IMU based system for collecting data about the transport comfort

Željko Jovanović, Dejan Vujičić, Dragan Janković

***Abstract*—This paper describes the system for collecting data about transport comfort. Those data are received via 9DOF sensor board, which gives Euler angles (yaw, pitch, and roll), as well as the values of 3-axes accelerometer, gyroscope, and magnetometer. These values are intended for use with Android application that collects and displays them, along with the GPS coordinates. Also, the user has the ability to subjectively assess the current comfort level.**

***Index Terms*—Euler angles; transport; comfort; accelerometer; magnetometer; gyroscope; Android;**

I. Introduction

The term transport comfort cannot be strictly defined, but it is of great importance in the assessment of transport quality. The problem is the subjective comfort feeling which is different for every person. Comfort depends on many factors like acceleration (vibration), noise, temperature, compartment space, etc. If only mechanical effects are of interest, then generally the acceleration and vibration that passengers feel during the ride have the greatest impact on passenger comfort. These dynamic factors are produced by: vehicle condition, driver skills (driving style), and road condition. Vehicle condition factors that affects transport comfort are tires, suspension, shock absorbers, seats, etc. Road conditions are probably the most important for the passenger's comfort and safety. They can be categorized as static and dynamic factors. Static factors are commonly associated with a location, like road bumps and potholes. Dynamics factors appear suddenly, like rain, snow, or landslides. Also, the impact of other traffic participants is significant dynamic factor. These factors produce high and low frequency vibrations. High frequency vibration are produced by road surface, while low frequency are produced by driving style (vehicle turning, accelerating, and breaking).

In 1972, the International Organization for Standardization (ISO) issued a standard: "A Guide to the Evaluation of Human Exposure to Whole-Body Vibration" [1] which is still in general use. It is used for the evaluation of working conditions and exposure to the vibrations. Even it is in general use, it is based only on accelerometer analysis which is not always a good choice.

Željko Jovanović, Faculty of Technical Sciences in Čačak, University of Kragujevac, Svetog Save 65, 32000 Čačak, Serbia (phone: 381-32-302-721, e-mail: zeljko.jovanovic@ftn.kg.ac.rs

Dejan Vujičić, Faculty of Technical Sciences in Čačak, University of Kragujevac, Svetog Save 65, 32000 Čačak, Serbia (phone: 381-32-302-721, e-mail: dejan.vujicic@ftn.kg.ac.rs

Dragan Janković, Faculty of Electronic Engineering, University of Niš , Aleksandra Medvedeva 14, 18000 Niš, Serbia (phone: 381-18-529-543, e-mail: dragan.jankovic@elfak.ni.ac.rs

The authors of [2, 3] showed little match between ISO 2631-1 [1] comfort prediction results and self-reported results during heavy machinery routines for construction, forestry, and mining vehicles. Since subjective comfort was different from the predicted one, in the proposed research Neural Network (NN) are implemented to learn to predict subjective comfort. The authors of [4] showed a high correlation between whole-body vibration exposure and disability pension retirement.

Based on these, it is important to monitor transport conditions in order to analyze transport comfort and its effects on passengers.

The role of smartphones is increasing in this area of research. The reason lies in the fact that smartphones equipped with sensors such as accelerometer, gyroscope, and GPS are increasing their processing capabilities for better performances. Some phones have processing power almost as classic computers. The paper [5] presented a system based on mobile phones to detect potholes on the roads. The phones were placed in taxi vehicles and recorded the locations of detected discomfort. For detection, only vertical (Z-axis) was used. In the paper [6] smartphones are used to monitor conditions during transport. Potholes, bumps, and siren sounds are detected.

Comfort calculations are usually based on the accelerometer signals processing. Accelerometer detects dynamic movements and is also affected by the static gravity influence. For appropriate dynamic calculations, it is necessary to eliminate the static gravity influence from accelerometer signal values. This is usually done by some signal filter implementation. The authors of [7-9] developed the automotive real-time observers and attitude estimation system, based on an extended Kalman filter (EKF). The authors of [10] used high-pass filter for the road potholes detection.

Vibration duration exposure and interaxial influence need to be addressed. In [11] authors didn't observe any statistically significant differences in discomfort between the 10, 15 or 20-second vibration exposure. In [12] authors showed that single axis vertical vibrations were typically associated with the less discomfort than multi-axis vibrations. Also, different sensitivity for different axes is detected, for similar ranges of vibration. According to these, the data from all axes need to be collected for appropriate comfort level classification. Although the vertical axis is the most influential, the others cannot be ignored.

Artificial intelligence usage is increasing in this field of research. In [13] neural network was used in order to analyze the quality of public transport. In [14] Bayesian network was used for recognizing the mode of transport. For artificial intelligence implementation, it is necessary to collect a lot of data for its training.

II. 9DOF SENSOR BOARD AND EULER ANGLES

The information about transport comfort can be obtained by using the 9DOF (Nine Degrees of Freedom) sensor board, which incorporates three 3-axial sensors: accelerometer, gyroscope, and magnetometer. These sensors output data that can be furthermore used as parameters for determination of comfort level.

In this paper, the SparkFun 9DOF RAZOR IMU SEN-10736 sensor board [15] is used. It consists of 3-axes ADXL345 accelerometer, 3-axes ITG-3200 gyroscope, and 3-axes HMC8553L magnetometer.

In order to represent the attitude of an object, data from these three sensors have to be combined into Euler angles. The most common way of interpreting Euler angles is using the terms of yaw, pitch, and roll. In general, those angles are retrieved by rotating the axes of one coordinate system around the other [16]. The one is fixed to the ground, and the other is moving relative to the ground (hereby attached to the sensor board). Those rotations are expressed as matrices of cosine angles between axes of interest, so that a vector described in one coordinate system can be described in another by multiplication with rotation matrix.

The algorithm used for data fusion and determination of Euler angles is DCM algorithm [17]. The firmware for here used device can be found at [18]. Magnetometer readings are used for yaw determination, while accelerometer and gyroscope are used for pitch and roll determination. Fig. 1 shows the yaw, pitch, and roll axes on the sensor, as well as the coordinates that 3-axes sensors are using.

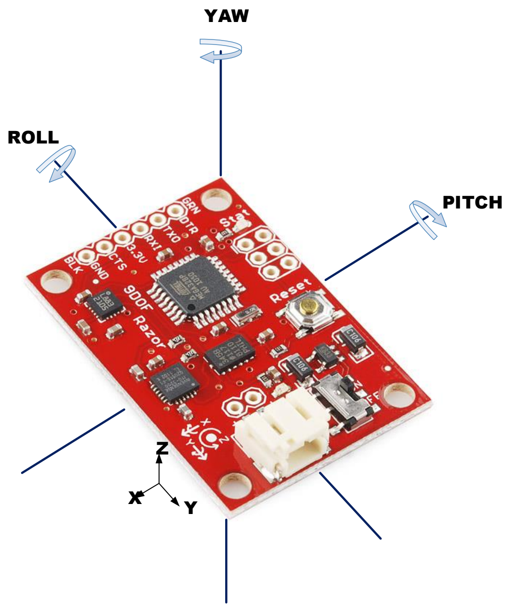

Fig. 1. SparkFun 9DOF RAZOR IMU SEN-10736 sensor board with the orientation of the yaw, pitch, and roll axes, together with x, y, and z axes.

The initial firmware was modified in order to adjust to the needs of the system. At first, information about the values of Euler angles and particularly sensor readings weren't able to be transported all at once. Thus, the firmware was slightly modified to ensure that both type of information are sent as binary values.

The sensors on the board have to be calibrated in order to achieve maximum possible accuracy. Calibration is done in situ, so the minimum and maximum values of all nine axes in three sensors are supplied into the firmware.

The Bluetooth module [19] is connected to the board in order to send data to the Android application. The whole system is battery powered via Li-Po charger [20].

III. ANDROID APPLICATION

The appearance of the Android application written is shown in Fig. 2.

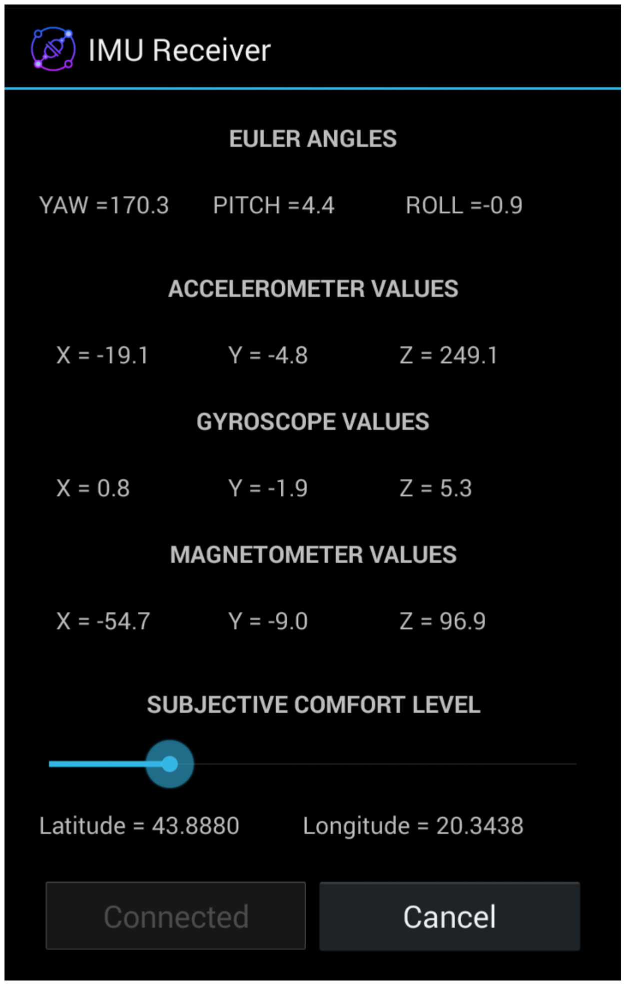

Fig. 2. The appearance of Android application for collecting the sensor data.

As can be seen from Fig. 2, the main parts of the application are text fields depicting actual readings from the sensor board. The readings are sent every 20ms, and application receives them and stores into a file on the local storage. Furthermore, the user has the possibility to personally assess the level of the transport comfort by changing the slider value, where left slider position describes maximum level of comfort, and the right position the minimum level (given numerical value of 100). This information can be very useful to the system in order to test the sensor readings for accuracy.

Also, the application receives GPS coordinates and stores them, as well, into the file.

IV. RESULTS AND DISCUSSION

The testing of the system was conducted by driving the car in the area shown in Fig. 3. The sensor system was placed on the flat surface inside the car, and the passenger was evaluating his own sense of comfort. The driving speed was held approximately at the constant rate.

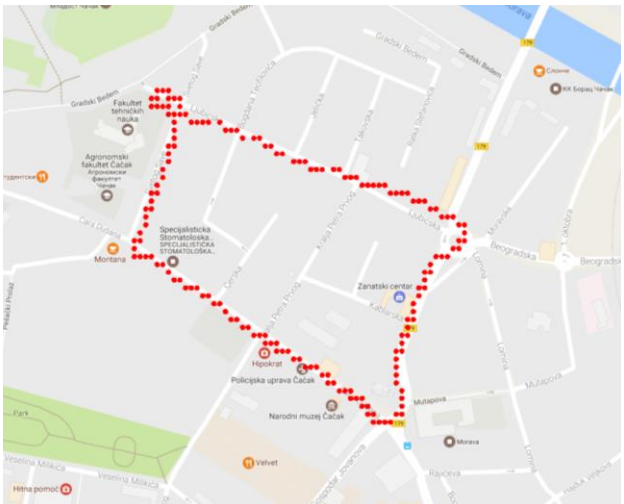

Fig. 3. The driving area for conducting the test

The values of Euler angles, accelerometer, gyroscope, and magnetometer data from all three axes, together with subjective comfort levels, are given in Fig. 4, Fig. 5, Fig. 6, and Fig. 7, respectively.

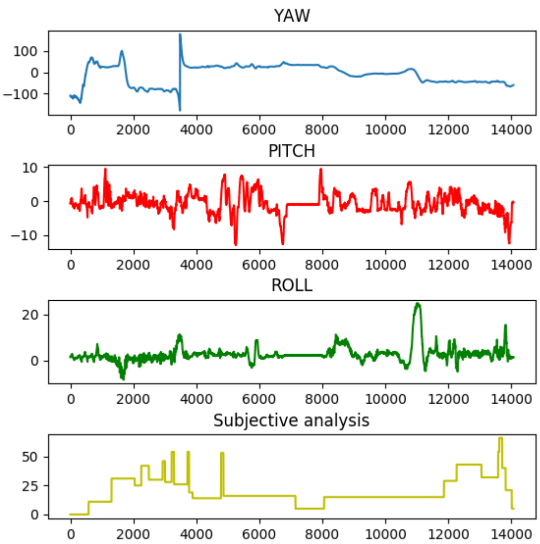

Fig. 4. The values of Euler angles with the subjective assessment of the comfort level.

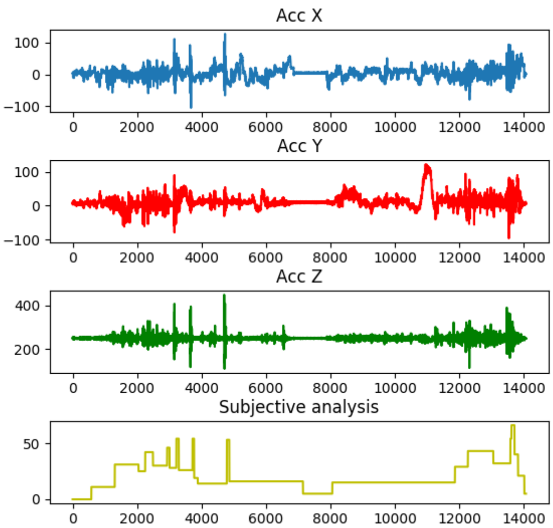

Fig. 5. The values of accelerometer data with the subjective assessment of the comfort level.

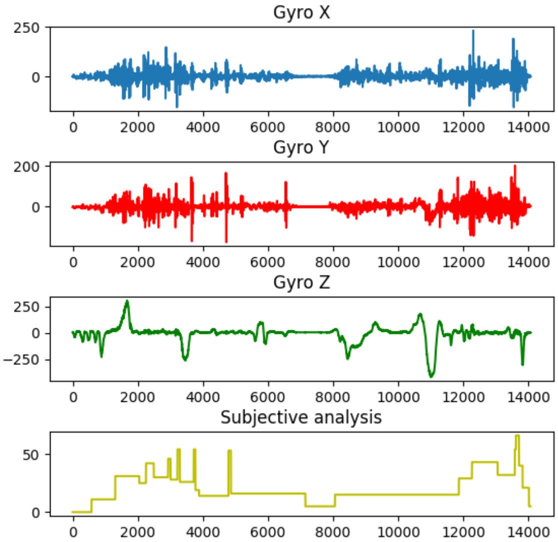

Fig. 6. The values of gyroscope data with the subjective assessment of the comfort level.

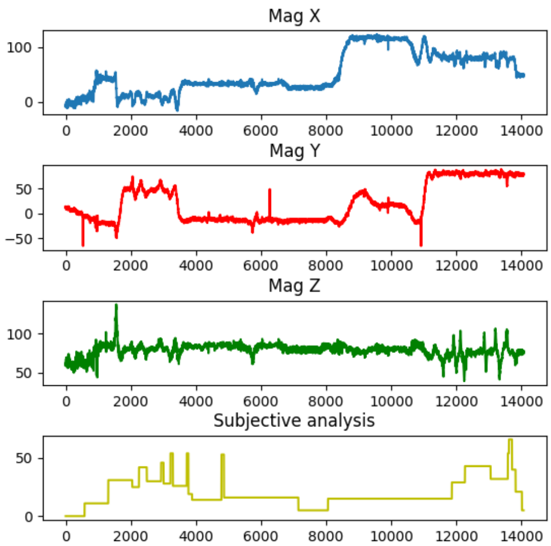

Fig. 7. The values of magnetometer with the subjective assessment of the comfort level.

Based on the subjective assessment of the driving comfort, the first and the last quarter of the path was discomfort, primarily because of the potholes and irregularities on the road surface.

Yaw determines the heading of an object. Steady values indicate driving on the straight road, while rising or falling values indicate steering. Pitch determines angular distance from the horizon plane. High positive values indicate driving uphill, while high negative values indicate driving downhill. Roll determines the angle between vehicle and horizon planes. From Fig. 4, it can be seen that pitch and roll values indicate driving on the primarily flat road, while yaw data are inconsistent with the depicted driving area, especially on the last quarter of the trip. The reason for this can be found in Fig. 7, where it can be seen that x- and y-axis values of magnetometer have high readings on the last quarter, meaning that there were some magnetic disturbances in the environment that were causing improper calculations of the yaw values.

It is interesting to see that spikes in the accelerometer and gyroscope data, especially on the accelerometer z-axis and gyroscope y-axis, determine the potholes on the road. These values are consistent with subjective assessment of the road conditions.

V. Conclusion

The driving comfort assessment using IMU (Inertial Measurement Unit) was conducted in this paper. The sensor board supplied the Euler angles and values of three-axial accelerometer, gyroscope, and magnetometer to the Android application. This application enables collecting the GPS coordinates, as well as subjective assessment of the driving conditions, and logging all these values in the file.

The presented test values showed that this system can be used in order to determine the transport comfort levels. However, we encountered the magnetic disturbances on the way, which corrupted the yaw values. The solution is to use better sensors or to develop anti-magnetic shield, that would also isolate the sensor plate from movements non-relative to the vehicle.

These data can be further supplied to an intelligent system based on certain machine learning algorithms or to the neural network, in order to analyze data and indicate irregularities on the road network.

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