POTHOLE DETECTION SYSTEM: 'MONITORING ROAD SURFACE ABERRATIONS USING A WIRELESS SENSOR NETWORK'

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Abstract: Potholes are a major obstacle for road transport which greatly affect the commute time and comfort. Detecting and locating the potholes ensures a better commute and helps in preventing any possible fatalities. The system would be installed on a vehicle and would perform the function of road surface monitoring, using the inherent mobility of the vehicle. The system would consist of a sensing unit, micro-controller unit and a GPS subsystem. The sensing unit consists of accelerometers, deployed at specific positions which would help them make use of the accelerations generated during the motion of the vehicle. The data generated from the accelerometers would indicate the presence of potholes or severe road surface anomalies. The micro-controller unit then collects the data, which is then processed utilizing the Machine Learning algorithms. This onerous task of data processing, leads to the distinguished possibilities of pothole detection or vibrations generated due to a severe lateral unevenness on the surface of the road. At the time of the detection, the GPS unit logs the co-ordinates of that location, which then can be represented on a map and shared through a mobile application, enabling the users to choose alternative ways depending on the conditions of the road in their respective routes of travel.

Index Terms- Wireless Sensor Networks, GPS, Cloud Computing, Pothole Patrol.

I. INTRODUCTION

Municipalities around the world spend millions of dollars to maintain and repair their roadways. Keeping our roadways in good condition is a challenging problem, due to the harsh weather conditions and normal wear and tear. Because municipal budgets are constrained, determining which roads need to be fixed becomes important. Alarming the drivers regarding the road surface conditions at night or when the lighting is poor is extremely needful as well. In recent years, fast economic growth and rapid technology advance have led to significant impact on the quality of traditional transport system.Road surface monitoring is a problem which fundamentally requires mobility to solve; it cannot be solved by using static sensors on the road surfaces. The data is to be dynamically sensed through sensors installed on the vehicle. The use of sensors in the smart phones as in [1], [2] can lead to the dampening of vibrations, and also disorientation of the sensors, as the position of the phone is not fixed. This can lead to false detection, and it has been seen that the potholes cannot be detected when the vehicle is moving at slower speeds. The method in [1] will not always work because magnetometer is not present in all phones and is also susceptible to magnetic interference and increases battery consumption. In addition, the performance of this algorithm was not evaluated for various different types of speed-breakers, vehicles and drivers. The pothole patrol [3] required manual intervention for most of the process, which is not desired. The accelerometer approaches however have a universal disadvantage, as typical drivers strive to avoid potholes, so the probability of hitting a road anomaly is considerably lower than what would be expected.

II. PROPOSED PROTOTYPE

The sensing unit would consist of tri-axial accelerometers, which would record the vibrations/accelerations produced in the three different directions x, y and z. The data obtained from the accelerometers can be visually represented as g-force vs. time. The vibrations along z and x axis would indicate the vibrations due to the depth of the anomalies and lateral unevenness respectively. The vibrations along the z axis would represent the rapid accelerations and the braking of the vehicle. It is to be noted that the directions along y direction can also be obtained without any interaction with a pothole, but rather due to intense braking. The data obtained from the accelerometers can be visually represented as g-force vs. time. The accelerometers would have to be placed at a specific position on the vehicle, where the vibrations produced would not get dampened by the suspensions. As the processing of the data highly depends on the sensitivity of the vibrations obtained, this is a predominant aspect of the system. The capacitance based accelerometers are preferred for this application due to its lower impedance, which is useful for the A-D conversion to be efficient. Accelerometer breakout boards with a desired sensitivity of $\pm 8g$ are interfaced with the Micro-controller unit using either of the SPI or I2C protocols.

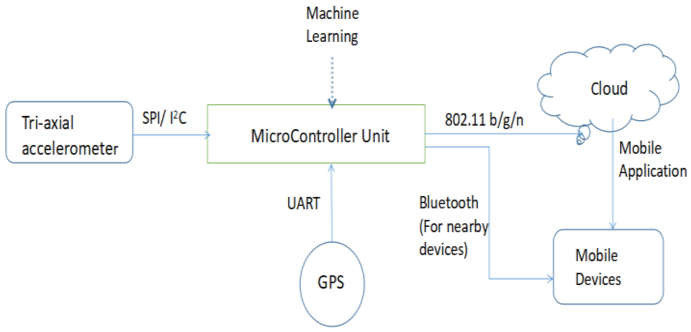

Fig.1 Block Diagram

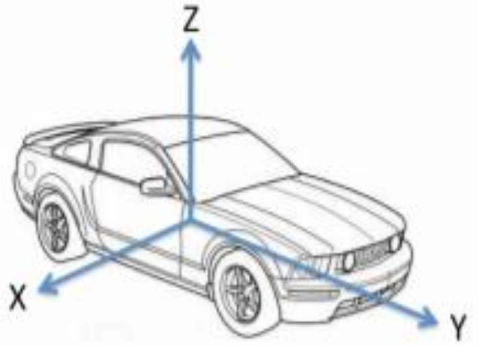

Fig2 . Axes with respect to the vehicle

The GPS subsystem logs the co-ordinates of the location, as soon as anomaly detection is triggered. A GPS unit with a hot start is desired, as the time to be taken for recording the co-ordinates, is very minimal (0.5-2 sec). This unit would also provide information about the velocity of the vehicle, through the nmea sentences, which are recorded as the output. The form factor of the GPS unit is also important as the size of the system is to be maintained as small as possible, in order to be feasible for the installation on the vehicle. The GPS unit would be interfaced with the MCU using the UART protocol.

The micro-controller unit acts as the central node for collecting the data from the subsystems, and then processing the data. This unit would also be responsible for storing the data onto the cloud, and also transmit the data to the nearby devices. The MCU is chosen according to the memory requirements of the algorithm, integrated modules for wireless connectivity (802.11 b/g/n), and the desired software compatibility for running the algorithms as well as for using the technologies like Android nearby, Bluetooth Low Energy to transmit the data to the mobile devices in proximity.

These three units together form the integral hardware unit of the pothole detection system, and are predominantly responsible for collecting and storing the raw data.

III. MACHINE LEARNING

Machine learning is used to process the data, into the possible set of outputs i.e. speed bumps, potholes etc., and is chosen as the system has to adapt itself over time, based on the speed of the vehicle and the conditions of the road surfaces. Machine learning makes this possible as it acts as a self-adapting medium, based on the written algorithm.

3.1 Algorithm Approach

The algorithm has to differentiate the data from the accelerometers, and classify them into the possible outputs. The output variables would be assigned a predefined threshold values. The initial approach to the algorithm is done using the classification algorithm based on supervised learning. Supervised learning is a branch of machine learning, which requires a training set of data to be provided in order to determine the relation between the input data and the output variables. In order to eliminate the possibilities of inaccuracies of human observations, the training set would be defined with the help of a semi/unsupervised anomaly detection algorithm. Amidst the continuous data being obtained, this algorithm would differentiate the abnormal recordings, and these observations can be used to define the thresholds.

The above algorithm is the main approach for the classification purpose. However, the system may come across some unspecified conditions, where the traditional algorithm finds it difficult to produce the correct output. Two other approaches for their own specific purposes are:

1) Instance based learning: This can be used when a certain recorded data, cannot be classified into the defined set of outputs. This uses a nearest neighbour approach, estimated using a similarity parameter. Thus, the data under dilemma is considered into the category of the estimated nearest neighbouring data.
2) Ensemble Learning (Boosting): This is used when the errors are observed in the processed data. The data which are wrongly classified, are given more weight sequentially, and thus more significance. This helps in decreasing the possibilities of a false detection or assigning data to the wrong set of output.

3.2 SVM Learner / Classifier

A kernel is a similarity function. It is a function that is provided to a machine learning algorithm. It takes two inputs and spits out how similar they are. Support Vector Machines are based on the concept of decision planes that define decision boundaries. In the case of binary classification, it builds two dimensional boundaries, to classify the data. Support Vector Machine (SVM) is primarily a method that performs classification tasks by constructing hyper planes in a multidimensional space that separates cases of different class labels. A decision plane is one that separates between a set of objects having different class memberships. In this case, the different class memberships would be the different possible outputs like potholes speed bumps, minor bumps etc.. Classification tasks based on drawing separating lines to distinguish between objects of different class memberships are known as hyper plane classifiers. This is done by mapping (transformation) and rearranging the objects using a set of mathematical functions known as kernels. Support Vector Machines are particularly suited to handle such tasks.SVM by definition is well suited for binary classification. In order to perform multi-class classification, the problem needs to be transformed into a set of binary classification problems. There are two such approaches:

One vs. Rest Approach (OvR): This strategy involves training a single classifier per class, with the samples of that class as positive samples and all other samples as negatives. This strategy requires the base classifiers to produce a real-valued confidence score for its decision, rather than just a class label; discrete class labels alone can lead to ambiguities, where multiple classes are predicted for a single sample.

One vs. One Approach (OvO): In the one-vs.-one (OvO) strategy, one trains K (K − 1)/2 binary classifiers for a K-way multi-class problem; each receives the samples of a pair of classes from the original training set, and must learn to distinguish these two classes. At prediction time, a voting scheme is applied: all K (K − 1)/2 classifiers are applied to an unseen sample and the class that got the highest number of "+1" predictions get predicted by the combined classifier. Like OvR, OvO suffers from ambiguities in that some regions of its input space may receive the same number of votes.

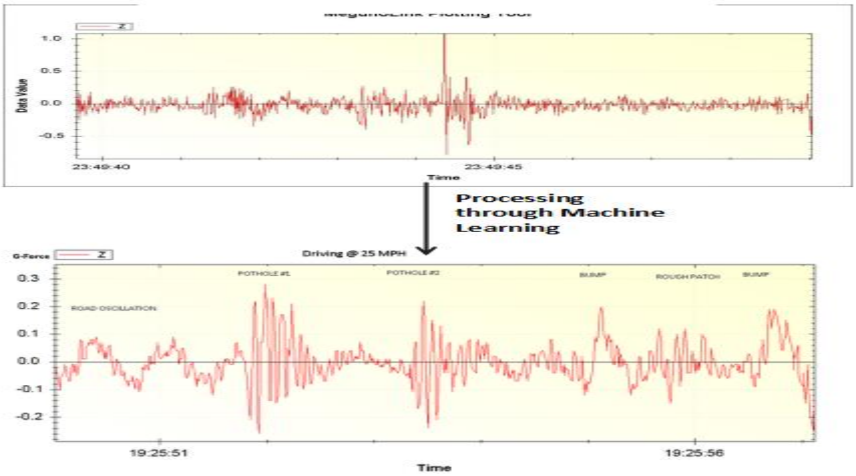

Fig3. Classified accelerometer data

IV. CLOUD COMPUTING

Cloud computing is the delivery of on-demand computing services from applications to storage and processing power typically over the internet. Cloud computing services cover a vast range of options, from the basics of storage, networking, and processing power through to natural language processing and artificial intelligence and standard office applications. Pretty much any service that doesn't require you to be physically close to the computer hardware that you are using can now be delivered via the cloud. This application would use either of the PaaS or SaaS aspects of the cloud computing, which would help in effectively storing the data and managing it through the back end. As mentioned, the cloud would further be related to two other aspects if the system, which are data representation and management. These are done through a mobile application and a crowd-sourcing platform respectively.

4.1 Crowd-sourcing/Continuous data duration

The concept of crowd-sourcing comes into picture when the system is installed on a multitude of vehicles. The data is continuously obtained from all these sources/nodes, and the data in the mobile application is to be updated accordingly, by curating this data recorded in the database. The veracity of the data is to be verified for maintaining the efficacy of the system. Data Tamer, ZenCrowd, CrowdDB, Qurk are some examples of the data curation platforms. The assumptions made by a general RDBMS are restrictive; and some queries cannot be completely answered by machines only. Processing such queries requires human input for providing information that is missing from the database, performing computationally difficult functions, and for matching, ranking, or aggregating results based on fuzzy criteria. CrowdDB is one such platform which uses human input via crowd-sourcing. These methods of continuous data curation would be responsible for monitoring the data from the multitude of systems, and establish the veracity of the visualized data.

4.2 Mobile Application

The mobile/web application would represent the obtained location data on a digital map. The application can be built by using the PaaS aspect of cloud computing. Besides the crowd-sourcing applications mentioned above, open source applications like OpenStreetMap can be used for representing the locations, and further monitor them as well.

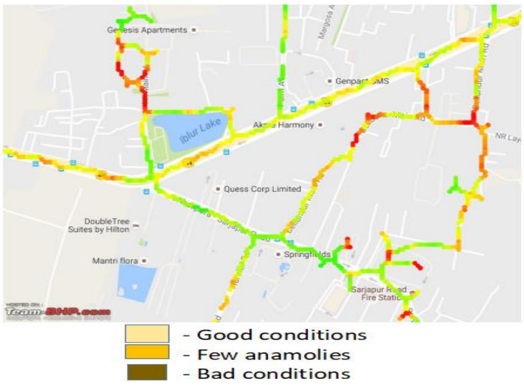

Fig4. Visual representation of the data in the mobile application.

The locations in the map are updated in the mobile application in analogous to the data obtained after the back end management. This is significant as a number of vehicles may travel through the same routes, and it has to be updated with respect to the continuously obtained data from the vehicles.

If multiple options for data transfer are desired, it can be transferred to the devices in the required proximity via Bluetooth Low Energy etc. Technologies like Android Nearby as well can be treated as alternatives for data transfer, for compatible devices. It is to be noted that all of these additional options may lead to the increase in power consumption.

V.CONCLUSION

The severe disorientations in the road surfaces have lead to a multitude of accidents, some of them even being fatal. The proposed Pothole Detection System is an efficient system for monitoring the road surface anomalies, using an array of sensors and effective communication media. Since satellite navigation has almost become prevalent, integrating this application with it would be beneficial in alerting the driver about the conditions of road surfaces in their respective routes of travel. This system is superficial in terms of portability as the accelerometers don't have to be re-oriented, once installed. The algorithm being implemented has no compromises whatsoever for every aspect of detection of aberrations. The future work would include installing the system on different types of vehicles, and determine the best position on the vehicle for the sensors, and envisage even simpler media of communication.

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