DRIVING COMFORT ASSISTANCE SYSTEM CONSIDERING TWO SENSORS DATA

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Abstarct: In the present work, a system using data from two sensors located next to the driver and to the mass centre of the bus is proposed. Three degrees of discomfort have been used – comfortable, moderately uncomfortable and very uncomfortable. These levels are set out in the questionnaire. A survey was conducted. Respondents were selected between the ages of 14 and 65 and were divided into three age groups – adults, middle-aged and young. Accelerometer systems with MPU-6500 (TDK InvenSense Corp.) sensors are used. A correlation method (CORR) and sequentially improving estimation methods are used for feature selection, which significantly reduce the number of combinations of features obtained. Selected sensor data is entered into feature vectors. These vectors are reduced by principal component analysis. Predictive models have been created that take into account the age of passengers. The use of data from two sensors and separation of the passengers according their age, leads to an increase in the accuracy of predicting passengers discomfort level (DL) of up to 98%. These results can be used to evaluate and guide the vehicle driver in order to improve his driving style. In addition, the simplified interface does not distract the driver from the road conditions. The results obtained can lead to an improvement in the parameters of the transport process, which covers the interest of the carrier related to the efficient use of vehicles, and hence the reduction of fuel consumption and harmful emissions. However, it should be recommended that, when developing systems to ensure comfort of travel, adjustments should be made to suit the age group of passengers carried on public transport buses.

Key words: stated preference survey, predictive model, customer satisfaction, passenger comfort, passenger service,
driver assistance system

1. INTRODUCTION

The deterioration of the comfort of traveling in vehicles is due to vibrations, noise and ambient temperature. Drivers' poor driving experience makes the public transportation system less attractive (Vrcan et al., 2011; HaoLiang et al., 2018).

The regulatory documents (ISO, 1978) mainly address the vertical vibration leading to a strong sense of discomfort in commuters. Research into the vertical stability of the passenger is also the subject of scientific research. Improvements in train travel have been explored (Sharma et al., 2018), and also in sea and river passenger transport ships (Kim et al., 2014).

In Bulgaria, which is in the European Union, bus is one of the main methods of public transport in urban and interurban environments (Tsvetkova, 2017). From the available literature, there are known solutions related to attempts to improve travel comfort. Tab. 1 summarises the more commonly used methods for improving the comfort of public transport.

Tab. 1. Methods for improving the comfort of passengers in public transport vehicles

Method	Advantages	Disadvantages	Reference
Active seat suspension	It works individually for each passenger, feedback with different sensors.	Low stroke of the actuator, depends on the weight of the passenger, high cost of realisation.	Ikeda et al., 2018; Sikora, 2018
Active bus suspension	Long stroke of the actuator, built by serial bus manufacturers, feedback with different sensors.	Pneumatic or hydraulic pump with high power consumption is required.	Jurkiewicz et al., 2017; Long et al., 2018
Driver assistant systems	Opportunity for software realisation on a mobile phone.	The system is not active, it depends on the driver's level of experience.	Stoichkov, 2013

Driver-assisted systems have very good potential than the other two active suspension methods. They can be implemented on a mobile phone using the sensors of this device. They can also be applied to older bus models that do not have active suspension systems.

Solutions are known using the sensors available in the mobile phone. Combining their data gives better results than using an accelerometer alone. The advantage of these systems is that when one of the sensors fails, the operation of the system can continue with data from the other sensors. A major drawback of

the method is that such a method can only be used for a limited period of time after the failure of a major sensor in the system (Stoichkov, 2013).

The decision to use neural networks is made by car and mannequins (Kim eta al., 2019). The disadvantage of this type of system is that it uses complex computational procedures and is suitable for operation in a controlled environment. It is necessary to propose a system that is suitable for real-world application of urban transport. The analysis made shows that the appropriate classification methods are those that use simplified calculation procedures, can be applied by technical means, and that can be placed directly on public transport buses because they speed up the calculation process and reduce the system response time.

It is not clear from the available publications whether the age of travellers is important for the comfort of travel. Such an analysis needs to be done.

The purpose of the article is to evaluate the possibility of improving travel comfort by using data from two sensor systems, depending on the age of the passengers.

2. MATERIAL AND METHODS

Iveco Poker Bus (FIAT-IVECO S.p.A.) is used. The bus has a total length of 7.5 m. Accelerometer systems with MPU-6500 (TDK InvenSense Corp.) sensors are used. The systems are mounted in protective housings. The connection between them is via Bluetooth communication. HC-06 modules are used. The module provides Bluetooth 2.0 connection at a speed of 2,400 bit/s. The first sensor system is located next to the driver and the second near the bus centre.

Fig. 1 shows a block diagram of the sensor system used. This scheme is applicable to both systems installed near the driver and to the centre of mass of the bus.
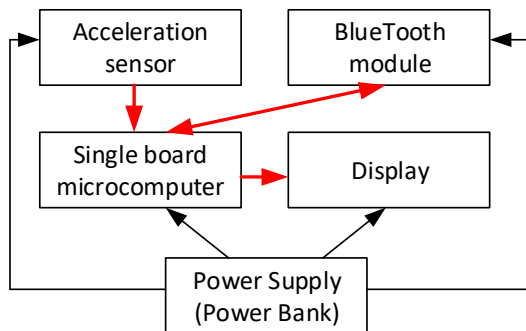

Fig. 1. Block-diagram of a measurement system

Fig. 2 shows a schematic diagram of the experimental layout, with the arrangement of the sensor systems used.

The designations of accelerations along the sensor-driver axes are: X, Y, Z (m/s^2) – for linear accelerations; A, B, C (rad/s) –for angular accelerations. The axes of the sensor to the centre of mass of the bus are: X1, Y1, Z1 – for linear accelerations; A1, B1, C1 – for angular accelerations. The determination of the angular acceleration values on the rotary axes is calculated. This option is preferred because the gyroscopic sensor that is inserted into the MPU-6500 sensor has the disadvantage of obtaining a so-called 'drift' upon measurement (Li et al., 2019). The determination of the angular acceleration values is made by the following mathematical relations:

$$A = \mathrm{atan}(Y, Z), rad/s \qquad (1)$$

$$B = \mathrm{atan}(X, Z), rad/s \qquad (2)$$

$$C = \mathrm{atan}(X, Y), rad/s \qquad (3)$$

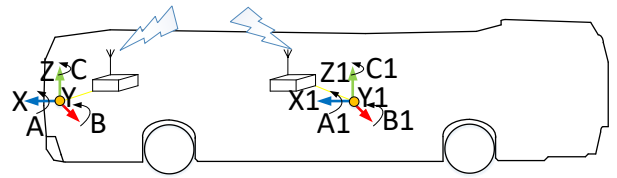These calculations are made for both sensor systems used.

Fig. 2. Experimental setup – general view

Attempts were made in the light-part of day. Meteorological conditions are free of precipitation, clear, sunny weather, ambient temperature 17 °C and relative humidity 50%RH. Location of measurements are Tenevo Airport, Tundja Municipality, Bulgaria.

Based on the available literature (Smith et al., 2006), many data are needed and many people are interviewed to obtain objective results for travel comfort. Such analyses are only achievable under controlled and laboratory conditions with pre-prepared respondents. For this reason, the survey developed contains only disaggregated levels of discomfort. Three degrees of discomfort have been used – comfortable, moderately uncomfortable and very uncomfortable. These levels are set out in the questionnaire. The graphics used are with Creative Commons CC0 (https://pixabay.com).

A survey was conducted. Respondents were selected between the ages of 14 and 65, and were divided into three age groups – adults, middle-aged and young. Before completing the survey, a clarification is made as to what each degree of discomfort means, which should be noted after each manoeuvre.

The following methods have been used to select features describing the degree of discomfort (Su et al., 2017):

- Correlation method (CORR). Correlation dependence allows one to look for unknown links between features that describe discomfort. In the selection of features, those that have the least possible correlation with each other are sought;
- Method for selecting regression features by analysis of adjacent components (FSRNCA). The algorithm is suitable for selecting features for regression analysis;
- Method for ranking significant forecasting parameters (RELIEFF). The method is a selection function using the ReliefF algorithm for classification and the RReliefF algorithm for regression. This algorithm works well when evaluating the significance of characteristics for distance-based models;
- Weight averages obtained from the feature selection methods. The arithmetic mean of the weights of the features was used.

Principal Components (PCs) obtained by Principal Component Analysis were used to reduce the volume of feature vector data (Mladenov et al., 2015).

An initial model was used to describe the relationship between the main components and the degree of discomfort of the type:

The model coefficients are analysed, depending on the p-level value, for each of them. Non-informative coefficients are rejected by the model.

The residuals have been analysed (Tasev et al., 2011), which

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are determined by the difference between the model values and the actual values.

The accuracy of the predictive models is estimated on the basis of statistical parameters. The coefficient of determination (R2), sum of squares of error (SSE) and root mean square error (RMSE) were used as the criteria for model evaluation.

The validation of the results obtained was done with data not used in the previous measurements. Mainly nonlinear manoeuvres are used − left and right turns, as well as reverse turns.

All data were processed at a level of significance α=0.05.

3. RESULTS AND DISCUSSION

As a result of the calculations and analysis of results, the developed system is presented in general form. Selection methods for feature vectors by which passengers discomfort are predicted, depending on the age of the travellers. Predictive models have been developed. A system for indicating the degree of discomfort is proposed. Validation of the proposed system has been made. The results obtained are compared with those of the available literature.

Fig. 3 shows the sensor devices mounted next to the driver and to the centre of mass of the bus.
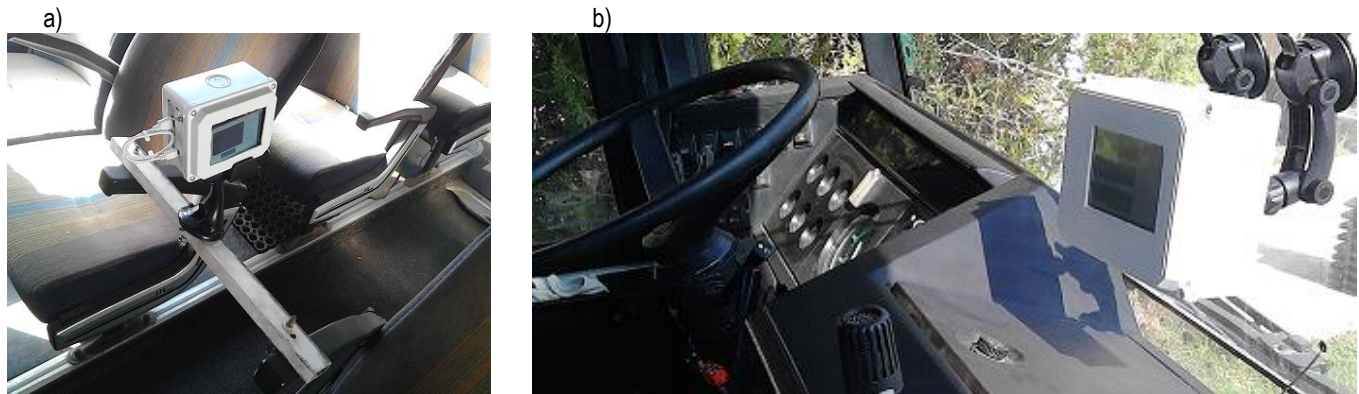

Fig. 3. Measuring devices – general view: (a) a measuring device installed near the mass centre of the bus, (b) a measuring device installed near the bus driver

Tab. 2 lists data for selected feature vectors. It can be seen that, by the RELIEFF method (6 features), the same traits were selected for all age groups according to which the degree of discomfort can be predicted. The highest number of traits were selected by the FSRNCA method (6–10 features), followed by the CORR method (4–7 features).

major components describe with sufficient accuracy over 95% of the variation in feature vectors. Results of averaged (A) travel comfort data are also presented. The use of average passenger discomfort data does not show sufficient accuracy to predict it. It is seen that the separation of the data by age groups shows an increase in the values of the coefficient of determination and the reduction of errors.

Tab. 2. Selected feature vectors

Age group	Method	Feature vector	Selected features
Old (O)	CORR	OFV1	X, Y, A, B, X1, B1, C1
	FSRNCA	OFV2	X, Y, A, B, C, X1, Z1, A1, B1
	RELIEFF	OFV3	Z, C, X1, Y1, Z1
MA	CORR	MFV1	C, Y1, A1, C1
	FSRNCA	MFV2	Y, A, C, X1, Y1, Z1, A1, C1
	RELIEFF	MFV3	Z, C, X1, Y1, Z1
Young (Y)	CORR	YFV1	Z, B, C, Y1, A1
	FSRNCA	YFV2	X, Y, Z, A, B, C, X1, Y1, Z1, C1
	RELIEFF	YFV3	Z, C, X1, Y1, Z1
Averaged (A)	CORR	AFV1	X, C, A1, C1
	FSRNCA	AFV2	X, B, C, X1, Z1, A1
	RELIEFF	AFV3	Z, C, X1, Y1, Z1

CORR, correlation method; FSRNCA, method for selecting regression features by analysis of adjacent components; MA, middle aged

Tab. 3 shows the results of preliminary analyses of passengers' discomfort, depending on the age of the respondents. Two

Tab. 3. PCR results for predicting passengers' discomfort

Feature vector	R^2	SSE	RMSE	Feature vector	R^2	SSE	RMSE
OFV1	0.95	1.06	0.29	YFV1	0.95	0,.81	0.25
OFV2	0.98	0.49	0.19	YFV2	0.99	0.19	0.12
OFV3	0.95	0.59	0.29	YFV3	0.93	1.07	0.29
MFV1	0.94	1.39	0.33	AFV1	0.88	1.27	0.71
MFV2	0.96	1.04	0.28	AFV2	0.89	0.84	0.25
MFV3	0.94	1.38	0.33	AFV3	0.88	0.97	0.57

PCR, principal component regression; RMSE, root mean square error; SSE, sum of squares of error

The selected feature vectors, reduced by the principal component analysis method, were used to construct models for predicting the degree of discomfort for three age groups of travellers. After removing the insignificant coefficients from the base model that have p-Value $\gg \alpha$, it has been found that the relationship between travel discomfort and major components of the feature vectors can be described by the following models:

$$OFV2 \quad D = 2,31 + 0,99.PC1 - 0,72.PC2 - 0,01.PC1^2 - 0,55.PC2^2$$

R2=0,98
SSE=0,01   (5)
RMSE=0,02

$$MFV2 \quad D = 2,06 + 1,12.PC1 - 1.19.PC2 - 0,13.PC1.PC2$$

R2=0,98
SSE=0,04   (6)
RMSE=0,02

$$YFV2 \quad D = 2,08 + 1,06.PC1 - 1,51.PC2 - 0,04.PC1^2$$

R2=0,98
SSE=0,02   (7)
RMSE=0,05

Low standard error values are observed. The coefficients of all models are significant because the p-value is much less than the accepted level of significance α = 0.05.

SSE and RMSE error values are low. The results show that the models obtained describe a significant part of the change in the degree of discomfort in travel, depending on the age group of travellers.

These estimates are not a sufficient criterion for evaluating the model. A residuals analysis needs to be done.

Residuals analysis shows that the models obtained are adequate. When analysing the residuals, there is a lack of systematic deviation of the actual data from the theoretical data, which is a sign of their normal distribution. The analysis of standardised coefficients shows that the first major component of the feature vectors has a significantly greater influence on the predictive power of the models.

Based on the models obtained, three degrees of discomfort have been defined, which can be used in driver signalling by visual indication. The display is divided into three levels − green, yellow and blue, depending on the level of discomfort. Fig. 4 shows the defined degrees of discomfort.
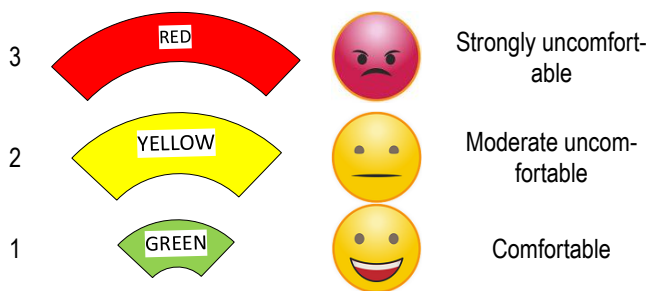

Fig. 4. Indication of the level of discomfort

Tab. 4. Results of system validation

M		M1, DL			M2, DL			M3, DL		
V, km/h		40	50	60	40	50	60	40	50	60
O	S	1	2	3	1	2	3	1	2	3
	R	1	2	3	1	3	3	2	2	3
MA	S	1	1	3	1	1	3	1	1	3
	R	1	1	2	1	1	2	1	1	2
Y	S	1	2	3	1	2	3	1	2	3
	R	1	1	2	1	1	2	1	1	2

DL, discomfort level; MA, middle aged; M-manoeuvre; O, old; R, respondents; S, system; V-speed; Y-young

Tab. 4 shows the results of system validation. The following manoeuvres were performed at speeds of 40 km/h, 50 km/h and 60 km/h: M1-linear acceleration; M2-curvilinear acceleration; M3-curved slow-down acceleration. The levels of discomfort shown were obtained from a survey of respondents who participated in the previous stages of the survey. Three degrees of discomfort have been defined. The degree of discomfort reported by the system and those of the respondents was also reported. It can be seen that the degree of discomfort determined by the system and the respondents' answers coincide with a difference of up to 5%.

The results obtained confirm, supplement, and refine those reported in the available literature. The proposed model for predicting the degree of discomfort by Ivanov et al. (2019) can be used to predict the degree of discomfort with an accuracy of up to 87%. The models proposed in this paper, depending on the age of the respondents, increase this accuracy to 98%. The results presented by Ikeda et al. [8], where the authors evaluate the degree of discomfort in one respondent, mainly take into account the vertical vibration only. Kim et al. (2014) proposed a system using neural networks. Despite the many factors they used in their model, they achieved 70% accuracy only. Moreover, the neural network method used made their system slow and unsuitable for real-world public transport applications. Same problem also happened with Rekabdar et al. (2018). The system proposed in this paper eliminates this shortcoming by using simplified computing procedures that are suitable for use in a real public transport environment. The influence of the length of the vehicle is also taken into account in the present work. Regardless of the results obtained, which, to one degree or another, improve and complement the well-known travel comfort solutions, and research should continue towards the creation of a generalised model that takes into account the factors such as age of travellers, atmospheric, road conditions, and the particularities of the urban environment in which these systems are implemented. As demonstrated (Stoichkov, 2013), improving travel comfort and proper bus handling indirectly leads to a reduction in fuel consumption, prolongs the life of vehicles and also reduces harmful emissions to the environment.

4. CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

The results obtained in this paper confirm, supplement and improve the parameters mentioned in the available published literature.

Models have been obtained for predicting travel comfort, depending on the age of travellers. Separation of passengers into age groups has been found to improve the accuracy of prediction of the discomfort rate by up to 98%. Due to the large deviations of the averaged analytical models, it is not appropriate to use an averaged model when predicting travel comfort. This means that individual models must be designed for each age group.

In the present work, a three-level discomfort indication system is proposed. These results can be used to evaluate and guide the vehicle driver in order to improve his driving style. In addition, the simplified interface does not distract the driver from the road conditions. The results obtained can lead to an improvement in the parameters of the transport process, which covers the interest of the carrier related to the efficient use of vehicles by the reduction of fuel consumption as well as in reduction of harmful emissions. However, it should be recommended that, when developing systems to ensure comfort of travel, adjustments should be made to suit the age group of passengers carried by public transport buses.

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