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Road Condition Detection Using Smartphone Sensors: A Survey

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Abstract

Monitoring the road condition has gain significant importance in last few years. There are various reasons for extending research in this field: first, it will ensure safety and comfort to various road users; second, smooth roads will lead to less vehicle damage and government investment; third, the availability of low cost sensors in Smartphones; fourth, the rapid increase in the rate of Smartphone users. Thus, it is necessary to develop systems which are able to detect road conditions using sensors present in Smartphone. Several methods have been proposed towards addressing this problem. This paper reviews the various road conditions detection systems appeared in the literature. This paper also provides the areas which can be further modified to develop a more robust system.

Keywords: accelerometer, bumps, GPS, machine learning, potholes.

1. Introduction

Road is a vital part of people's day-to-day lives. When road is put into use after construction, it will lead to develop various anomalies due to continuous rolling under the wheels, and snow, rain and other natural factors. This will affect the quality of driving. With the availability of information regarding the road conditions, road users can be cautious about or avoid the bad roads. It is desirable to have a mechanism for detecting the condition of roads and get them repaired as soon as possible. As a result, working on monitoring road conditions has gained significant attention in recent time. The traffic conditions in developing countries, like India, are more complex owing to varied road conditions, heterogeneous mix of vehicles and chaotic traffic. Since India is a developing country there is a constant requirement for good quality transportation, infrastructure and services. This problem has not been totally addressed in India as it is a huge nation with pretty a sizable population. Potholes, speed breakers, mud pits, grains, cow dung, garbage and shards of glass are just a number of the things that may be found on the road while driving in India. The marriage, funeral procession or birthday may cause a never-ending traffic jam with lots of honking horns. Bad riding quality, insufficient pavement thickness and poor geometrics are other problems faced by Indian roads. India is also a home of rural population which has to face tough time during monsoon season. Consequently, it is of great significance to continuously observe the traffic and road conditions in real time to make transportation system more comfortable and efficient.

Many of the proposed techniques require dedicated hardware deployed in vehicle [1-3] or at various road junctions. These methods have mostly focused on developed world, with its comparatively simple road and traffic flow pattern. These methods are expensive. Furthermore, installing sensors in large number of vehicles and at various junctions is impractical due to large monetary cost and human effort required. Several methods are proposed to detect road conditions using mobile phone sensors [4-7]. The Smartphone based method eliminates the need to deploying special sensors in vehicle. This method also has the advantage of high scalability as the number of mobile users is increasing rapidly.

2. Methods for Detecting Road Conditions

The most common approach for detecting road condition is using sensors to recognize the vibration patterns of the vehicle caused due to any deformity or obstacle on the road. A major part of work is done using the sensors deployed in the mobile vehicles for collecting road roughness data to detect road anomalies. As the number of Smartphone users is increasing, methods using Smartphone sensors are also developing. Most of the methods use tri-axial accelerometer and GPS to collect the data for analysis. This section provides the methods/systems/algorithms for detecting road anomalies like potholes. Part A describes the methods that require dedicated sensors to be deployed on the vehicles. The methods that use Smartphone present in vehicles as the source of collecting sensor data are discussed in Part B.

Methods using dedicated sensors. Hull et al., proposed a distributed mobile sensor computing system, CarTel [1]. This system includes a set of sensors installed in vehicles to collect and process data and send it to portal based upon the continuous queries which are processed by continuous query processor on remote nodes. It uses sensors like GPS for monitoring the movements of vehicles. CarTel includes, CafNet, a networking stack that uses opportunistic connection (e.g. Wi-Fi, Bluetooth) to transfer information between portal and remote nodes. These information can be used for various applications such as time of travel, route planning. CarTel currently does not offer a way to aggregate information gathered across different users and it does not include machine learning; it just replies to the queries based upon the data stored in relational database.

Pothole Patrol system [2] uses 3-axis accelerometer and GPS mounted on the dashboard to monitor road surface. It not only identifies potholes but also differentiate potholes from other road anomalies. It collects the signals using accelerometer. It uses machine learning algorithm to identify potholes. These signals are then passed through a series of signal processing filters, where each filter is designed in such a way that it will reject one or more non-pothole events (manholes, expansion joints, railroad crossing). For training the machine, it uses a threshold value to classify potholes based upon search over values of each parameter and also computes a detector score which is to be maximized. It also classifies the data by location to filter out misclassified events. It also uses an external GPS to detect the location of potholes. This system gives a false positive rate of less than 0.2% in controlled experiments.

RCM-TAGPS [3] system collects the sensor data using three-axis accelerometer and GPS. The sensor data has 4-tuples: current time, location, velocity and three direction accelerations. This system also does the data cleaning before processing or analyzing it to deal with technical challenges like GPS error, transmission error. This system analyses the Power Spectral Density (PSD) to detect pavement roughness using Fourier transform. The International Roughness Index (IRI) is calculated based upon PSD. The pavement roughness is then classified in four levels (excellent, good, qualified and unqualified) according to, the Technical Code of Maintenance for Urban Road CJJ36-2006 [8], one of the industry standards in the People's Republic of China. This standard evaluates the pavement roughness by Riding Quality Index (RQI). Based upon the value of RQI, the pavement roughness is classified. This system provides the evaluation of a section of road based upon its roughness. This system does not provide the proper location of pothole, bump or manhole.

Methods using Smartphone sensors. Nericell [4] uses mobile Smartphone to monitor road and traffic conditions. It detects potholes, braking, bumps and honks using accelerometer, microphone, GSM radio and GPS sensors present in smart phones. It uses triggered sensing where the operation a high energy consuming sensor (GPS, microphone) is activated by a low energy consuming sensor (accelerometer, cellular radio) making the system energy-efficient. It uses strongest signal (SS)-based localization algorithm, so that the relevant location can be tagged with sensed information such as honking or bump. It uses GSM radios for energy-efficient localization. This system uses Smartphone and its embedded accelerometer to detect the various events. The phone can lie at any arbitrary orientation and, hence, it's embedded accelerometer. Therefore, it must be oriented along the vehicle's axis before analyzing the signals. This system uses an algorithm based upon Euler angles for reorientation. The sensor is virtually rotated along the vehicle's axis using pre-rotation, tilt and post-rotation angles (Euler angles). The post-rotation angle is calculated using GPS, so to avoid extra energy consumption the pre-rotation and tilt angles are monitored continuously and whenever there is any significant change in these angles, GPS is turned on and reorientation process is done again. It detects the braking event by analyzing the y-value of accelerometer. If the value is above a certain threshold value then it will shown as a braking event. It gives a false negative rate of 4-11% for braking event. This system can also differentiate between stop-and-go traffic and pedestrians based upon the magnitude and frequency of the values of accelerometer. It detects bump based upon the z-value of accelerometer. It provides two heuristics based upon the speed of the vehicle. If speed is greater than 25kmph, it uses z-peak heuristic where a spike along z-value above a specific threshold is classified as a bump. At low speed, z-sus heuristic is used which detects a sustained dip in z-value for at least 20ms. It gives a false positive rate of less than 10% and false negative rate between 20-30%.

It also detects the honks using the microphone present in Smartphone. The number of honks detected is send to the server. The honk detector performs a discrete Fourier transform and detects the frequency domain spikes. It detects a honk if the spike is in 2.5 kHz to 4 kHz region.

Mednis et al., [5] proposed a system which uses Android OS based Smart-phones having accelerometer sensor for detection of potholes in real time. This system detects events in real time and also collects the data for off-line post-processing. The data is collected using 3-axis accelerometer sensor present in Smart-phones. They have proposed four algorithms for detection of potholes. The first two algorithms (Z-THRESH and Z-DIFF) are for real time detection and the other two (STDEV(Z) and G-ZERO) are used for off-line post-processing of data. Z-THRESH algorithm classifies the measurements based upon the values above specific threshold level for identifying the type of pothole (small pothole, cluster of potholes, large potholes). Z-DIFF algorithm calculates the difference between two consecutive values and searches for the difference exceeding specific threshold. This algorithm detects fast changes in acceleration data in vertical direction. STDEV(Z) algorithm calculates standard deviation of accelerometer data in vertical direction over a specified window size. This algorithm classifies the events based upon the standard deviation value exceeding a specific threshold level. G-ZERO algorithm uses specific measurement tuple to detect the event. This algorithm searches for the tuple where all the three-axis data values are near to 0g. This data tuple indicates vehicle is either entering or exiting a pothole i.e. it is in a temporary free fall. Z-THRESH, Z-DIFF and STDEV(Z) algorithms assumes that the position of accelerometer's Z-axis is known. G-ZERO algorithm can analyze the tuple without information about z-axis position. This system gives a true positive result of 90% (approx.).

Wolverine [6] method uses Smartphone sensors for traffic state monitoring and detection of bumps. It uses accelerometer sensor to collect the data. The device (phone) is to be reoriented as it can have any arbitrary orientation when kept inside the vehicle. This system reorients the phone in two steps using accelerometer and magnetometer. In first step, phone's axes are aligned with geometric axes. A rotation matrix is formed using Gravity Vector given by accelerometer and Magnetic Vector given by magnetometer. This rotation matrix represents the angles of rotation of device's axes to align with geometric axes. In second step, the new device's axes are aligned with vehicle's axes. The direction of motion of vehicle is located using GPS to find the angle of motion of vehicle with magnetic north to transform the device's axes towards vehicle's axes. This system detects two events i.e. braking and bump. The bump event is detected by the standard deviation on window of one second duration with sampling rate of 50 readings per second over the z-axis value. The braking event is detected by using the difference between the maximum and minimum value within a window for y-axis value. The sensor data is classified using k-means clustering algorithm into two classes which is labeled manually as either smooth or bumpy (for bump detection) and brake or not (for braking detection). This labeled data is used to train Support Vector Machine (SVM) for classification of data points during test phase for vehicle state prediction. This system gives 10% false negative rate for bump detection and 21.6% false negative rate and 2.7% false positive rate for braking detection.

Singh et al., [7] proposed a mobile phone application that uses GPS, accelerometer and microphone to collect the data. This application detects road and traffic conditions along with driving behavior. This application is used to detect various events based upon the patterns observed. This application does not use machine learning. It is completely based upon the patterns obtained from the sensor data.

Most of the above described methods have used accelerometer and GPS for collecting the data. Some of these methods have also used machine learning algorithms to include self-calibration functionality in the system. Table 1 summarizes the above methods based upon these parameters.

Table 1: Summarization of some of the previous methods.

Method	Sensors	Smart phone Used	Machine Learning Implementation	Accuracy
CarTel [1]	Camera, OBD device, WiFi	No	No	----
Pothole Patrol [2]	Accelerometer, GPS	No	Yes	<0.2% false positive
RCM-TAGPS [3]	Accelerometer, GPS	No	No	-----
Nericell [4]	Accelerometer, Microphone, GPS, GSM Antenna	Yes	No	11.1% false positives and 22% false negatives
Real time photole detection using android smartphone with accelerometers [5]	Accelerometer	Yes	No	90% true positive
Wolverine [6]	Accelerometer, Magnetometer, GPS	Yes	Yes	10% false negative (for bump detection) and 21.6% false negative rate and 2.7% false positive rate (for braking detection)

3. Challneges Ahead

Although a lot of effort has been done to detect road conditions, a lot of methods/systems have been developed using Smartphone sensors, a highly reliable method is yet to be built. Real time road anomalies detection is so challenging that none of the methods using Smartphone sensors can address it alone completely.

Although some of the methods using dedicated sensors are able to detect potholes with higher accuracy. Several research areas are discussed in this section.

Vibration patterns of sensor data. A given pothole or any other road anomaly may not necessarily give the same pattern during each drive over it. The sensors readings depend upon the speed of the vehicle, how it approached the road anomaly and the position of the sensor i.e. its orientation. It also depends upon the suspension system of the vehicle, if the suspension system is not in normal condition, sensors will show more deviation based on the large vibration experienced by the vehicle. A system is needed that considers all situations.

Benign events. There are many events that are not considered as road anomalies such as expansion joints, railroad crossings, door slams etc. These events are to be differentiated from the potholes. An efficient system is to be developed that is able to classify different events effectively.

GPS error. GPS provides the longitude and longitude values of a location. It is used to detect the location of potholes to users. It has an error of 3.3 meters [2]. This error must be minimized to get the exact location where events to be detected have occurred. It may also be possible to miss some GPS data in urban areas among tunnels and tall buildings [8]. A method to minimize the localization error is still an open problem.

Network overload and delay. The sensor data is to be uploaded on the server at back-end. If a large amount of data is needed to be send over the network it may lead to network congestion leading to delay or loss of data. Therefore, the application is needed that must keep the network usage to minimal. It will also save the communication cost.

Privacy. The application requires the location of the device to detect the location of road anomaly and can be retrieved by user; hence it may lead to privacy breach. There is a need of an application that is able to hide user identification to maintain the privacy of user.

Machine learning technique. Machine learning techniques can be implemented instead of threshold based classification as different vehicles may yield different sensor data for same pothole. It will make the system more efficient and introduce self-calibration functionality.

4. Conclusion

Roads are needed to be monitored continuously for roughness and other anomalies to avoid inconvenience to the road users. Road monitoring can also help to predict the estimated arrival time from one place to another. This paper presents a detailed survey of methods for detecting road conditions. Form the survey, it is noted that the most commonly used sensors accelerometer and GPS. Smartphone sensors are gaining importance in this field as they are cost effective and also increase scalability. Analyzing form the research activities, it is certain that this area will gain more importance in recent future. There are several research issues, listed in section IV, that can be explored for improvement in existing methods and develop a highly reliable method.

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