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Development and Research of Information System Elements for Passengers Drive Comfort Improvement

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Abstract: *Preliminary theoretical analyzes have been made, which show that heavy acceleration reduces comfort are available. This applies both to the acceleration when starting and stopping. High levels of acceleration are most common when braking. An analysis of passenger comfort based on accelerometer data and a survey was conducted. The speed of travel, the acceleration in the direction of accelerometer X axis, the rotation axis C have a significant influence on the degree of passenger discomfort. The results obtained complement and partly improve those from the available literature with a model using only one linear and one rotary axis, by which the discomfort is described with sufficient accuracy. A regression model has been obtained, which is a suitable basis for building a driver assistance system to provide passenger comfort in public road transport. A model of a "Driver Assistant" microprocessor system based on studies is proposed.*

Keywords: *Passenger drive comfort, Driver assistant system, Regression model, Graphical user interface.*

1. Introduction

Meeting passenger requirements and expectations for safe and quality transport requires strict compliance with applicable national and European legislation. European policy is in constant competition with the ever-increasing demands of passengers, which need to be tracked and adequately addressed. For this purpose, automated measurement systems are developed, supported by regulatory documents and programs to improve travel conditions. They cover the process of ensuring safety, comfort, reducing negative environmental impacts [1].

The efficiency of transport performance can be assessed through performance indicators. Such an indicator is a numerical characteristic of the system, which assesses the adaptation of the system to the tasks set before it.

Achieving comfort when traveling by public transport is a theme that is affected by standards and normative documents. Convenience of public transport is largely controlled by world-recognized quality standards. One of these standards is the EN 13816 [2] adopted by the European Union for public transport services assessing the level of passenger satisfaction on a number of factors such as convenience, accessibility, information, duration, care for travelers, travel comfort, safety and environmental effects. This European Standard specifies the requirement to define, target and measure the quality of public passenger transport services and provides guidance on the choice of appropriate measurement methods.

Influence of maneuvers on the passenger comfort. The influence of bus maneuvers during movement is described and studied in [3, 4]. The results presented in the literary sources show that the kinematics of passenger movement due to the preparation for the maneuver initiated by the driver himself and by the interaction with the pedals and the steering wheel. The test data show significant distraction among the individuals involved, depending on whether they are men, women, children, which is independent of their anthropometry. Turning the torso at a turn, overtaking, mismatch is similar to emergency maneuvers. Similarly, a torsion constriction is observed to keep the person's initial position. Compared to the use of mannequins, results similar to those of the volunteers were obtained; the major changes in the position were slightly ahead and stronger offsets [5]. Unlike people, mannequins do not restore their original position. Hence, the recommendation in performing dummy trials is to conduct each maneuver separately and restore its original position.

The analysis of the types of maneuvers in bus management shows that the main maneuvers are related to the deviation from the rectilinear motion of the bus.

Driver assessment and guidance systems. The overview of on-board driver assist systems shows that the main parameters to be measured are acceleration and deceleration, engine revolutions, gear selection, driver notification of improper driving. The main purpose of these systems is to reduce fuel consumption and eco-driving. The use of these systems is in line with the EU's climate change and energy package, the 20-20-20 [6] European climate change mitigation target, according to which the reduction of carbon dioxide emissions will improve the environment and reduce the effect of global warming. A common disadvantage of these systems is that they do not take into account the influence of driving style when used in public transport vehicles. More research needs to be done on the use of such systems in public road transport to make it attractive, accessible, comfortable, safe, environmentally friendly, and high-speed for passengers [7].

Besides embedded microprocessor systems are available at the present stage of development of science and technology. Mobile devices for communication – phones with different operating systems are increasingly used [8]. For these devices, applications for driving style and environmental impact analysis have been developed, working independently of the on-board microcomputer system of the vehicle. From the analysis of more common applications for mobile phones, it is seen that they are designed to determine the speed and acceleration of the vehicle [9]. Two are the main sensors that use – GPS and accelerometer. In some cases, methods for indirect determining engine parameters, driving styles, are used. An advanced option is the application of methods for combining sensor data by which, by means of a synthetic signal based on data from several sensors (e.g., GPS, accelerometer, and compass), the direction, velocity, acceleration of the vehicle is measured much more precisely. Their purpose is to evaluate the style of driving, environmentally friendly driving by reducing emissions and fuel consumption. Both in embedded systems and in mobile applications, there is no assessment of the impact of driving style on the attractive, accessibility, comfort, and safety of passengers in public transport.

The purpose of the article is the design and validation of driver assistance system that allows to efficiently and accurately improve passenger comfort in full-scale equipped vehicles for laboratory and real traffic environment.

2. The theoretical backgrounds

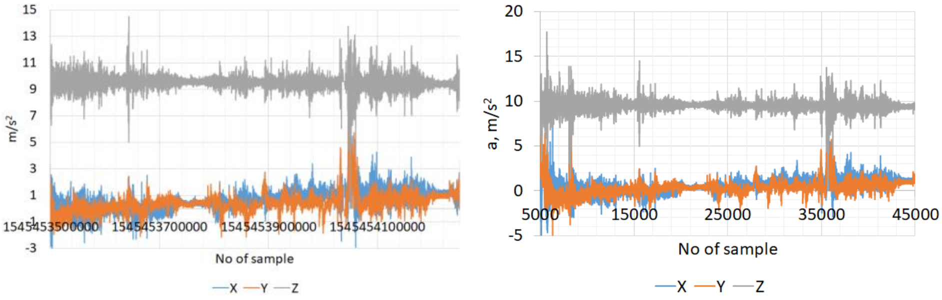
Preliminary theoretical analyzes have been made, which shows that heavy acceleration may occur, that reduces comfort. This applies both to the acceleration when starting and stopping. High levels of acceleration are most common when braking. These high acceleration levels are not acceptable to passengers.

Fig. 1 shows the two routes analyzed by urban transport. GPS data recorded in *.nmea file format, WGS84 geographic system, is mapped to a Google Maps digital map (Google, Inc.).

(a) (b)

Fig. 1. Analyzed routes from city bus: first route (a); second route (b)

From the preliminary studies carried out on public transport travel, some deficiencies can be noted in the course of the vehicle while avoiding the fact that some of the reasons for the unpleasant sensation of travel are due to the need for the driver to comply with the driving situation. Fig. 2 shows the change in acceleration of road vehicles on the two public transport routes. *X*, *Y* and *Z* represent the linear accelerations along the respective axes measured in m/s^2. There are four types of suspected comfort disturbances such as rapid braking, lateral acceleration, pumping and thrust. Vertical accelerations are shown in the graph, but are not addressed in the present work, as they are subject of a study in many standards and publications of other authors [10].



(a) (b)

Fig. 2. Changes in the acceleration of the transport vehicles on both routes
X, *Y*, *Z* – axes of acceleration, measured in m/s^2; No of sample, also means No of measurement: first route (a); second route (b)

Heavy acceleration that reduces comfort are available. This applies both to the acceleration when starting and stopping. Acceleration graphs show that high levels are most common when braking. These high acceleration levels are not acceptable to passengers. Sharp startups and stops and "pumping" are perceived as very inconvenient. They also influence the ability to maintain balance of passengers. Repeating sharp turns with high lateral accelerations in both directions reduce comfort, resulting in visibly unpleasant emotions in passengers. Uneven driving, so-called "Pumping", reduced comfort and caused nervous condition and unpleasant sensations in travelers, which led to remarks to driver. Vertical accelerations and vibrations caused by damaged road surfaces or speeding obstacles also caused unpleasant sensations among passengers.

3. Research methods

A survey of accessible literary sources [11] shows that many data and many people's interviewing are needed to obtain objective travel comfort results. Such analyzes are only achievable in laboratory conditions with pre-prepared respondents. In real-world travel, respondents would not want to answer too many questions but are willing to fill in a brief survey with a small number of questions after kindly asking for it. For this reason, the survey should contain a small number of precise, easy and clear questions to the respondents and be suitable for interviewing a small number of people.

The following types of questions are selected: questions describing a specific response to the degree of comfort; numerical evaluation of the reaction as a score.

A 5-grade evaluation scale is selected which can be directly related to the measured acceleration values in the different axes of motion of both the vehicle and the respondents. The selected respondents are of average age and weight [12]; they are neither active athletes nor are they in poor health. Respondents were informed about the purpose and the tasks set in the survey.

Experiments have been carried out in the bright part of the day. The weather conditions are without rain, clear, sunny weather, ambient temperature 17 ^{o}C, relative humidity 50% RH. Measurement site Tenevo Airport, Tundzha Municipality, Bulgaria.

The data obtained from the survey are grouped by age of the respondents, as this criterion gives a statistically significant difference (at a level of significance $\alpha = 0.05$) between responses. These data were used in compiling a regression model and correlation analysis with data from accelerometer sensors.

Microcomputer systems, including Pololu LSM6DS33 (Pololu Corporation, USA) based on the ST LSM6DS33 sensor, are mounted on the mass center and on the driver. Each respondent has mobile phones and captures data from their accelerometers. The sensors used are of close technical nature and the measurement error for both sensors is the same.

4. Results and discussion

A survey was conducted in a total of seven maneuvers involving the rectilinear and curvilinear movement of the vehicle at three different driving speeds of 40, 50 and 60 km/h. Three levels of discomfort are used 1-comfort; 2-discomfort; 3-high level of discomfort. These defined levels are obtained from the survey and compared to the other measured parameters – speed, linear and angular acceleration. The survey results are presented in table 1 with mean values for parameters studied. S is velocity in km/h; *X*, *Y*, *Z* are linear accelerations in m/s^2; *A*, *B*, *C* are rotational (angular) accelerations in rad/s; DL is Discomfort Level (degree of discomfort).

Table 1. Survey results

S	*X*	*Y*	*Z*	*A*	*B*	*C*	DL	*S*	*X*	*Y*	*Z*	*A*	*B*	*C*	DL
40	–1.52	–1.49	–0.40	–2.88	–2.89	–2.37	1	60	–0.05	–0.38	–0.14	–2.80	–1.95	–1.71	2
40	–2.47	–1.44	–1.11	–2.49	–2.72	–2.61	1	60	0.30	–0.73	–0.74	–2.35	–1.18	–1.18	2
40	–2.47	–0.45	–0.77	–2.10	–2.84	–2.96	1	50	–1.68	–2.02	–0.83	–2.75	–2.68	–2.26	2
50	–1.16	–0.98	–0.25	–2.89	–2.93	–2.44	1	50	–1.15	–0.45	–0.29	–2.56	–2.89	–2.77	2
40	0.23	–1.22	–0.43	–2.80	–1.08	–1.38	1	50	–1.81	–0.66	–0.65	–2.36	–2.80	–2.79	2
40	0.65	–0.06	–0.07	–2.26	–0.10	–0.09	1	60	0.23	–2.52	–0.96	–2.78	–1.34	–1.48	2
40	–0.83	–1.04	–0.23	–2.93	–2.87	–2.24	1	50	–1.55	–1.64	–0.51	–2.84	–2.82	–2.33	2
40	0.38	–2.52	–0.98	–2.77	–1.20	–1.42	1	60	0.25	0.12	–0.04	–0.32	–0.16	0.46	2
40	–1.65	–0.54	–0.24	–2.73	–3.00	–2.83	1	50	–1.07	–1.20	–0.30	–2.90	–2.87	–2.30	2
50	0.00	0.96	–0.45	–0.44	–1.58	1.57	1	60	–0.80	–1.21	–0.25	–2.94	–2.84	–2.16	2
60	–0.61	–0.11	–0.18	–2.12	–2.85	–2.96	1	60	0.23	–1.33	–0.59	–2.72	–1.20	–1.40	3
60	0.76	–0.46	–0.15	–2.83	–0.20	–0.55	1	60	–0.51	1.67	–0.39	–0.23	–2.49	1.87	3
40	–2.49	–2.08	–0.83	–2.76	–2.82	–2.45	1	60	–1.29	1.02	–0.35	–0.33	–2.88	2.47	3
50	0.41	0.18	–0.10	–0.50	–0.23	0.40	1	60	0.52	–1.03	–0.85	–2.45	–1.02	–1.11	3
60	–1.03	–0,80	–0.28	–2.81	–2.88	–2.48	1	60	–0.86	–0.11	–0.22	–2.04	–2.89	–3.01	3
60	1.00	–0.40	–0.14	–2.80	–0.14	–0.38	1	60	0.61	–0.49	–0.46	–2.39	–0.64	–0.68	3
40	–1.65	0.20	–0.26	–0.91	–2.99	3.02	1	60	–2.77	–1.26	–0.74	–2.61	–2.88	–2.71	3
40	0.08	1.65	–0.17	–0.10	–1.15	1.52	1	60	–2.49	–2.14	–1.18	–2.64	–2.70	–2.43	3
40	–0.75	–0.06	–0.14	–2.00	–2.95	–3.06	1	60	–1.93	–0.15	–0.77	–1.76	–2.76	–3.06	3
50	–0.42	1.18	–0.17	–0.14	–2.76	1.91	1	50	1.89	0.85	–0.87	–0.80	–0.43	0.42	3
50	–2.02	0.36	–0.31	–0.72	–2.99	2.97	1	60	–1.71	–1.00	–0.37	–2.79	–2.93	–2.61	3
60	–1.00	–0.24	–0.26	–2.30	–2.88	–2.91	1	60	–2.57	–0.01	–0.36	–1.59	–3.00	–3.14	3
50	–1.47	1.82	–0.39	–0.21	–2.88	2.25	1	–	–	–	–	–	–	–	–

Table 2 shows the correlation between the degree of discomfort and the measured speed, acceleration, and angular displacement parameters. In this analysis all data from the survey are used. *X*, *Y* and *Z* are linear accelerations. *A*, *B*, *C* are rotational axes. It can be seen from the table that the speed of travel, the acceleration in the direction of movement *X*, the rotation axis *C* (about the axis *Z* of the accelerometer) have a significant influence on the degree of passenger discomfort.

The correlation is calculated in MS Excel 2016 (Microsoft Corporation), in Data Analysis Tool Pack, according to the formula

(1) $$r_{xy} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2(y_i-\bar{y})^2}},$$

where: x_i are all values of first compared parameter, y_i is the second compared parameter, i=1,…, n is the number of measurements for every parameter.

Table 2. Correlation between measured parameters and degree of discomfort

	Discomfort	*S*, km/h	*X*	*Y*	*Z*	*A*	*B*	*C*
S, km/h	0.56	1						
X	–0.14	0.14	1					
Y	0.02	0.05	0.20	1				
Z	–0.27	0.02	0.25	0.52	1			
A	0.05	–0.02	0.12	0.85	0.25	1		
B	–0.08	0.11	0.84	0.07	0.06	0.11	1	
C	–0.14	–0.05	0.34	0.66	0.25	0.79	0.32	1

The degree of discomfort is heavily influenced by the speed of the vehicle. The coefficients of the equation describing this relationship are above 0.1. The coefficient of regression R^2>0.8, which also confirms this relationship,

(2) $$D = 0.08V - 2.77, \qquad R^2 = 0.99,$$

where *D* is a degree of discomfort, and *V* is the speed of travel, km/h.

As in the previous case, the relationship between the acceleration along the *X* axis, the direction of movement and the degree of discomfort here is strong. The coefficients of the equation, which are much larger than 0.1, confirm what has been said so far. The high coefficient of regression (R^2>0.8) also demonstrates the strong link between the acceleration in the direction of movement and the degree of discomfort of the occupants of the vehicle,

(3) $$D = 4.57X + 4.79, \qquad R^2 = 0.99,$$

where *D* is a degree of discomfort; *X* is acceleration in the direction of travel, m/s^2.

The relationship between the angular motion along axis *C*, around the *Z* axis and the degree of discomfort is strong. The coefficients of the equation are greater than 0.1. Unlike the previous two cases here, the regression coefficient is just over 0.8. This again proves the strong link between the rotational movement and the degree of discomfort of the occupants of the vehicle,

(4) $$D = -1.19C - 0.31, \qquad R^2 = 0.81,$$

where *D* is a degree of discomfort; *C* is rotational motion around axis *Z*, rad/s.

Fig. 3 shows the resulting regression model describing the relationship between the three parameters: *X* axis acceleration, the *C* axis rotational movement and the degree of discomfort.

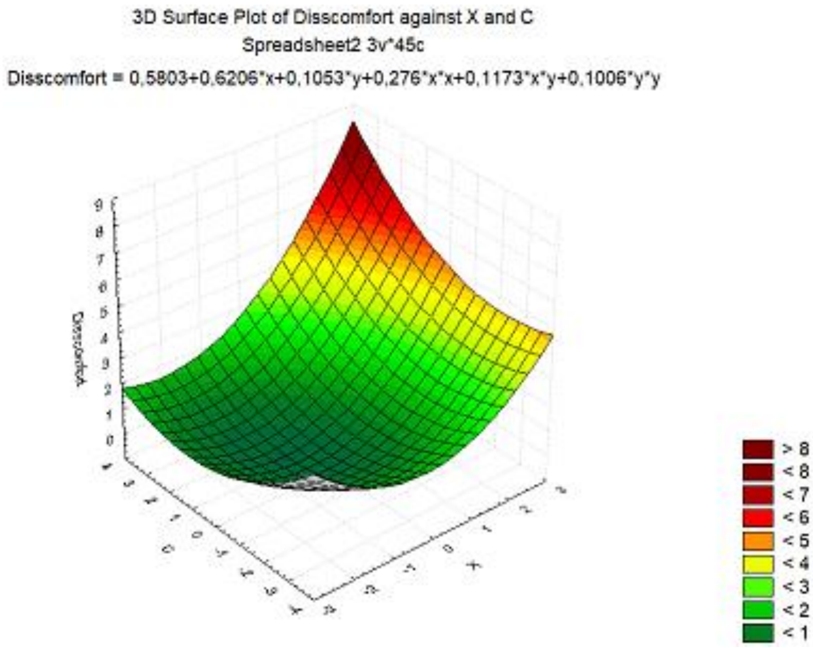


Fig. 3. Relationship between *X*, *C* and degree of discomfort *D*, *D*=*f*(*X*, *C*)

Linear model, that describe the relationship *D*=*f*(*X*, *C*) has R^2<0.5 and the coefficients have *p*-value > α = 0.05.

The relation between the studied parameters is non-linear and can be described by a model of the type:

(5) $$z = b_5x^2 + b_4xy + b_3y^2 + b_2x + b_1y + b_0,$$

where b_i, i=0,…, 6, are the coefficients of the model, *x* and *y* are independent variables, *z* is dependent variable. The model is obtained in Stat Soft Statistica v8 (Stat Soft, Inc.).

The resulting model has the form

(6) $$D = 0.1006C^2 + 0.1173XC + 0.276X^2 + 0.1053C + 0.6206X + 0.5803,$$

where: *D* is a degree of discomfort; *X* (ax, m/s^2) – axis *X* acceleration; *C* rad/s is the rotational movement around axis *Z* with R^2=0.87 and coefficients with *p*-value<α.

Based on the obtained dependencies and equations, a microprocessor system, consisting of three basic modules – hardware, software and graphical user interface - has been developed. The handset is based on: a single-chip microcomputer; acceleration and angular displacement measuring device; a storage device in permanent memory; visualization device.

Fig. 4 shows the assembly of the developed system in front of the bus driver.

The program part (software) is built on a modular principle, making it easy to read and modify the control program.

The graphical user interface consists of: Main menu; Passenger comfort display screen; Screen with graphical and numerical data representation; System user help information.

Fig. 4. Developed system, mounted in a bus

The principles of the *V*-chart [13] and the recommendations in the Code of Practice [14] for the creation of driver assistive systems were used to develop and build this system.

Fig. 5 shows a block diagram for connecting the devices used. The single board microcomputer manages the programmable display, the SD card module and the digital acceleration and angular motion sensor in parallel. The system is powered autonomously with a Power bank battery.

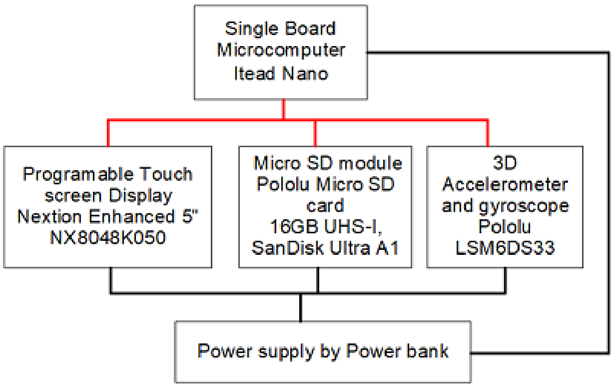


Fig. 5. Block diagram of the driver assistant system

4.1. System software

The software is fully implemented in the single board microcomputer. It is built on a modular principle with three parts: setup; initial initialization and basic program. The C language tools and the Arduino IDE system program are used to program Arduino microprocessor device.

Fig. 6 shows the structure of the generated control system software. It consists of four basic modules. The Initial Initialization Module prepares system hardware and software devices for work. The input module uses accelerometer and gyro data and accepts queries from the user interface. In the data processing module, the raw data from the sensors are filtered, the degree of discomfort is calculated. The output module controls serial display (UART), display visualization, and SD card storage.

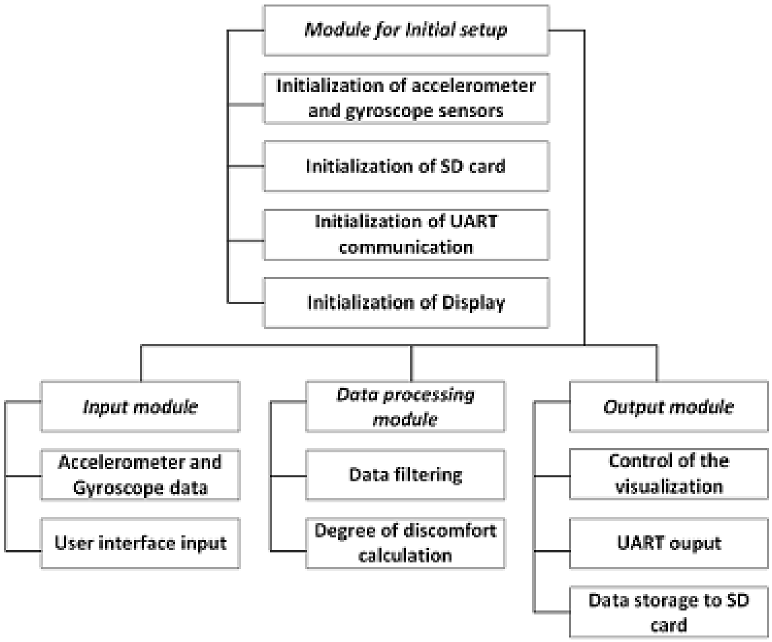


Fig. 6. Structure of the system software

In the tuning module, the string variables are reset, string length is defined, they are defined as variables. Libraries are loaded for: I^2C communication; acceleration and angular displacement sensor library; SDI card module SPI library SD card module management library.

The initial initialization module includes a UART serial communication speed setting. Communication on I^2C serial interface starts. Check for the presence of acceleration and angular displacement sensor. Checks for an SD card module. When available, a text file opens and a headline is recorded once. This line is saved after each system reboot or reboot. If the SD card module is not available, a serial channel error message is displayed.

The functions in the main program can be divided into three groups: reading and converting binary data from the acceleration and angular displacement sensor; record to SD card file; output of graphical and textual data on the measured acceleration; outputting data to the driver assistant screen.

Sensor data are read in binary code and convert to decimal numbers. These decimal numbers are used to calculate the acceleration and angular displacement values by the coefficients described in the sensor's datasheet.

With the write function in a text file on an SD card, the text file opens for recording. The acceleration and angular displacement values of one row, separated by a tab symbol, are sequentially recorded. The file closes. This operation is repeated continuously until the main program is executed.

The output on a coordinate system is a command containing a coordinate system number, a channel and a value of the measured magnitude. A cycle is run through which the symbol character elements are sent as symbol strings. Unlike Windows based text editors, three characters 0×FF are sent consecutively to the display line (in Windows they are CR+LF).

The output of the instantaneous acceleration value is by a command describing the text field number indicating that text and the acceleration value converted to a string will be sent because fractional numbers cannot be sent to the display.

The driver assistant control function checks whether the acceleration value is in the appropriate comfort zone. A command is displayed to display a green, yellow, or red figure on the display along the corresponding coordinate axis. The other elements that do not correspond to the current measurement on the particular axis are covered with a background color element. The command used indicates a figure for a figure, object figure, and graphic element number to be displayed. The graphical elements representing circles with red, yellow, green and white color are pre-set in the program, compiled by the system software on the display.

4.2. Graphical user interface of the driver assistant system

The Graphical User Interface of the Driver Assistant System consists of Main menu, the Assistant menu, the Charts menu, and the Help Information menu. Switching between the menus is performed by buttons activated by the touch screen functions. It is built with the Nextion Editor V0.53 (ITEAD Intelligent Systems Co. Ltd), which offers graphical user interface building and programming of the Nextion smart touchscreen display from the manufacturer. Fig. 7 shows the graphical user interface structure. From the main menu, the other menus in the system can be selected sequentially. After using the appropriate menu, it is possible to return to the main menu.

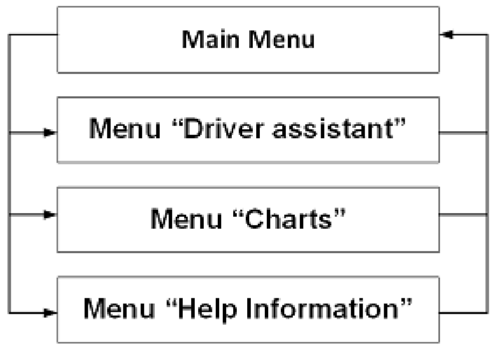


Fig. 7. Graphical user interface structure of “Driver assistant” system

The main menu shown in Fig. 8 is divided into two main elements – system information and a control button block for connection to the screens (pages) of the system.

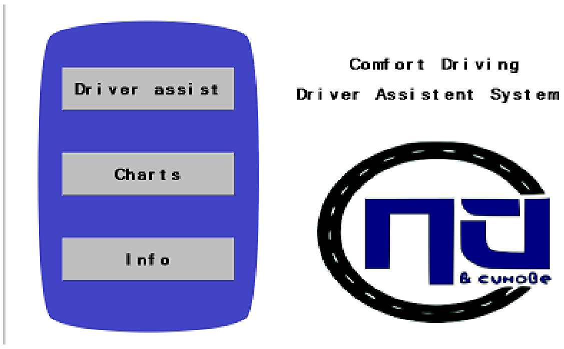
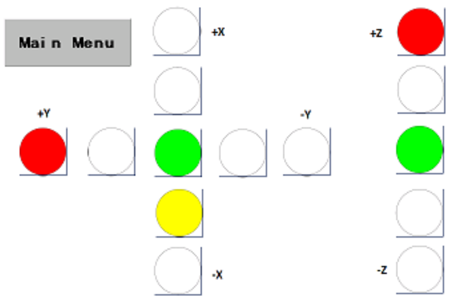


Fig. 8. Main menu

Assistant Menu is shown in Fig. 9. It consists of a button to return to the main menu and indications that indicate the degree of comfort of the passengers through a “traffic light” system.

	if (ax<=0.63){
	sendThis = “+*X*, green”;}
	if (ax>= –0.63){
	sendThis = “–X, green”;}
	if (1.6 < ax && ax <= 2.5) {
	sendThis = “+*X*, yellow”;}
	if (–1.6 > ax && ax >= –2.5) {
	sendThis = “–*X*, yellow”;}
	if (ax>2.5){
	sendThis = “+*X*, red”;}
	if (ax<–2.5){
	sendThis = "–*X*, red”;}

(a)	(b)

Fig. 9. Menu “Driver assistant”: visualization on the display (a); a pseudocode example for *X* axis indicator lights activation (b)

The acceleration values for the *Y*-axis, according to discomfort level are obtained after conversion of *X* and *C*. The discomfort limits for the *Z*-axis are in accordance with EN 13816:2002 standard [2]:

$$Y = \frac{X}{\tan(C)}. \tag{7}$$

Table 3 lists the limit values obtained for the discomfort level, depending on the acceleration along the three axes of motion.

The visualization is on the three moving axes *X*, *Y* and *Z* in positive and negative direction, which also indicates the influence of the reverse acceleration – when the vehicle brakes are pressed. The acceleration value limits are defined according the model obtained above. A pseudocode example is added that describes the way of activating the *X*-axis lights according positive or negative values of the acceleration in *X* direction, measured in m/s^2. The variable “sendThis” is used in a control command for the touch display being used. The activation of indicator lights for other axes, *Y* and *Z* is in the same manner.

Table 3. Discomfort levels used for visualization

Axis	Discomfort level		
	1-comfort (green)	2-discomfort (yellow)	3-high level of discomfort (red)
+*X*	from 0.63 up to 1.6 m/s^2	from 1.6 up to 2.5 m/s^2	above 2.5 m/s^2
–*X*	from –1.6 up to –0.63 m/s^2	from –2.5 up to –1.6 m/s^2	under –2.5 m/s^2
+*Y*	from 0.23 up to 0.28 m/s^2	from 0.28 up to 1.3 m/s^2	above 1.3 m/s^2
–*Y*	from –0.28 up to –0.23 m/s^2	from –1.3 up to –0.28 m/s^2	under –1.3 m/s^2
+*Z*	from 0.31 up to 0.8 m/s^2	from 0.8 up to 2 m/s^2	above 2 m/s^2
–*Z*	from –0.8 up to –0.31 m/s^2	from –2 up to –0.8 m/s^2	under –2 m/s^2

The graphics visualization menu is shown in Fig. 10. In this menu also a software button is provided to return to the main menu of the system.

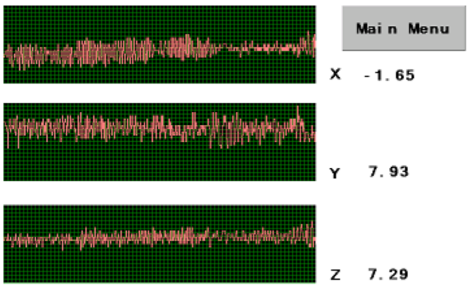


Fig. 10. Menu “Charts”

There are three coordinate networks showing in graphical form the variation of the acceleration values in m/s^2 on the three axes of motion *X*, *Y* and *Z* in their positive and negative directions. The instantaneous values of this acceleration are also displayed in text format.

The Help Menu may be in one in two languages – Bulgarian and English. The information displayed complements the technical description of the system and is selected so that it can be used on a journey without having to consult the complete technical documentation of the device. This screen describes the basic functions of the system in a synthesized form. As with the other screens, a software button is provided to return to the main menu.

4.3. Validation of the developed system

Validation of the developed system was made. This is done on a route that was not used in the initial analysis and in developing the model describing the relationship between acceleration, angular displacement and degree of discomfort.

Fig. 11 shows results of system validation. The degrees of discomfort and accelerations on axes *X*, *Y* and *Z* in m/s^2 were applied.

The indicated degrees of discomfort were obtained in a survey of respondents who participated in the previous stages of the study. Three levels of discomfort are defined: 1 – no discomfort; 2 – little uncomfortable; 3 – high degree of discomfort.

In the stages of the trip, after passing the different sections of the route, the bus stopped and a poll was completed. The results of it are referred to as a “degree of discomfort” on the graph. The degree of discomfort obtained from system data has also been reported. The graph shows that the degree of discomfort determined by the system and by survey coincided with a difference of up to 10%.

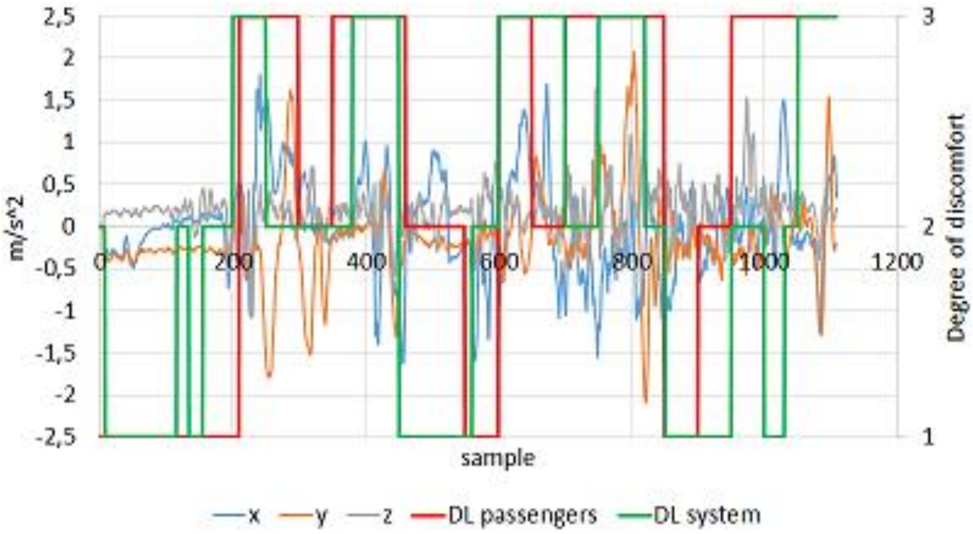


Fig. 11. Results of validation of the developed system:
X, *Y*, *Z* – acceleration over axis; DL – degree of discomfort

The validation of the system shows that the degree of discomfort defined by the developed system and that indicated by the respondents have a minimal difference (up to 10%). This shows that the developed system has potential for driver guidance to ensure comfortable and safe travel in public transport. Further studies need to be made in relation to the application of the system, depending on the peculiarity of the relief, the geographic area concerned and studies related to its application in urban and extra urban environments. The obtained results confirm those reported by Wang, Ma and Hooka [15] and Rekabdar and Mousas [16], which state that many topics remain on the improvement this type of driver assistant systems. Data from a larger population of subjects and wider variety of vehicle types should be collected for the generalization of the ride discomfort model. This problem remains still unresolved.

5. Conclusion

The analysis of passenger comfort based on accelerometer data and a survey showed that the degree of discomfort could be predicted with sufficient precision by accelerometer data for axis *X* – acceleration in the direction of motion of the vehicle and on the rotational axis *C* about the vertical axis *Z* of the accelerometer. The movement on the rotary axis can be directly measured with a gyroscope or indirectly calculated. The disadvantage of using a gyroscope is that the so-called “Drift” leads to an increase in the error in the measurement of the deviation on the rotary axes of motion. When using a gyroscope, it is necessary to use correction calculations from the accelerometer data.

The results obtained complement and partly improve those from the available literature with a model using only one linear and one rotary axis, by which the discomfort is described with sufficient accuracy.

The resulting model is an appropriate basis for building a driver assistance system to provide passenger comfort in public road transport.

A model of a "Driver Assistant" microprocessor system based on studies is proposed. A sequence has been developed for setting up this system. A graphical user interface on a modular principle has been built up, consisting of four modules. Functionally the user interface allows for acceleration measurements. The built-in interface includes features for pre-processing the received measurement data. The utility allows adding additional functionality and help information for the added modules. Within the framework of the research, developed system has potential for driver guidance to ensure comfortable and safe travel in public transport with accuracy up to 10%.

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