A survey on smart phone-based road condition detection systems

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Abstract

With the advancement in technology, Intelligent Transportation Systems (ITS) aims to maximize the safety and convenience of the transportation system. It focuses on the integration of technology into the traditional transportation structure for future smart cities. With the proliferation of the road network in all nations across the world, road surface condition data has become a critical component in reducing road accidents. Road condition monitoring is an important part of transportation management and affects the safety of the commute. Different methods based on manual, automatic, and semi-automatic monitoring of road conditions have been proposed in the literature. In this paper, we present a survey of smartphone-based road condition monitoring techniques. The data is acquired using smartphones and the algorithms discussed detect the road anomalies like manholes, speed bumps, potholes, and cracks, etc. A comparative analysis has been carried out based on the benefits, drawbacks, and methods used by various techniques. Furthermore, new research directions for smartphone-based detection of road surface anomalies have been presented.

Keywords

ITS, pothole, road condition, smartphone, speed bump

1. Introduction

The monitoring of road surface conditions has grown increasingly crucial in recent years. Road surfaces that are well-maintained improve road user safety and comfort. As a result, it is critical to regularly monitor road conditions in order to improve the transportation system's driving safety.The density of road surface anomalies is one of the key indicators used to identify road surface conditions [1]. Statistical data obtained from collected road surface information, visual field inspections, or vehicles equipped with special devices that measure and monitor road surface conditions are commonly used by municipalities. However, these technologies are time-consuming, expensive, and frequently lack the data coverage needed to provide a comprehensive picture of road conditions in large cities. Therefore, there is a needfor a low-cost, and efficient automatic or semi-automatic road surface detection technology.With the support of the Internet of Things (IoT), Intelligent Transportation Systems (ITS) employs different communication technologies to the traditional transportation system and improves the safety of road users [2], [3]. All decisions are made based on the raw data acquired by sensors or special equipment, so the data collecting step is critical.Different technologies employing laserscanners, video cameras, vibration-based approaches, and smartphone-based approaches are being used for data collection pertaining to road surface conditions. Smartphone-based detection has emerged as a significant supplemental technology for identifying road surface abnormalities [4].

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Figure 1shows the statistics of the five countries with the world's largest road networks in terms of road network, population, and smartphone users [5]–[7]. It is evident that a good percentage of the population owns a smartphone. Therefore, smartphone-based road condition detection techniques could benefit the majority of road users without any additional investment.

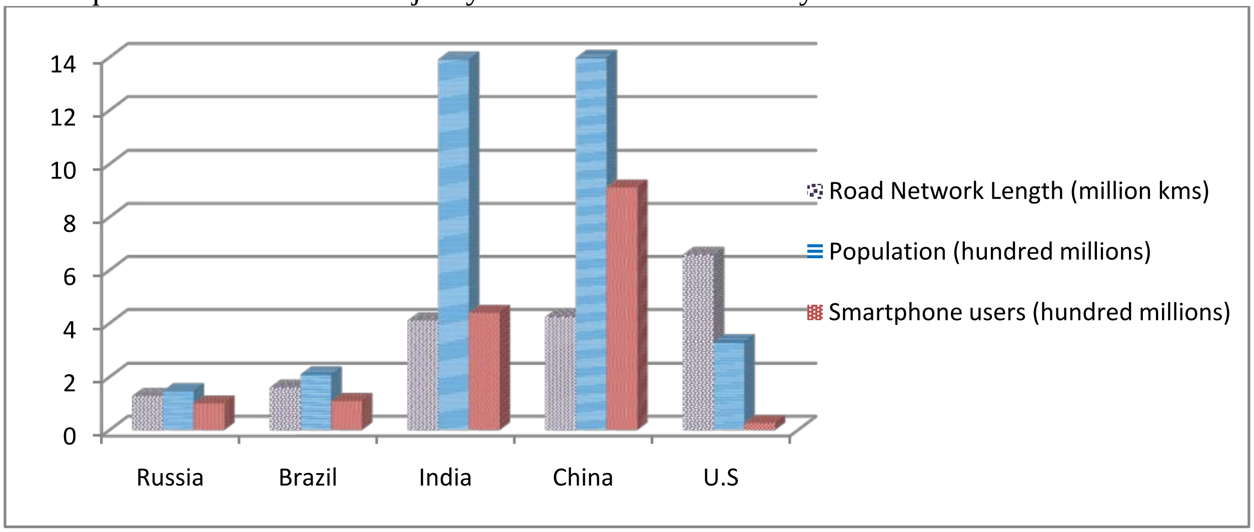

Figure 1: Road network and smartphone user's analysis

Figure2 shows the process of smartphone-based road condition detection process. Data collected by smartphone inbuilt sensors is filtered and processed for anomaly detection and then an alert is generated on the smartphone. In this paper, we focus on smartphone-based road condition detection techniques that detect several road anomalies like speed breakers, potholes, manholes, and road cracks etc. based on the data acquired using a mobile smartphone. Section 2 discusses the various state-of-the-art smartphone-based road condition detection techniques followed by a comparative analysis. Section-3 concludes the work with future research directions.

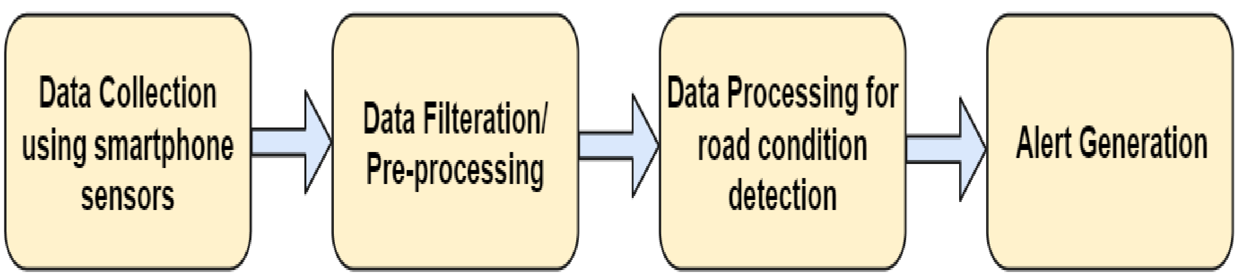

Figure 2: Smartphone-based road condition detection process

2. Smartphone-based Road condition detection techniques

Based on the technique used for data processing for road anomaly detection, the smartphone-based road condition detection techniques presented in this paper have been classified into twocategories: threshold based and machine learning based techniques.

2.1 Threshold based techniques

The sensor data acquired using a smartphone is analyzed to identify the patterns or values that represent the unfavorable road conditions. Different approaches have been proposed in the literature that apply thresholds to the accelerometer Z-axis data that represents vertical acceleration. Thresholding on the value of the absolute difference of accelerometer Z-axis data to detect road anomalies has been proposed in [8]–[10].The technique presented in [11] employed thresholding along with signal and image processing techniques and yields an accuracy of 93% for road anomaly detection. To overcome the limitations of static thresholding, adaptive thresholding has been employed in [12]to detect potholeswith an accuracy measurebetween 94-99%.Another technique to apply threshold on roughness index to identify road ruts has been proposed in [13]. The accuracy of the proposed method is 94%.

2.2 Machine learning based techniques

The researchers have employed various supervised and unsupervised machine learning techniques to process the data acquired using smartphones and identify the unfavorable road conditions. The supervised learning technique to detect road anomalies has been employed in[14]–[16]. To improve the accuracy measure, the techniques proposed by the authors have been enhanced by neural networks or signal processing techniques. The signal processing approach of Dynamic Time Warping (DTW) has been used in [17]and the system detects road bumps and potholes with 88% accuracy. In [18], authors employed deep learning techniques for object detection using the images captured by a smartphone. The proposed technique detects potholes approximately 100m ahead enhancing the safety of road users to great extent. A pothole detection technique based onConvolutional Neural Network (CNN) has been proposed in [19]. The proposed system yields 97% accuracy and uses Google API to map the detected pothole on Google Maps.
Table-1 provides the comparative analysis of the different smartphone-based state-of-the-art road condition detection techniques based on their advantages and disadvantages.

Table 1:
Comparison of smartphone-based road condition detection techniques

Ref & Year	Technique employed	Road Condition detected	Advantages	Disadvantages
[20] (2011)	Comparison of STDEV(Z), ZThresh, Z-DIFF, and G-ZERO	Pothole	Advanced real-time pothole detection with limited hardware and software resources	No auto-calibration of the accelerometer
[21] (2012)	Analysis of amplitude of accelerometer readings	Road bump/ Speed-breaker	Simple implementation and optimum battery usage	The performance is dependent on type of the vehicle
[22] (2012)	Thresholding on accelerometer Z-axis data	Road bump and pothole	Road condition classification into large range of categories	The smartphonemust be fixed at a particular position on floorboard for accurate results.
[11] (2013)	Z-DIFF and Multi-modal sensor analysis	Speed bump and potholes	Flexible and fast implementation with visual output	The algorithm is sensitive to the shape of the road anomaly
[9] (2014)	Temporal derivative of Z-DIFF	Road bump and potholes	Auto-calibration/orientation of the accelerometer data	The smartphone must be fixed to the dashboard
[12]	Adaptive thresholding	Potholes	Reduced pothole	Algorithm requires more

(2015)			location determination errors using GPS data	computational power
[10] (2015)	Threshold-based approach on data from accelerometer	Speed bump and road pits	Early warning is generated with an accuracy measure of 80%	No auto-calibration of the accelerometer and reduced performance in case of highly rough road segment
[14] (2011)	Support Vector Machine (SVM)	Speed bump and potholes	The technique is independent of the speed of the vehicle	The results have been formulated using limited data from few drivers
[23] (2012)	K-means clustering algorithm	Classify road as smooth or bumpy	The study generates good training data	The machine learning model needs to be improved for reducing the false positives
[24] (2013)	Machine learning technique: Multi-Layer Perceptron (MLP).	Road surface conditions: manholes and cracks	High accuracy for two classes of road anomalies/events	Not efficient when the system encounters a greater number of road anomalies in a small area
[15] (2014)	SVM for classification	Classify road anomalies	Identify the road anomalies for wider road segments as well with 90% accuracy	The system did not efficiently for inclined road segments
[25] (2015)	SVM	Speed bump	Reduced false positives as accelerometer results have been validatedusing gyroscope readings	Less detection accuracy
[26] (2015)	Image processing algorithm	Pothole detection and classification of road anomalies	Highly accurate in ideal environmental conditions	The system is dependent on the surrounding environmental conditions at the time of image capture
[17] (2017)	Dynamic Time Warping (DTW)	Road bump and pothole	Less complex, fast and detection accuracy is not affected by varying vehicle speed	The performance is reduced on roads with more road anomalies in a small area
[27] (2017)	Gaussian Model	Speed bump and potholes	The algorithm is computationally efficient	The system identifies the severity of the road anomaly when vehicle speed is 15-20 kmph
[28] (2017)	Decision tree classification algorithm	Pothole and smooth road detection	Mapping of road anomalies to the map. More accurate road anomaly detection using data from accelerometer and gyroscope.	The classifier can be improved for other road anomalies and road type
[29] (2017)	Supervised machine learning technique	Speed bump, potholes, and manholes	The inclusion of data mining algorithms alleviates problems related to vehicle speed	The accelerometer data is the input to the feature extraction algorithm. It should be combined with gyroscope data for validation
[30]	Mahalanobis- Taguchi	Manhole	The system considers	Overlap between the

(2018)	System (MTS)	cover, pothole, and speed bump	different characteristics of road conditions and predicts road quality accurately	characteristics of pothole and covered manhole leads to increase in pothole detection error rate
[16] (2019)	SVM, Neural Networks: Supervised machine learning techniques	Cracks and potholes	Multi-class classification technique that considers relationship between the acquired data from different dimensions	Real-time detection by placing smartphone at different locations was not done.
[31] (2020)	Deep learning technique	Road ravels, cracks, potholes, and manholes	Road anomaly severity is also calculated	More computational power is required at the time of model creation
[32] (2020)	KNN and Improved Gaussian Model	Speed bumps and potholes	The algorithm adapts according to the vehicle speed thus improving the accuracy of the system	The algorithm can be improved for other road anomalies and severity of the detected anomaly
[33] (2020)	Decision Tree: machine learning technique	Speed breakers and potholes	Improved performance as data considered from auto-oriented accelerometer is combined with gyroscopedata. Different types of vehicles were considered for performance evaluation.	The system accuracy reduces for rough road surface conditions
[18] (2021)	Deep learning object detection technique: YOLOv4	Potholes	The range of detection is 100 m and alert generated ahead of time.	Constrained by illumination conditions

3. Conclusions and future research directions

The smartphone-based road condition detection techniques provide a cost-effective solution using a pervasive device i.e., a smartphone. However, there are certain challenges associated with the implementation of smartphone-based systems like the placement of smartphone in the vehicle and differentiation between different types of road conditions. Different threshold based and machine learning based techniques have been proposed in the literature for road condition detection. However, to take the advantage of computationally efficient threshold-based technique and highly accurate machine-learning based approach; a hybrid technique needs to be developed to identify road conditions keeping in view the implementation cost. The communication between vehicles to transmit road condition information before hand for safety and convenience could be another area of interest. The generation of dynamic maps with updated road-condition information can be also used by authorities to streamline maintenance works.

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