Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 3 (2014) 185 – 194

Transportation Research Procedia

www.elsevier.com/locate/procedia

17th Meeting of the EURO Working Group on Transportation, EWGT2014, 2-4 July 2014, Sevilla, Spain

Smartphone application for assessing various aspects of urban public transport

E. Simonyi*, Z. Fazekas, P. Gáspár

Institute for Computer Science and Control, Kende u. 13-17, Budapest, H-1111, Hungary

Abstract

A smartphone application (i.e., an app) developed for facilitating the assessment of urban public transport services is presented and its applicability and versatility is demonstrated in the paper. The app was developed for the iOS platform and is being tested in conjunction with some concrete assessment tasks. The app takes spatiotemporal measurements of the motion of an individual vehicle with the help of the smartphone's built-in GPS and inertial sensors and logs the vehicle trajectory, velocity and acceleration data. The acquired vehicle data is then processed, visualized and analysed according to the concrete requirements. Apart from establishing features like average vehicle speed over a particular route, duration of the service and average waiting time at stops, many other features can be derived from the vehicular motion data gathered by the app. The longitudinal acceleration data, for instance, can be used to detect strong braking events. If braking data is collected over a longer period of time, frequent braking events that occur at particular road/track locations mark dangerous locations. Braking data can also be used to assess driver behaviour and passenger discomfort. The latter is particularly important for elderly people, people with certain health conditions, and for people with mental or physical disabilities. The collected vertical acceleration data can be used to identify road/track faults and can be used to assess the vibration load to passengers. The trajectory, speed and vibration data can be used to profile routes in geodesic sense, according to road quality and according to passenger/driver vibration load. Samples of the data collected and evaluated are presented in conjunction with public transport services in Budapest, Hungary.

Selection and peer-review under responsibility of the Scientific Committee of EWGT2014

Keywords: Smartphone; Evaluation of public transport services; Spatiotemporal measurements;

* Corresponding author. Tel.: +36 1 279 6000; fax: +36 1 466 7483.
E-mail address: erno.simonyi@sztaki.mta.hu

Selection and peer-review under responsibility of the Scientific Committee of EWGT2014
doi:10.1016/j.trpro.2014.10.104

1. Introduction

A smartphone application (i.e., an app) developed for facilitating the assessment of urban public transport services will be presented in the paper. With the help of the app and a smartphone's built-in GPS and inertial sensors, one can carry out spatiotemporal and kinetic measurements on-board a road vehicle, for instance on-board an urban public transport vehicle. Our aim was to develop a simple app for a widely used smartphone, namely an iPhone 4S, for ordinary passengers, i.e., ordinary clients of the public transport service, who can take measurements as they ride a bus or a tram.

Our measurement device (i.e., the smartphone running our app) is a far-cry from professional, high precision whole-body vibration dosimeters and analysers, such as the SV 100 developed and manufactured by Svantek (see their website technical details). SV 100 is integrated with a tri-axial whole-body accelerometer seat-pad. The analyser performs real-time simultaneous vibration analysis over a full octave, or one-third of an octave in frequency domain (as selected). Furthermore, it features all the various standard weighting filters for the whole-body vibration measurements. Their device is meant – and also priced for – professionals, not for the general public.

Before we dive into the technical details of our measurement device, we will motivate the need for such an app and the need for easy-to-carry-out, but not very precise trajectory, speed and acceleration/vibration measurements, particularly in conjunction with assessing various aspects – including passenger comfort – of urban public transport services.

We touch upon the socio-economic situation of our home city: Budapest (Hungary) and to the state of its public transport network to motivate the development and use of the app.

Clearly, the measurement device presented herein can be used and the measurement described can be carried out in either of the mentioned cities, or in fact in any other cities worldwide.

2. Characterization of the target urban environments

The city of Budapest has multi-scale geographical, architectural and transport characteristics, similar to the situations described in (Ariza-Villaverde *et al.*, 2013) and in (Tero *et al.*, 2010) in connection with other cities and towns.

The Hungarian capital has a multi-ethnic, multi-cultural and multi-economic-regime history. It can be characterized as a socially divided, economically multi-layered city. Some of these "multi-features" slowly evolved over the last millennium or so, some are fairly recent changes. The "multi-feature" approach – with reference to the multi-generation, heterogeneous vehicles and roads – can be also used to describe the road network in Budapest and the state of the road network, and can also be used to characterize the public transport of the city and the vehicle fleet used in the service.

According to a recent article on Index (one of Hungary's most popular news sites), a big chunk of the bus fleet of the Centre for Budapest Transport (CBT) is in critical technical condition, and is long overdue for withdrawal from the service. The average age of the buses in the CBT fleet is 19 years, so using those feels like a time-travel back to the 20th century. The average distance covered by a single bus is about 1.2 million km's. To be fair to CBT, there are some new posh buses in the service, as well. However, from time to time, one can read news reports about smoking trolley-buses and underground carriages from the last century, which when they are not in the daily service, patiently wait for their disposals. Again, there are some nice, fairly recent trolley-buses and underground carriages in service, newly which are very much liked by the CBT's clientele. A recent and positive development of the public transport system is a brand new line of underground railway service (CBT Metro 4) which was opened a few months ago.

Budapest's road network is in a similarly heterogeneous condition with roads ranging from the smooth, world-class roads to the ragged back-street roads.

Mohan and his co-authors (2008) – a more technical reference is made to their paper in Subsection 3.2 – characterize the urban traffic flows in cities of the poor/underdeveloped/developing regions of the world as rather complex. This is due to varied road conditions (e.g., potholed roads), chaotic traffic with lots of braking and honking, and a heterogeneous mix of vehicles (often with a large percentage of two-, and three-wheeled vehicles in the mix).

Though the mix of vehicles is not as heterogeneous in Budapest as in Bangalore, which is Mohan and his co-authors' home town and their place of measurement, e.g., there are practically no three-wheeled vehicles in Budapest; still the traffic is very hectic and the conditions are very similar to those in Bangalore.

Public transport service with the mentioned wide range of buses running over the world-class to third-world roads can be quite different experience. The general public in Budapest is mostly accustomed to this heterogeneity of the service, but some people (e.g., elderly people, pregnant women, passengers recently undergone some medical operations) are more vulnerable to the poor travel conditions and to the mechanical shocks and vibrations caused by these conditions.

3. Evaluation of human exposure to whole-body vibration on-board of various vehicles

Clearly, the clientele of the public transport services are far less exposed to whole-body vibrations caused by the vehicles than the drivers of these vehicles.

According to Bovenzi (2006) long-term occupational exposure to intense whole-body vibration is associated with an increased risk for disorders of the lumbar spine and the connected nervous system. To some extent, the neck-shoulder, the gastrointestinal system, the female reproductive organs, the peripheral veins, and the cochleo-vestibular system are also affected by long-term vibration.

Bovenzi & Zadini (1992) studied low back symptoms in urban bus drivers exposed to whole-body vibration. Low back symptoms occurred more frequently for those drivers who were exposed to more intense whole-body vibration in terms of the total (i.e., lifetime) vibration dose, the equivalent vibration magnitude and the duration of exposure (i.e., years of service). Funakoshi and his colleagues (2003) studied the prevalence of low-back pain and its within-two-year incidences amongst taxi drivers in Japan. They found that a significant statistical relationship exists between these and the total mileage covered by the drivers.

Nevertheless, there are papers – many from 1970's – dealing with passengers' exposure to whole-body vibration on-board of vehicles. More recent studies are reported in (Suzuki, 1998), (Chen *et al*., 2009) and in (Park *et al*., 2013).

There are now accepted international standards for evaluation of human exposure to whole-body vibrations. ISO 2631-1 (1997) standard defines measurement methods for measuring periodic, random and transient vibration affecting the human body as a whole. ISO 2631-5 (2004) standard defines measurement methods and provides health risk prediction in case of the multiple shocks. These standards summarize factors that determine separately or in combination the degree to which a vibration exposure will be acceptable for humans.

The ISO 2631-1 standard outlines current opinion and provides guidance on the possible effects of vibration on health, comfort and perception and motion sickness. The frequency range considered in the standard is 0.5 Hz to 80 Hz for health, comfort and perception, and 0.l Hz to 0.5 Hz for motion sickness.

In connection with perceived vibration exposure in public transportation, the standard defines six comfort levels. These are as follows: "not uncomfortable" (0 m/s^2 - 0.315 m/s^2 with the acceleration values measured as round mean square over 1s time-steps), "a little uncomfortable" (0.315 m/s^2 - 0.5 m/s^2), "fairly uncomfortable" (0.5 m/s^2 - 0.8 m/s^2), "uncomfortable" (0.8 m/s^2 - 1.25 m/s^2), "very uncomfortable" (1.25 m/s^2 - 2.0 m/s^2) and "extremely uncomfortable" (above 2 m/s^2).

A daily 8-hour exposure at "very uncomfortable" and "extremely uncomfortable" levels is not acceptable according to the standard. It should be underlined that vulnerable passengers, such as ambulance patients and the ones mentioned in Section 2, will reach these comfort perceptions at lower levels of exposure than those given in the standard.

3.1. Using smartphones for similar practical measurements

The "smartphone-world" is expanding with an incredibly rapid pace; in 2012 already about 80% of the world's population owned some kind of an intelligent device according to Go-Gulf web-application and development website (2012). Smartphone-world, therefore, is a huge market and facilitates practical measurements and data collection based on the built-in sensors on a range of scales. The built-in sensors, which nowadays can be found in most smartphones include among others GPS sensors and accelerometers. In respect of acceleration measurements, Fig. 1 shows the coordinate system used for a particular smartphone.

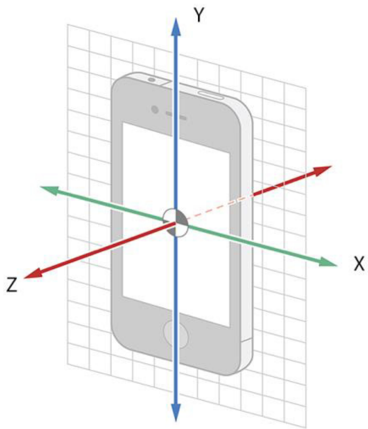


Fig. 1. The coordinate system used in acceleration and rotation measurements on a particular smartphone. (Source: Apple Inc.)

Nickel and her co-workers (2011) proposed a novel gait-based user authentication method for smartphones and tablets. The characteristics of the user's gait are captured using the built-in accelerometer of the mobile device, which is securely placed in a holder/pocket on the side of the user at the waist. Among other spectral features, the authors rely on the Mel- and Bark-frequency cepstral coefficients computed from the measured discrete acceleration values and utilize a support vector machine for classification (after a short calibration/ training session).

Khan *et al.* (2010) used smartphones equipped with built-in accelerometers for recognizing simple daily activities of subjects. As the authors of the paper wanted to avoid a single compulsory placement – such as used by Nickel *et al.* for their gait based system – of the mobile device with respect to the human body, they had to find a recognition method that tolerates the different positions thereof. They collected acceleration data with the smartphone placed at different body positions identified with various pockets of the subject's clothing. They computed motion features such as autoregressive coefficients and signal magnitude area and employed linear and kernel discriminant analyses to extract significant discriminating features which maximize the interclass and minimize the intra-class variance. The classification itself was performed by artificial neural nets.

3.2. Trajectory and whole body vibration measurement with mobile phone

Closer to our present topic, Mohan et al. (2008) report on their research and development efforts in respect of monitoring road and traffic conditions in cities, particularly in their home city Bangalore (India), using smartphones equipped with GPS and accelerometer sensors, as well as, microphones. They see the smartphone-based monitoring of vehicles and road traffic as a realistic alternative to the deployment of dedicated sensors on vehicles, see e.g., (Fazekas *et al*., 2011) and (Fazekas *et al*., 2012), and on the roadside (Qin *et al*., 2010), or the tracking of mobile phones by service providers (Rose, 2006).

Their system, called Nericell, deals with issues like virtual reorienting the accelerometer, performs honk detection (using the microphone of the smartphone) and vehicle localization in an energy efficient way.

4. Processing and visualization of the trajectory and vibration data

The aforementioned expansion of smartphone usage also applies to Hungary. On the other hand, the composition of the public transport vehicle fleet in Budapest is quite diverse often comprising of some "historic" buses, trolleys and other vehicles. Most of the elderly and/or physically vulnerable people often need to use old vehicles when travelling with public transport services. Considering these people's vulnerabilities and to support their tenders, the application described below was developed to provide them with easily accessible, free public data on whole-body vibrations aboard public transport vehicles.

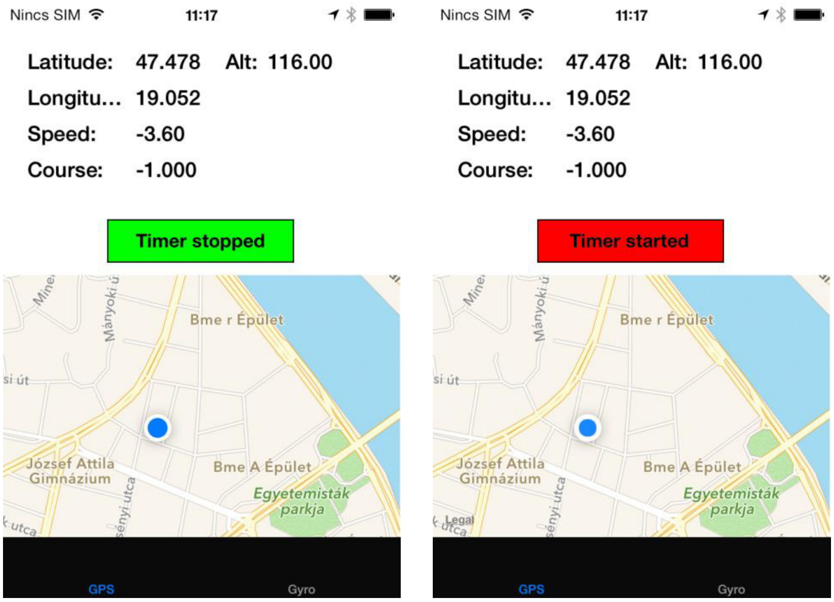


Fig. 2. Screenshots of the measurement app, with incorrect GPS sensor initialization represented by the -1.0 ° Course value.

With the iPhone's built in sensors augmented with 3G cell information we estimate the longitude, latitude, altitude and speed values of our current position and measure the corresponding 3-axis acceleration and rotation/orientation. A basic user interface displays the values of the current coordinates and our course/heading in degrees, and also the current estimated speed in m/s. The user interface is necessary in order to diagnose any kind of incorrect sensor initialization problems like the one that can be seen on Fig. 2.

For the accurate representation of our accelerometer's vibration data we first need to know its orientation. Although there are many known algorithms to virtually reorient a "disoriented", non-flatly placed device, in our measurements according to Fig 1, we assumed that the phone will always be lying on its back with the *z* axis facing upwards, and the *x* axis facing towards our movement direction. For the readings to be reasonably accurate in this constellation, we always firmly placed the smartphone on one of the seats found on the respective public transports.

For the accurate representation of our accelerometer's data we first need to know its orientation. Although there are many known algorithms to virtually reorient a "disoriented", non-flatly placed device, in our measurements according to Fig 1, we assumed that the phone will always be lying on its back with the *z* axis facing upwards, and the *x* axis facing towards our movement direction. For the readings to be reasonably accurate in this constellation, we always firmly placed the smartphone on one of the seats found on the respective public transports.

During our test we noticed a severe drain – an almost 30% with a 60Hz sample rate in 20 minutes – on the iPhone's 1432 mAh battery due to the energy consumption of the various sensors, most significantly the GPS sensor and also, although in a much less significant way to the logging frequency of our application.

After running several tests – ranging from the maximal 100Hz down to 10Hz sampling rate – to estimate the reasonable sampling frequency required, and taking the power consumption and the cluttering of data while using the higher sampling rates into account, we finally choose a rate of 10Hz.

In our measurements we mostly focused on instantaneous, big changes in the acceleration values. For this purpose we used an adaptive, first order IIR high pass filter to remove smaller, non-relevant readings and to neglect the constant effect of the gravity along the *z* axis.

5. Evaluation of some concrete public transport services in Budapest

In this section, we present and assess trajectory and kinetic data collected from three particular public transport services in Budapest:

- a bus ride in a hilly part of Budapest on a nice, comfortable new bus,
- a rack rail ride in the same district, and
- a bus ride on articulated bus in the center of the town.

Fig. 3. The trajectory of a short bus ride on a nice, comfortable new bus running on a good road in a well-off district of Budapest (displayed with Google Earth). The speed and longitudinal acceleration data are also shown for the ride.

In Fig. 3, we present the trajectory, speed and longitudinal acceleration data for the first ride from the above list. The trajectory of the ride is overlaid onto a satellite image from Google Earth. The locations and the properties of the markers were input to Google Earth as a KML structure.

The bus ride took place on a working day before the afternoon peak hours. The initial segment of the trajectory is shown enlarged in the left inlay, while the type of the bus is shown in the right inlay.

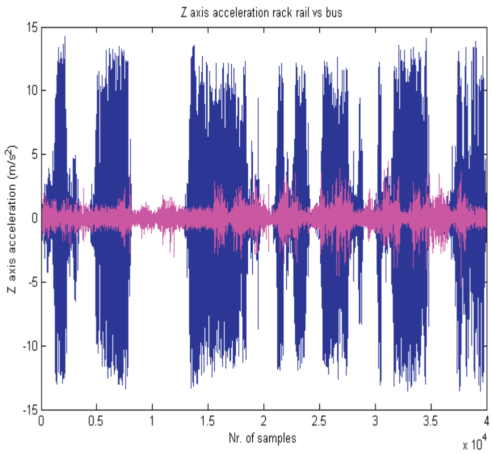
The speed of the bus is indicated with white (0 - 3 km/h), light purple (4 - 10 km/h), purple (11 - 20 km/h) and dark purple (21 - 50 km/h), while the acceleration is shown with green (0 - 4.9 m/s^2), yellow (5.0 - 9.9 m/s^2) and orange (> 10.0 m/s^2) markers. From the resulting data we can observe that besides the bit sudden and rough start, the ride was indeed “shock-free” and quite comfortable.

In Fig. 4, the trajectory of a ride on Budapest Rack Rail (BRR) train from the hilly part of Budapest down to the centre of the town. A BRR train is shown in the inlay (source: www.budapestinfo.eu). The speed of the BRR trains is low: usually under 25 km/h. The trip with BRR is very romantic, but the carriages are indeed very shaky as can be seen from this figure and Fig.5. In the left image, only the vertical acceleration data is shown for the recorded trajectory. As in Fig. 2, green is used for the 0 - 4.9 m/s^2 acceleration range, yellow for the 5.0 - 9.9 m/s^2 acceleration range, while orange is used for vertical accelerations bigger than 10.0 m/s^2.

In Fig. 5a, b the Z axis acceleration and speed data of the BRR is compared with the respective values of the urban bus. We can observe that besides the train stations – and an especially long stop due to another BRR – the shaky nature of the vehicle is quite big.

Fig. 4. The trajectory of a ride with Budapest Rack Rail (BRR) from the hilly part of the city down to the centre of the town (displayed with Google Earth). The trip with BRR is very romantic, but the carriages are very shaky. Photo from www.sikerado.hu.

In Fig. 6a, the trajectory of a bus ride is overlaid onto a satellite image. The image shows the central area of Budapest. It is displayed with Google Earth. The locations and the properties of the markers were input to Google Earth as a KML structure. The bus ride took place on a working day before the afternoon peak hours on a 10 - 15 years old articulated bus.



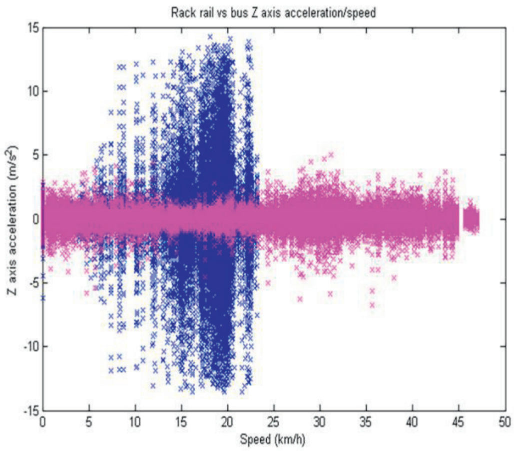


Fig. 5. Comparison of the vertical acceleration values for the bus ride (purple) shown in Fig. 6 and the rack rail ride (blue) shown in Fig. 3.

The speed – marked with white (0 - 3 km/h) through light purple (4 - 10 km/h) and purple (11 - 20 km/h) to dark purple (21 - 50 km/h) – and the acceleration – marked with green (0 - 4.9 m/s^2) through yellow (5.0 - 9.9 m/s^2) to orange (> 10.0 m/s^2) – of the bus are indicated in an aggregated way.

Two road locations where the bus stopped for some time are shown with Street View in Figs. 6b-c. The first such location is a bus stop, which is indicated by the white speed mark near the centre of the trajectory image. The second one is near a traffic light. It is located in a Y-junction of the major roads forming a λ; the green and purple lines of markers in Fig. 6a form the right line of the λ.)

The road locations where major vertical acceleration values had been detected were carefully inspected by the authors using Google Street View. The inspection was carried out in the same fashion as was reported in (Fazekas, *et al*., 2011), (Fazekas *et al*., 2012) and (Fazekas *et al*., 2013) in conjunction with the statistical analysis of trucks' braking locations and patterns. The purpose then was to find dangerous road locations, to locate certain driving manoeuvres and some road objects producing glare, respectively. In the present case, the purpose was slightly different.

Fig. 6. The trajectory of a bus ride (top image) in the center of Budapest displayed with Google Earth. The speed (white to dark purple) and acceleration (green to yellow) data are also shown for the ride. Two examples of the road locations from the above bus ride where the bus stopped for some time: a bus stop (corresponding to the white speed mark near the center of the trajectory image) and a traffic light (near the Y-junction of the major roads forming a λ in the trajectory image). The road locations of the likely causes of two major vertical acceleration values detected during the ride: a sewer lid which is passed by another bus in the photo (we were not that lucky) and a biggish pothole in the bus lane.

In Figs. 6d-e, the most likely causes of two major vertical acceleration values (shocks) detected during the ride are shown. The first is a sewer lid, which is passed by another bus in the photo; sadly we were not that lucky. The other is a biggish crack of the road surface in the bus lane.

6. Future work and conclusions

An iOS smartphone application was developed to assess several aspects of urban public transport services. We demonstrated its applicability and versatility in the paper with measurements made on different public transport vehicles in Budapest, Hungary. The app takes spatiotemporal measurements of the motion of an individual vehicle with the help of the smartphone's built-in GPS and inertial sensors and logs the vehicle trajectory, velocity and acceleration data. We present some examples of how such an application using its collected vertical and horizontal acceleration data can be used to identify events or routes which, based on their vibration load value can be unhealthy for its passengers, particularly for the elderly people or people with certain health conditions.

The "smartphone-world" is expanding with an incredibly rapid pace. Already, around 80% of the world's population owns some kind of an "intelligent device". Also, with the emergence of high speed wireless networks, such as 4G/LTE and 802.11ac gigabit Wi-Fi, and with the growing popularity of cloud-based services, it seems feasible to create cloud-based databases based on various measurement data coming from smartphones. As everyone is able to use – in some limited context – the sensors on their phone with some dedicated, sometimes freely available application, the number of participatory measurements/contributions databases could significantly increase in the near future.

With trajectory and vibration data, such as used herein, and with a properly set-up and well-advertised participatory, possibly cloud-based, database, one could efficiently analyze and to some extent predict passenger comfort perceptions and possible health risks associated with using certain public transport services/routes; using these at different times, on different types of vehicles. Of course, the precision and the relevance of the travel logs submitted for inclusion in the database would still have to be monitored as the quality of input data is crucial for the utility of such a database.

References

Ariza-Villaverde, A. B., Jiménez-Hornero, F. J., & De Ravé, E. G. (2013). Multifractal analysis of axial maps applied to the study of urban morphology. Computers, Environment and Urban Systems, 38, 1 - 10.

Bovenzi M. (2006). Health risks from occupational exposures to mechanical vibration. La Medicina del Lavoro, 97(3), 535-541.

Bovenzi M. & Zadini A. (1992). Self-reported low back symptoms in urban bus drivers exposed to whole-body vibration. Spine, 17(9), 1048-59.

Chen, H.-C., Chen, W.-C. Liu, Y.-P., Chen, C.-Y. & Pan, Y.T. (2009). Whole-body vibration exposure experienced by motorcycle riders – an evaluation according to ISO 2631-1 and ISO 2631-5 standards. International Journal of Industrial Ergonomics, 39, 708 - 718.

Fazekas, Z., Biró, Zs., & Gáspár, P. (2012). Statistical analysis of data describing the relationship between driver, truck and characteristics of the road. Transport Problems, 7, 77 - 85.

Fazekas, Z., Gáspár, P. & Kovács, R. (2011). Determining truck activity from recorded trajectory data. Procedia - Social and Behavioral Sciences, 20, 796 - 805.

Fazekas, Z., Simonyi, E. & Gáspár, P. (2013). Glare in Street View images may signify unsafe road locations. In Breda, R., Ceskovic, M., Draganova, K. & Kmec, F. (Eds.), Proceedings of the International Scientific Conference Modern Safety Technologies in Transportation (pp. 54 - 59), Zlata Idka, Slovakia.

Funakoshi, M., Tamura, A., Taoda K., Tsujimura, H., & Nishiyama, K. (2003). Risk factor for low back pain among taxi drivers in Japan. Journal of Occupational Health, 45(6), 235-247

Go-Gulf website (2012). Smartphone users around the world – Statistics and Facts, http://www.go-gulf.com/blog/smartphone/

ISO 2631-1 (1997) Mechanical vibration and shock – evaluation of human exposure to whole-body vibration – Part 1: General Requirements. International Organization for Standardization, Geneva, Switzerland.

ISO 2631-5 (2004) Mechanical vibration and shock -- evaluation of human exposure to whole-body vibration -- Part 5: Method for evaluation of vibration containing multiple shocks. International Organization for Standardization, Geneva, Switzerland.

Khan, A. M, Lee, Y.-K., Lee, S. Y., & Kim, T.-S. (2010). Human activity recognition via an accelerometer-enabled-smartphone using kernel discriminant analysis. In Proceedings of 5th International Conference on Future Information Technology (pp. 1 - 6), Busan, South Korea.

Mohan, P., Padmanabhan, V. N. & Ramjee, R. (2008). Nericell: rich monitoring of road and traffic conditions using mobile smartphones. In Proceedings of the 6th ACM Conference on Embedded Network Sensor Systems (pp. 323 - 336), New York, NY, USA

Nickel, C., Brandt, H. & Busch, C. (2011). Classification of acceleration data for biometric gait recognition on mobile devices. In. Brömme, A. & Busch, C. (Eds.), Proceedings of the Special Interest Group on Biometrics and Electronic Signatures (pp. 57 - 66), Darmstadt, Germany.

Park, M.-S., Fukuda, T., Kim, T. G, & Maeda, S.: (2013). Health risk evaluation of whole-body vibration by ISO 2631-5 and ISO 2631-1 for operators of agricultural tractors and recreational vehicles. Industrial Health, 51, 364 - 370.
Qin, H., Zi Li, Yanfei Wang, Xuejia Lu, Wensheng Zhang & Guiling Wang (2010). An integrated network of roadside sensors and vehicles for driving safety: concept, design and experiments. In Proceedings of the International Conference on Pervasive Computing and Communications (pp. 79 - 87), Mannheim, Germany.
Rose, G. (2006). Mobile phones as traffic probes: practices, prospects and issues. Transport Reviews, 26, 275-291.
Suzuki, H. (1998). Momentary discomfort caused by vibration of railway vehicle. Industrial Health. 36, 98-106.
Tero, A., Seiji Takagi, Tetsu Saigusa, Kentaro Ito, Bebber, D. P., Fricker, M. D., Kenji Yumiki, Ryo Kobayashi & Toshiyuki Nakagaki (2010). Rules for Biologically Inspired Adaptive Network Design, Science, 327, 439 - 442.