the driver and draw his attention that should be focused on monitoring the road situation. The system should not provide the driver with the information that can cause the dangerous behavior of the driver or other road users. The system should provide the driver with high-priority information rather than the information related mostly to the safety.
Simplicity	The system instructions should be simple, correct and easy to understand. The visual information should be given piece by piece to ensure the step-by-step control of the system.
Cognitive compati-bility	The interface should not cause the driver’s mixed reaction. The result of the drivers’ actions should not be different from what he expects.

The main design manuals regarding the HMI for vehicles are European Statement of Principles on Human Machine Interface [15], JAMA – Japan Automobile Manufacturers Association Guidelines for InVehicle Display Systems [16] and Alliance of Automobile Manufacturers (AAM) [17]. These manuals summarize the key aspects of safety applicable for the human-machine interfaces of the automobile and communication systems.

3 Development of cooperative HMI

3.1 Cooperative HMI

As noted above, cooperative systems are such systems that wirelessly communicate with other cars.Therefore, under the term of a cooperative HMI, we will consider an interface system, distributed among several vehicles [18, 19]. An additional monitor is installed on each vehicle or a compact unit is embedded into the existing HMI to provide information about safety in APH, which gives the information about the safety level.

This informationis formed and dynamically adjusted basing on the overall situation for each car (the state of the vehicle, driver and road conditions), which is in the danger zone.

It is clear that these must be adaptive HMI, which reflects not only information about the condition of the car, but of the driver as well. If a driver starts to doze off or falls asleep, it is necessary to wake him up and inform the drivers of motor vehicles that are nearby.

The property of adaptability in the HMI becomes apparent in several forms: changes in the content of the information provided, dialogue, sharing of tasks between man and machine, the speed of adaptation [20, 21]. One of the versions of cooperative HMI ar chitecture is based on the use of cloud computing (CC).

Cooperative HMI provides the measure values of the parameters of vehicle and driver state in real time via the Internet into the "cloud." Here, the data from all the cars is dynamically processed and transmitted to the motoring public.

Information from the HMI of one vehicle passes through the "cloud" and is displayed on the HMI of another vehicle. In turn, the information from the HMI of another vehicle, is also transferred to the HMI of the first vehicle. This information is taken into account when the risk analysis of each vehicle is performed.

There are important issues in developing of HMI: optimization of the information necessary for driver for the safe driving mode; determination of the information views, which stimulate the driver; control and prevention of the driver's detraction.

3.2 System architecture

The system consists of three projects combined in a single solution:

– server end – the decision support system (DSS);

– client end – the user HMI;

– Core-project that includes data models for the communication protocol and the common utility functions.

The server end is the web-application, the core of which is the DSS. The web-application is managed by the Apache Tomcat server that supports the HTTP protocol. The protocol allows the interaction between the client and the server. The client end is implemented for the Android platform and it stands for the user interface. The ground map is the key element. The data exchange is performed wirelessly using the data types specified in the general Core-project. Java serves as the platform for creating the system in question. Figure 1 shows the architecture of the system.

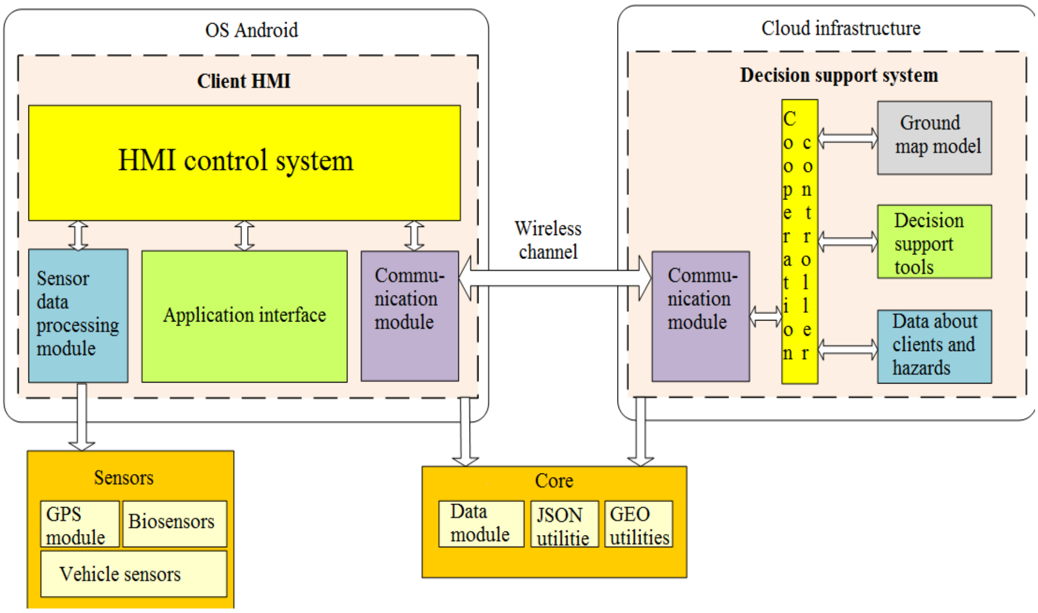


Fig. 1. Architecture of the cooperative HMI based on cloud computing.

The client and the server cooperate wirelessly through the module for communication. The general convenience functions and data models for packetizing can be found in the Core-project that is used by the both sides.

Since the communication protocol should provide equal rights for the client and the server, it has been agreed to implement the communication protocol based on TCP from the Java EE – WebSocket specification.

The protocol ensures the free data exchange: two equal participants exchange data, each one working independently and sending data to the other one when necessary (fig. 2).

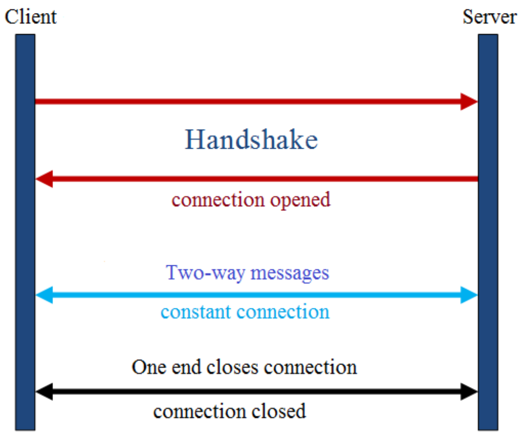


Fig. 2. Work principle of the communication protocol WebSocket.

The data is packetized. The packets stand for the data type from the core-project in the JSON format. The packets are formed and parsed on both sides in the communication module.

3.3 Interface design

The human-machine interface provides the driver with the information about the road situation, the driver's state and the vehicle's state. At the first start of the client application the registration form is displayed where the driver needs to enter his personal data (nickname, age, sex).

The working area on the display is covered with the ground map (fig. 3).

Fig. 3. Visual interface.1 – current position; 2 – other vehicle; 3 – server connection indicator; 4 – driver's state indicator.

The current state and the direction of the vehicle are marked on the map with the help of the special arrow indicator. The map is to be centered according to the current position. The position of other vehicles is displayed by means of arrows having different colours.

The driver's state is displayed by a special indicator (fig. 4).

Fig. 4. Driver's state:1 – good, 2 – poor.

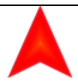
The HMI provides for the feature of manual signals to other drivers about the dangerous road stretch by pressing a button with the schematic representation of hazards types on a special board (fig. 5).

Fig. 5. Hazards menu.

The speech recognition has been adopted in the HMI for the voice hazard signal transfer. The command for
signal transfer consists of two fields: key phrase and hazard type. The key phrase should be brief and easy to pronounce. The possible key phrases are: "OK, motor", "Go, machine" or simply "Danger", "Danger ahead". According to the survey results, the majority of the drivers prefer to set their own key phrases for the control commands.

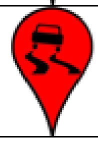
Hazards are indicated on the map with markers displaying the hazard type (table 2). The marker is coloured according to the hazard level (table 3).

Table 2. Hazard type.

Poor road	Ice condition	Fog	Caving	Aggressive driver
				

Map scale should be set according to the range of the lowest hazard level. When the hazard description is queried, an informative message with the enlarged hazard marker and the distance to the hazard object is displayed.

Table 3. Hazard level.

Hazard level	Colour	Icon
Low	Yellow	
Middle	Orange	
High	Red	

New hazard is accompanied by the short voice signals. If the hazard level is high, the driver is informed by the voice messages communicating the hazard, for example: «Aggressive driver ahead, distance one hundred fifty meters, speed 90 kmph», «Fog in a hundred meters». Voice messages should repeat at a 10- second interval.

The driver is provided with the possibility to query the hazard description using voice commands like "Voice the hazard", "Describe the hazard".

The map scale can be configured, the voice and sound messages and volume level can be set or disabled.

Display brightness and contrast should be adjusted to the daytime. The voice messages volume level is to be adjusted to the noise level in the car.

The overall picture of the road is at the driver's disposal. He can see the ground map, monitor other vehicles moving on a real-time basis. The driver's awareness is improved as the position of the cars undetected through the glass or by the mirror can be obtained. The blind spot issue is resolved. Due to the voice description of the hazards, the cognitive load is reduced, the probability of the driver's distraction of the display is lowered.

3.4 Development of client and for human-machine interfaces prototype

The client HMI subsystem is implemented on OS Android. It consists of several modules that interact via the HMI control system.

The vehicle's sensors data is obtained from the board computer through the wired interfaces. The requests to the biosensors can be done through wireless interfaces. The current coordinates are obtained from the GPS receiver through the wire communication channel.

The module for communication is responsible for receiving and transmitting the messages to the server. The packets are formed by the client subsystem using the data models from the Core-project.

The interface of the application includes the following modules:

1. Visual interface responsible for displaying the following elements on the monitor:

– registration page (personal data filling);

– ground map, current position, and position of other participants, hazard objects on the ground map;

– indicators of the driver's state and server connection;

– hazards panel;

– signals setup control panel.

2. Speech synthesizer responsible for voice warnings generation.

3. Speech recognition responsible for voice commands recognition.

4. Sounds management responsible for sound warnings.

The HMI control system is responsible for the interaction with other modules in the system. It obtains the data from the sensor interfaces and transmits it to the communication module where packetizing takes place and the packets are sent to the server.

The user setup control module is responsible for configuring and storing the personal data and parameters of the signals. The hazard control module is responsible for the refreshing of the hazards list provided by the server.

The emulation module is responsible for emulation of the vehicle movement and the data obtained from the biosensors.

Figure 6 stands for the connection between the client, the server, and the core modules.

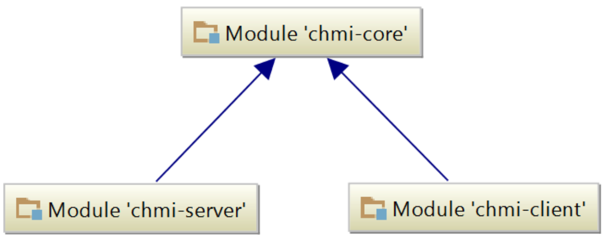


Fig. 6. Module structure of the system.

The common classes for the client and the server applications are specified in the Core-project.

4 Research and assessment of safety

4.1 Automobile safety survey

At the interface design stage, the questionnaire has been conducted involving 93 vehicle drivers, in which the respondents have been offered to assess the types of signals about the hazards and the ways of interaction with the system. The results of the survey are presented on the charts below (fig.7–13).

The survey involved 93 people, of which 70% were male and 30% female. 69% of respondents were of the age from 20 to 30, 23% – from 30 to 40 and 8% had more than 40 years. 50% of respondents experienced a road accident at least once, 28% - several times, 5% - a lot of times and only 16% never had an accident on the road.

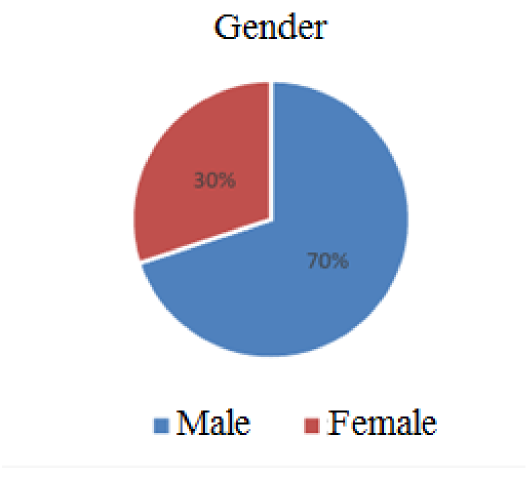


Fig. 7. Respondents' gender.

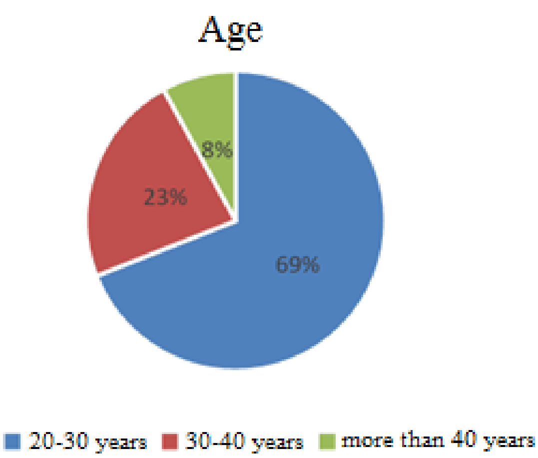


Fig. 8. Respondents' age.

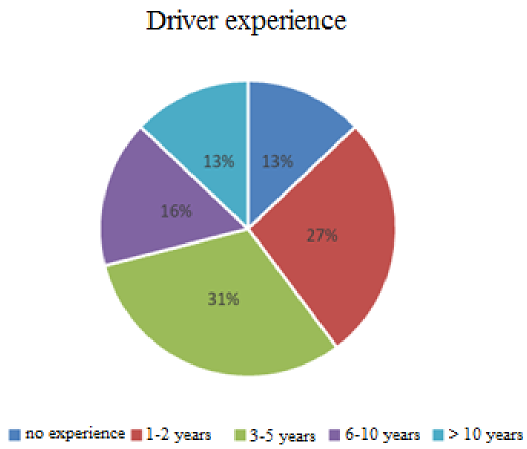


Fig. 9. Respondents' driver experience.

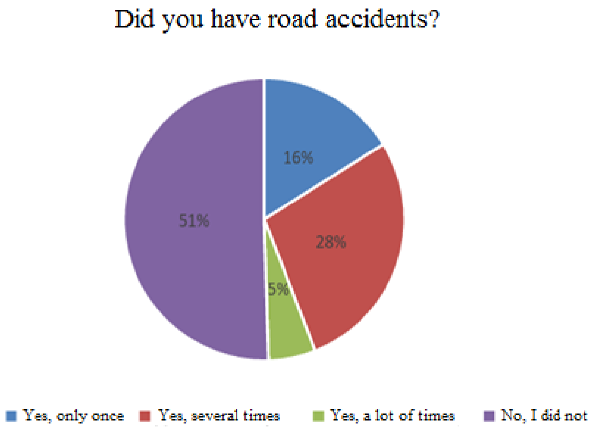


Fig. 10. Road accidents history.

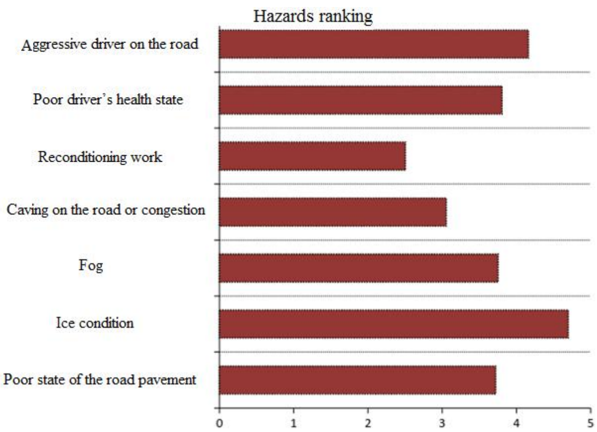


Fig. 11. Hazards ranking.

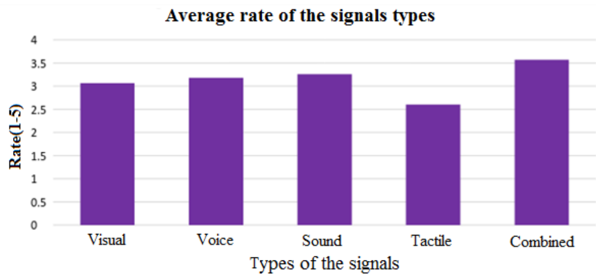


Fig. 12. Preferences in types of the signals.

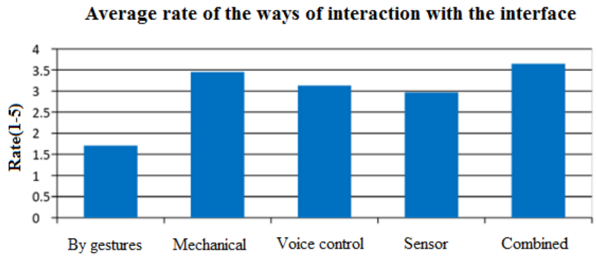


Fig. 13. Preferences in ways of interaction with the HMI.

The results of hazards ranking show that the ice condition and the poor state of the road pavement are considered as the most dangerous situations, and the reconditioning work are ranked as the least dangerous.

The results of ranking the ways of interaction show that the sound and voice signals are more preferable along with the combinations of different types.

The results of the assessment of the ways of interaction with the interface show that the mechanical and voice interaction, as well as the combinations are more preferable, while interaction by gestures is the least appropriate.

The most preferable key phrase for the voice commands is the combination of the welcoming word and the name of the vehicle which can be set by the driver.

4.2 GOMS method adaptation and human-machine interface efficiency assessment

The client HMI time indicators assessment model is given in the table 4.

Table 4.GOMS method adaptation for the HMI.

№	Operator	Code, time young / elderly
1	Mental psych-up Compare the hazard description with the	Mental M = 1.50 /2.55 s

	position on the map	
	Assess the most dangerous objects on the map	
2	Reach the monitor with the hand	Reach D = 0.45 / 0.77 s
3	Mark the position on the monitor with the finger	Mark Y = 0.80 / 1.36 s
4	Find the marker on the map	Search P = 2.30 / 3.91 s
5	Find the control element on the monitor	
6	Press the object on the map	Press H = 1.2 / 2.04 s
7	Press the button	
8	Wait for a response from the interface	Interface response O = 0.1 s
9	Say the key voice command aloud	Voice command G = 1.5 s
10	Say the signal voice command aloud	
11	Listen to the message about the hazard	Listen S = 3.5 s
12	React to the situation	Rection PE (experimental)

4.2.1 Models development and the calculation of tasks execution

Task 1. Pass the signal about the dangerous road section via the monitor.
1) M – Mental psych-up – 1.50 / 2.55.
2) D – Reach the monitor with the hand – 0.45 / 0.77.
3) Y – Move the hand (finger) to the left hazard panel – 0.80 / 1.36.
4) H – Get the hazard panel out – 1.2 / 2.04.
5) Y – Move the finger to the button of interest– 0.80 / 1.36.
6) H – Press the hazard button – 1.2 / 2.04.
7) O – Wait for a response from the system – 0.1.
The sequence:

$$M + D + Y + H + P + Y + H + O$$

Time for the young people:

$$t1 = 1.50 + 0.45 + 0.80 + 1.2 + 1.2 + 0.1 = 5.25 \text{ s.}$$

Time for the elderly people:

$$t2 = 2.55 + 0.77 + 1.36 + 2.04 + 2.04 + 0.1 = 8.86 \text{ s.}$$

Task 2. Pass the signal about the dangerous road section using the voice command.
The sequence:

$$M + G + M + G + O$$

$$t1 = 1.50+1.50+1.50+0.1 = 4.6 \text{ s.}$$

$$t2 = 2.55+1.50+2.55+0.1 = 6.7 \text{ s.}$$

Task 3. Disable the sound signals.
The sequence:

$$M + D + Y + H + Y + H + O$$

$$t1 = 1.50+0.45+0.80+1.2+0.8+1.2+0.1= 6.05 \text{ s}$$

$$t2 = 2.55+0.77+1.36+2.04+1.36+2.04+0.1 = 10.22 \text{ s}$$

Task 4. Request the hazard description.
The sequence:

$$M + D + P + Y + H + O + PE$$

$$t1 = 1.50+0.45+2.30+0.8+1.2+0.1+P= 6.35 \text{ s + reaction time.}$$

$$t2 = 2.55+0.77+3.91+1.36+2.04+0.1+P= 10.73 \text{ s + reaction time.}$$

Tasks that do not require user's actions.

Task 5. Learn the road situation.
The sequence:

$$P + M + PE$$

$$t1 = 2.30 +1.50+P = 3.8 \text{ s + reaction time.}$$

$$t2 = 3.91+2.55+P = 6.46 \text{ s + reaction time.}$$

Task 6 – Listen to the message about the hazard.
The sequence:

$$S + M + PE$$

$$t1 = 3.5+1.50+P = 5 \text{ s + reaction time.}$$

$$t2 = 3.5+2.55 + P= 6.05 \text{ s + reaction time.}$$

The quantitative evaluation of the HMI shows that the hazard signal is passed more effectively using the voice commands. The execution of the signalsetting task should be optimized through the voice commands, and thus less time will be spent by the driver. Additionally, we can conclude that the voice description requires more time compared to the situation of the driver executing the task of the ground map assessment. However, in this case the driver pays his attention to the map far more quickly which allows him to react to the situation faster.

4.3 Experimental research of CHMI for ITSs

The experiment has been conducted in laboratory conditions basing on the emulation of the vehicles movement on the road from one point to another one.

Experiment 1. Driver's state indication.

1) Starting state of the HMI. The identifier shows that the driver's state is good.

2) Set the parameters of the driver. Experimental profile 1 (fig.14):

Age = 25 years;
Pulse = 60;
Upper hypertension = 100;
Low hypertension = 50;

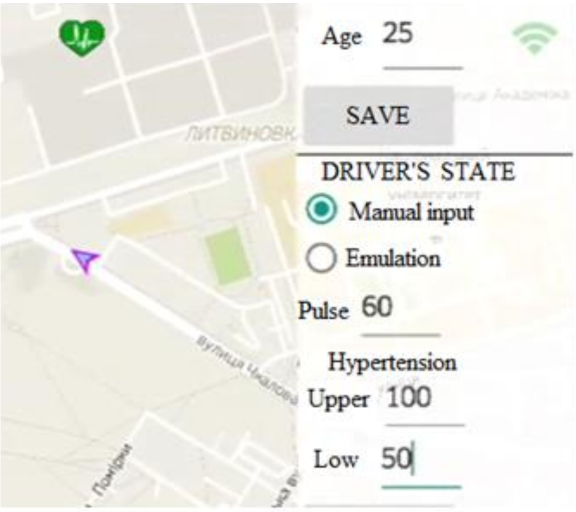


Fig. 14. Set the parameters of the driver. Profile 1.

The expected result is poor driver's state, and the indicator coloured in red.

3) The result of setting the parameters (fig.15)

The indicator shows that the driver has poor state.

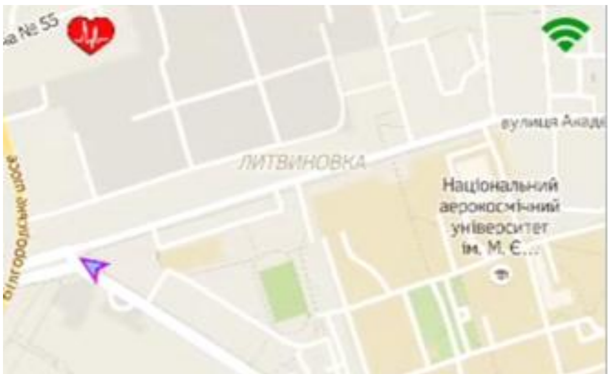


Fig. 15. Indication of the poor driver's state.

4) Set the parameters of the driver. Experimental profile 2 (fig.16):

Age = 25 years
Pulse = 80
Upper hypertension = 130
Low hypertension = 80

The expected result is the change of the driver's state indicator, the driver's state is good, and the state indicator gets coloured in green.

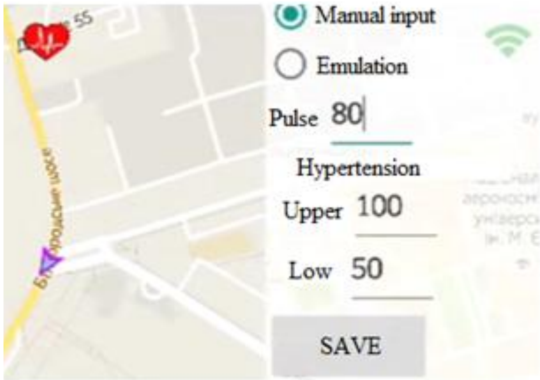


Fig. 16. Set the driver's parameters. Profile 2.

5) The result of setting the parameters (fig.17)

Fig 17. Indication of good driver's state.

The indicator shows that the driver has a good state.

Experiment 2. Emulation of the scenario «Dangerous road section».

When driving on the dangerous road section (ice condition, fog, poor road pavement, jam, road accident, reconditioning work) the driver can manually inform about the corresponding hazard using the tools of the HMI (the voice command or the menu) (fig. 18).

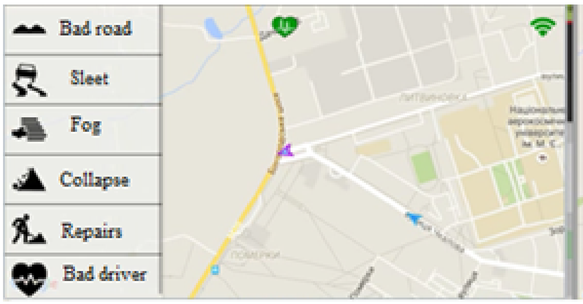


Fig. 18. Manual mode of hazard reporting.

In this example, ice condition is reported.

The information on the hazard is saved on the server and can be used to form the rod situation as to the other participants.

The road situation is formed on a real-time basis for each participant individually. The hazards are ranked by the server and displayed with the corresponding colours on the client HMI. Rank is assigned according to the distance and the hazard type.

5 Conclusion

In this work, the analysis of the available solutions regarding the cooperative intelligent transport systems and their human-machine interfaces has been conducted. The standards and recommendations in the area of transport systems interfaces design have been analysed. The requirements to the HMI for the cooperative ITSs have been formulated. The features of such interfaces have been identified.

The prototype of the system “Cooperative human-machine interface for intelligent transport systems” based on the cloud computing has been developed.

The HMI prototype in question has been examined in the laboratory conditions. The assessment using the GOMS method has allowed calculate the time to execute the task of user interaction with the system. The resulting data showed that the interface needs to be improved further.

The system “Cooperative HMI for ITSs” allows enhancing the vehicle safety and reducing the number of the road accidents.

Safety is improved by increasing the driver’s awareness about the road situation and the possible hazards on a real-time basis through the human-machine interface.

Future steps will be related to experimental research of the software system and more infrastructure-oriented assessment by development and modeling different scenarios for ITSs considering vehicle failures, driver problems and so on.

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