Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 51(6) (2020)363-366
DOI: 10.22060/ceej.2018.14136.5569

Evaluating Pavement Roughness Based on Vibration Analysis Due to Road Health Monitoring System

M. Arbabpour Bidgoli[1], A. Golroo[1*], A. Ghelmani Rashidabad[2], A. A. Suratgar[2], M. Azam Khosravi[2]

[1] Department of Civil and Environmental Engineering, Amirkabir University of Technology, Tehran, Iran

[2] Department of Electrical Engineering, Amirkabir University of Technology

ABSTRACT: The implementation of an efficient pavement management system is dependent on the acquiring desired information from the pavement condition. The automatic data collection is welcomed by mechanized systems due to adequate precision and speed. However, the various systems are developed that have high construction and operation costs. Therefore, the development of cost-effective devices that is independent from the vehicle vibrations and equipped with instrumentation is necessary. In this study, the health monitoring system is developed as a system of longitudinal profile measurement and road roughness evaluation based on response-type vehicle with applying the accelerometers, distance meter, geographical positioning system. Upon harvesting of the vibration response of the health monitoring system and the vehicle, data preparation and signal filtration are performed through the digital signal processing techniques. Therefore, the dynamic equations governing on the behavior of the health monitoring system are derived based on one degree of freedom. The dynamic parameters of system are extracted based on optimization approach using the genetic algorithm and the particle swarm optimization algorithm. Afterwards, the extracted longitudinal profile based on the vibration responses is became to the longitudinal profile with the specific speed by the developed algorithm which is set by the relationship between speed and frequency of harvested data. Then, the International Roughness Index is calculated from the longitudinal profile of the studied pathway by ProVal software. Accuracy of the health monitoring system results is validated by manual method with measuring of the error percentage average and the root mean square error normalized between the outputs of the system and the Road Surface Profiler with values of 19.72% and 9.68% respectively. Finally, evaluation of the repeatability and the obtained results from the validation output indicates accuracy and significant quality of the road health monitoring system.

Review History:

Received: 2/28/2018
Revised: 4/26/2018
Accepted: 4/26/2018
Available Online: 4/30/2018

Keywords:

Pavement Management System
Road Longitudinal Profile
International Roughness Index
Digital Signal Processing
Accelerometer

1. INTRODUCTION

The road pavement, as one of the country's most important national assets, accounts for a significant portion of its development budget annually. This budget is spent on the construction, repair, maintenance and improvement of road surfaces. Therefore, the need of pavement management system is inevitable with optimal allocation of credits and recognizing the current and future condition of roads. One of the most important parts of the PMS[1] implementation is the launching of data collection systems for the pavement condition evaluation in duration of pavement utilization. Among the necessary and effective information in evaluating of the pavement condition was considered acquiring and measuring of the pavement roughness in the road construction and utilization. The pavement roughness is one of the most important parameters of pavement condition, which directly affects occupant's comfort and driving safety in terms of the ride quality. Among several indicators for calculating and assessing of the pavement roughness, the international roughness index (IRI) had been proposed as the accepted standard for roads in Iran. In this regard, various systems were used to measure and evaluate the pavement roughness. In this research, it was decided to develop smart pavement health monitoring system based on the response-type of vehicle equipped with cost-effective instrumentation, so that it is possible to use the system in urban and suburban roads without causing traffic disruption.

2. LITERATURE REVIEW

S. Y. Chen et al. (2015), A. Maurya et al. (2016), and O. Rajmane et al. (2017) studied affordable systems based on Arduino and Smartphone for measuring roughness and detecting potholes. In these studies, the accelerometer sensor was used as the roughness measurement sensor. Data recorded by the Arduino board and pavement condition would be displayed by a smartphone application. The differences

1 Pavement Management System

*Corresponding author's email: agolroo@aut.ac.ir

between these authors are communication (cable, Wi-Fi, and Bluetooth) of sensors with the data recording board, smartphone as a display of the pavement position, GPS and Google Map software as the map of the paths [1] - [3]. In these studies, considering errors because of vehicle vibrations and sensor errors is very important.

The major disadvantage of these affordable systems such as smartphones and systems developed based on road/vehicle interaction was the dependency on the vehicle suspension system. In systems that were based on the response of the vehicle suspension system, there was a possibility of computational errors due to the use of approximate relationships and dynamic models to simulate and analyze the vehicle's vibration response and pavement roughness.

3. OBJECTIVE AND SCOPE

The aim of this research is to develop an automated health monitoring system for measuring pavement roughness based on the vibrational response of roads with cost-effective sensors including an accelerometer and geographical position system with a sufficient level of accuracy and precision.

The scope of this study is limited to calculation of the International Roughness Index (IRI) among the other pavement roughness indices. The data collection speed is restricted to 30 (km/h). And, the model is developed based upon urban roads. Further investigations are required to check whether or not this model can be applied to rural areas.

4. METHODOLOGY

In the first stage, design and development of the health monitoring system was carried out and data acquisition was conducted. In the second stage, after data collection, the pure data of acceleration due to the roughness of the pavement is obtained using digital signal processing methods and recorded vibration response and applied in measuring the longitudinal profile of the road. Meanwhile, the dynamic equations governing the health monitoring system and the dynamic parameters are extracted with the optimization problem-solving approach. Then, the longitudinal profiles of the studied paths are modified for a specific vehicle speed. After extraction of the results, the accuracy of the outputs of the health monitoring system and the validation of system performance are examined by calculating the IRI calculated by the longitudinal profile of the studied path using statistical analysis. Finally, the repeatability of the outputs of the system is evaluated after the validation process. The research method used in this study is shown in Figure 1.

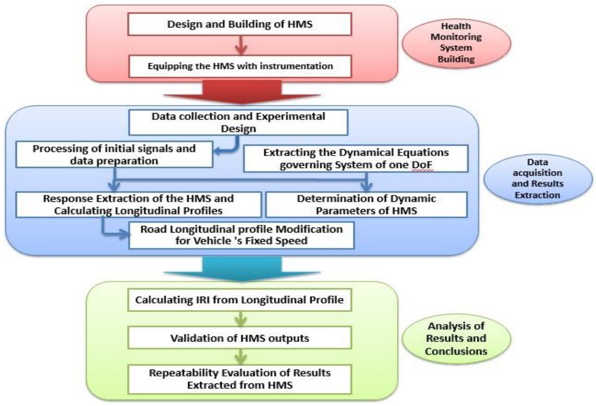

Fig. 1. Methodology

5. RESULTS AND DISCUSSION

The International Roughness Index (IRI) was calculated for each longitudinal profile acquired by the ProVal software. A segment of one kilometer located in the Shahid Hakim highway in Tehran was selected. The longitudinal profile of this segment was measured at a constant speed of 80 (km/h) with the health monitoring system and the RSP device. The values of IRI were calculated on the basis of the profiles acquired by the two devices used in this study and shown in Figure 2. In this figure, the horizontal axis is the value of IRI derived from the results of the health monitoring system (IRI_{HMS}) and the vertical axis represents the IRI resulting from the RSP device (IRI_{model}).

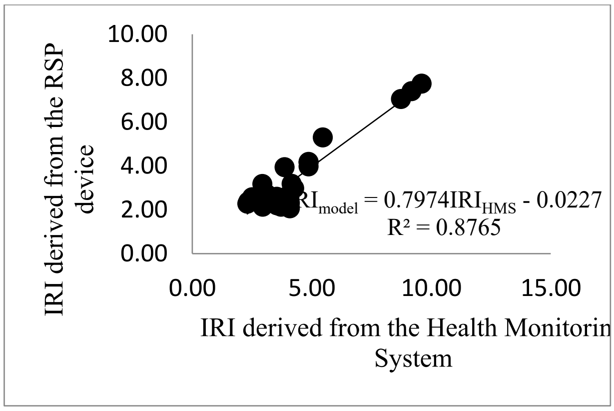

Fig. 2. International Roughness Index acquired by the health monitoring system and RSP device

The linear model IRI_{model} = 0.7974 IRI_{HMS} - 0.0227 with a high value of coefficient of determination of 0.8765 was derived from the regression analysis between the results of the health monitoring system and the RSP device as a precise appraisement system of pavement roughness. In order to analyze the error of the results of the health monitoring system, the root mean square error (RMSE) and the root mean square error normalized (RMSEn) were calculated which were equal to 59.28% and 9.68%, respectively.

As illustrated in Figure 2, it seems that the more that IRI the higher the correlation between the values of IRI measured by the health monitoring system and RSP. However, this claim needs more evidences concentrated on the higher values of IRI i.e., more rough pavement should have been surveyed to ensure the strength of correlation on higher values of IRI.

In order to validate the relationship between IRI derived from RSP and the health monitoring system, the same path on the opposite direction (divide into 7 segments each one is 100 meters) was surveyed. The IRI was computed based on the RSP, health monitoring system, and the model developed as represented in Table 1. In this table, the error percentage was calculated based on the difference between the IRI acquired through RSP and the model.

Table 1. Results of IRI of studied pathway segments

	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Seg. 6	Seg.7	Mean of Error Percent
IRI_{HMS}	5.6	4.2	2.5	2.3	3.3	2.3	2.5	
IRI_{model}	4.4	3.3	2.0	1.8	2.6	1.8	2.0	
IRI_{RSP}	5.3	3.9	2.5	2.3	3.2	2.4	2.6	
Error (%)	16.5	16.0	20.0	22.6	17.5	22.6	23.0	19.72

According to Table 1, the average of error percentage between the estimated roughness index (IRI_{model}) and the output of the international roughness index of the RSP device (IRI_{RSP}) is equal to 19.72%.

6. CONCLUSION

The achievements of this research are summarized as follows:

- The design and development of a new and cost effective system with the ability to measure the longitudinal profile of the road and calculate the International Roughness Index (IRI) with the speed of movement over the speed of walking.
- Determination of dynamic parameters of the health monitoring system without application of hardware testing and extracting the optimal responses of the system dynamic parameters by comparing two methods of Particle Swarm Optimization and Genetic Algorithm.
- The use of innovative methods in digital signal processing for filtration of acceleration signals acquired from the health monitoring system and vehicle led to the extraction of initial information for measuring the road longitudinal profile.

REFERENCES

[1] S. Y. Chen, A. Shih, and C. Y. Hsiao, 2015, "Road conditions detection using Arduino based sensing module and smartphone", IEEE Int. Conf. Consum. Electron. - Taiwan, ICCE-TW 2015, pp. 254–255.

[2] A. Maurya, A. Yadav, P. Arote, A. Baviskar, and J. Baviskar, 2016, "Real Time Arduino Based Depth Sensing for Road Condition Monitoring", Int. J. Recent Innov. Trends Comput. Commun. vol. 4, no. 4, pp. 947–952.

[3] O. Rajmane, V. Rane, and A. Bhosale, 2017, "Road Condition Detection Using Arduino Based Sensing Module And Android Smartphone", Int. J. Adv. Eng. Res. Dev. pp. 52–57.

HOW TO CITE THIS ARTICLE

M. Arbabpour Bidgoli, A. Golroo, A. Ghelmani Rashidabad, A.A. Suratgar, M. Azam Khosravi, Evaluating Pavement Roughness Based on Vibration Analysis Due to Road Health Monitoring System, Amirkabir J. Civil Eng., 51(6) (2020) 363-366.

DOI: 10.22060/ceej.2018.14136.5569