Development of a Smartphone Application for Longitudinal Irregularity Measurement in Flexible Pavements

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ABSTRACT

Several research groups, especially abroad, are developing many devices to measure longitudinal irregularity in flexible pavements. It is known that values above the limit set for this distress contribute negatively to the functional evaluation of pavements, as well as for riding comfort. Due to the importance of the study of this failure for flexible road pavements, this research paper proposes to describe the development of an application for the quantitative and qualitative determination of the International Roughness Index (IRI), measured in which the longitudinal irregularity is determined. The proposed tool, called SmartIRI, is based on the use of sensors installed on smartphones to obtain data by using accelerometers and GPS receptors embedded in a vehicle that travels at a constant speed on the analyzed section. This equipment operates differently from the perfilometer laser, a device often used for measuring the IRI, which despite high productivity, presents high costs and there are doubts concerning repeatability and reproductivity of the collected data. The data from the accelerometer and GPS receptor of the smartphone will be treated statistically and subsequently made available to the user or management organs so that they can use them as a decision-making aid.

Keywords: smartphone, longitudinal irregularity, pavements.

1. INTRODUCTION

The socioeconomic development of a country is strongly related to road conditions. Recent studies indicate that most Brazilian road sections are not yet available in adequate conditions for users, presenting problems in pavement, signaling and geometry. Added to this is the fact of long periods of maintenance neglect, making resources available only to recover the functional condition of the pavement.

Information on the structural and functional conditions of a pavement, as well as data on its longitudinal profile, are very useful and important for the analysis of surface irregularity, commonly measured by the International Roughness Index - IRI.

[1] It is known that longitudinal irregularity, besides affecting user safety and comfort, also compromises the useful life of the pavement, and to know more information about the pavement longitudinal profile, there is a high financial or time cost, being vital for the whole process that the measurement of this defect is done correctly. New methods to obtain the longitudinal irregularity are being studied, among them; there is the use of smartphones as a possibility to obtain data of the longitudinal profile, mainly for the developing countries that endure budgetary restrictions.

[2] The use of smartphones can be a viable alternative to estimate the surface condition in terms of irregularity and the riding comfort verified by the users, due to the action of vertical acceleration. Since in addition to being more accessible, these devices have many useful sensors, which several researchers and developers are exploring their use for various applications in different areas, which motivated the development of SmartIRI, the application presented in this paper.

Given this fact, this paper aims to propose a smartphone application to estimate the longitudinal irregularity (expressed as the IRI) present in road pavements and, with this, to evaluate vehicles rolling comfort quality.

2. LITERATURE REVIEW

According to [1], several of the irregularity measuring devices have been employed, depending on the type and principle used for surveying. Already [2] they address in a more specific way a classification of the measurement devives of irregularity. These measurement devives can be grouped into four classes. Table 1 presents advantages and disadvantages of each class.

TABLE 1 Characteristics of Classes

Class	Advantages	Disadvantages
I and II	Sophisticated devices; Manual profile generators are not so expensive; Fast, for automatic profile generators	Automatic profile generators are expensive to obtain, operate and maintain; They are not often employed due to their cost (automatic) and speed (manual); Obtaining data can be time consuming, when there is a high accuracy demand; Heavy components and need calibration before use.
III	Relatively low cost; Fast and moderate accuracy; High performance; High suitability among measuring instruments of irregularity.	Demand some development costs; For initial calibration and configurations, it demands exhaustive work.
IV	Low cost; Can be used regularly, when a study area is not large; You do not need expensive tools or equipment.	Results may be inaccurate; Intense work with a lot of consumed time, resulting in low performance and adequacy.

According to [3], some researchers have studied smartphones use for functional evaluation, mainly in determining longitudinal irregularity, mainly due to its low cost, easy operation and productivity.

For [3], the use of smartphones to evaluate the longitudinal unevenness of pavements can be seen as a response type measurement system, although it does not function as a conventional class meter, which accumulates displacements between a body and the rear axle of the vehicle. However, it measures the vertical accelerations by means of a smartphone fixed internally in the vehicle windshield.

For [3] and [4], there is a disbelief about the meter type response, as in the case of smartphones, especially when compared to profiles (class I or II). However, the same authors point out that smartphones can provide updates on the functional condition of the pavements, including a longitudinal irregularity in a short time, compared to other methods, which are costly, used with little or no frequency.

In this sense, the different types of equipment for evaluating longitudinal irregularity according to the type of information required should be considered, in addition to the time and means available. In fact, one device does not prevent the use of another. It is necessary to create solutions to allow a generation of significant information for an analysis of pavement performance [3].

According to [5], although these applications are innovative and promising, there are still some limitations to their use. The main limitations are:

a) Many applications are only looking to identify and locate holes, as well as classify them for gravity. However, few are being developed to evaluate the functional condition of pavements;

b) For most applications, the smartphone needs to be attached to a special holder on the vehicle windscreen;

c) Repetitive calibrations need to be performed prior to their use to provide consistent values with road functional condition.

2.1 Obtaining the Model

From data available in [3], it was possible to implement a model to calculate longitudinal irregularity according to the International Roughness Index (IRI) standards. This was possible due to high R^2 values reached in the relations between Speed and Square Root of the Quadratic Mean – RMS, and between IRI and RMS. It can be seen, therefore, that vertical displacement calculations were not performed using vertical acceleration data, but a correlation between RMS data and IRI values.

Minitab software was used to aid in obtaining the model. The parameters verified as premise were the adjusted R^2 (R-sq adj), the P-Value and the Variance Inflation Factor (VIF). For the adjusted R^2, a value of 91.13% was obtained, while for the P-Value, it was 0.0 and the VIF was 1.94.

After obtaining the model, an application for vertical acceleration data measurement was developed for data collection. The required settings to apply the model were gravity acceleration value removal on the Y-axis, since the smartphone is fixed in the vertical position, and data acquisition rate of 100 Hz.

The next step was to calculate IRI value based on the vertical accelerations values recorded on the smartphone. Given the values of these vertical accelerations, the RMS values were calculated every 100 m. Then, the obtained model was applied, in which, it calculates IRI value every 100 m, based in RMS values obtained previously. Results are available on the smartphone in .csv and .kml format

3. RESULTS

Based on the values of a benchmark application available on the market, it was found that the values calculated by SmartIRI were concordant. The IRI calculated on the

SmartIRI was compared to the IRI calculated by the reference application (ROADROID), both IRI values were calculated from the accelerations measured by the smartphones used in this research paper. Scatterplots and lines graphics were used to analyze the relationship between the values provided by the applications. Figure 1 presents the location of the smartphone in the vehicle and Figure 2 displays the correlation between the applications values.

FIGURE 1 Setting up the smartphone in the vehicle

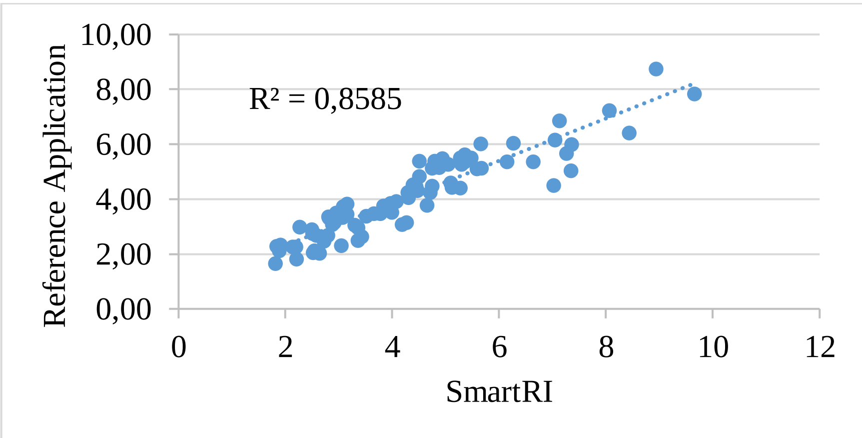

FIGURE 2 Correlation between applications

The SmartIRI was also compared to another method that serves as calibration for longitudinal irregularity measuring devices, the Level and Rod method. For this comparison, the maximum difference obtained for a segment of 320 m was 11%.

The SmartIRI application outputs a ".csv" spreadsheet with the measurement summary with IRI values every 100m and their respective quantitative and qualitative classification. A ".kml" file is also generated and can be observed in Figure 3. The dark green color indicates excellent (0 < IRI (m / km) < 2), the light green color indicates good condition (2 ≤ IRI (m / km) < 4), the orange color indicates a regular condition (4 ≤ IRI (m / km) < 6) and the red color indicates poor rolling condition (6 ≤ IRI (m / km)).

FIGURE 3 IRI measurement summary

4. ANALYSIS OF RESULTS

According to speed measurements (ranging from 20 to 120 km/h), it was found that lower speeds cause less excitation of the vehicle's suspension system, so the system has less ability to measure different wavelengths present in the pavement profile, which contributes to the values obtained for IRI [3].

[6] recommends that the minimum operating speed for response-type measurement devives, such as smartphones, is limited to approximately 25 km/h, since at low speeds there is the fact that tires involve high-frequency irregularities due to absorption of small protrusions in contact with the tires. The same authors also mention that at very low speeds, vertical acceleration is very small, which can interfere with IRI measurements.

Moreover, [2] states that the noise produced by smartphones has a greater effect at low speeds, since its amplitude approaches the measured signal and, therefore, decreases its relation with the real pavement irregularity. Due to these reasons, in the development of this research, it was observed that the best results were obtained with speeds between 60 and 80 km/h.

For high speeds, above 100 km/h, it was found that the vehicle suspension system begins to respond differently to the irregularities present in the pavement. The response system tends to mitigate IRI values, as it was observed that the tire envelope no longer existed, but the tires began to transpose the irregularity without impact, which interferes on the response type of measurement systems.

Regarding the possible analyzes of other results, one should: observe the influence of the macrotexture on response-type systems; identify the types of coatings of the sections analyzed and how the measurement response behave; verify velocity influence in irregularity measurement and, finally, compare sections with IRI values provided by the perfilometer laser with the SmartIRI and the Reference Application.

The IRI values obtained by means of smartphones do not correspond to those obtained with a profilometer, even if the order of magnitude of the results is similar [2]. This is due to the fact that vertical displacements were not calculated, but correlated with a comfort measure, in this case RMS. However, the proposed equipment and reference application were measured using a reference method (Level and Mira), which also serves as a calibration reference for laser profilers. Finally, an estimated IRI approximating the actual pavement IRI was obtained as a parameter, although the comparison was made with a reference application, and not with IRI direct measurement equipment.

5. CONCLUSION

Nowadays, with the advent of technology embedded in mobile devices, smartphones are increasingly being used for various types of data acquisition. Such condition can assist road agencies in decision-making.

Longitudinal irregularity measuring applications for field survey and data processing high performance are important to highlight, especially when associated with a Geographic Information System (GIS). When comparing applications with longitudinal irregularity measurement methods, such as the Level and Rod method, or determining the pavement functional condition, the SmartIRI performs better regarding time processing.

Data analysis and application use may indicate the presence of superficial imperfections on the road. Sections that provided high IRI values presented greater number of defects in the coating, confirmed by visual inspections made by the authors. The main distress that contributed to data dispersion were holes and patches, which generate greater riding discomfort.

Ultimately, another conclusion is that smartphones present themselves as a viable alternative in a preliminary analysis of pavements functional condition, because, through obtained information and correct data analysis, it can aid on management teams decision-making. These new technologies developed have low cost, easy operation and high productivity with potential for improvement and can be used on a large scale.

References

[1] Bernucci, L. B., Mota, L. M. G., Cerati, J. A. P. e Soares, J. B. Pavimentação Asfáltica. Formação Básica para Engenheiros. Abeda. Rio de Janeiro, RJ. 2007.

[2] Bisconsini, D. R. Avaliação da irregularidade longitudinal dos pavimentos com dados coletados por smartphones. Dissertação de Mestrado. Universidade de São Paulo. 2016.

[3] Douangphachanh, V. The Development of a Simple Method for Network-wide Road Surface Roughness Condition Estimation and Monitoring Using Smartphone Sensors. Tese de Doutorado, Tokyo Metropolitan University. Tokyo, Japão. 2014.

[4] Forslof, L. Roadroid: Continuous road condition monitoring with smart phones. In IRF 17th World Meeting and Exhibition, Riyadh, Saudi Arabia. 2013.

[5] Sayers, M. W., Gillespie, T. D., & Queiroz, A. V. The international road roughness experiment: Establishing correlation and a calibration standard for measurements. Washington, D.C. 1986.

[6] Karamihas, S.M., Sayers, M.W. The Little Book of Profiling. The Regent of the University of Michigan. 1998.