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Pothole Detection and Analysis System (PoDAS) for Real Time Data Using Sensor Networks

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Abstract: Potholes are a major nuisance on city roads leads to several problems and losses in productivity. Local authorities have cited a lack of geographic localization of these potholes as one of the rate limiting factors for repairs. This study proposes a novel low cost wireless sensors based end-to-end system called PoDAS (Pothole Detection and Analysis System) which can be deployed across major cities. We discuss multiple implementation models that can be varied based on the needs of individual cities. Our system uses cross validation through multiple sensors to achieve a higher efficiency than some of the previous models that have been proposed. We also present the results from extensive testing carried out in different environments to ascertain both the efficacy and the efficiency of the proposed system.

Key words: Wireless sensors, accelerometer, ultrasonic sensor, data processing, real time pothole detection, transportation

INTRODUCTION

Technology is best used when it supplements humanity's pursuit for excellence. Across the world and especially in developing countries potholes on city roads are a common sight. These potholes not only cost time to the commuters but the loss in productivity translates to a loss of millions of dollars to the global economy. Across cities, local municipalities and governing authorities have reported lack of information regarding the location and size of these potholes as the single biggest hindrance in their efforts to repair the roads. These problems are augmented during the rainy season when potholes tend to surface sooner. The researchers aim to solve this problem of localization of potholes using a unique combination of wireless sensors, a continuous online data collection technique and real time processing of the data rendering an easy to use interface for the local authorities.

We propose a unique solution called Pothole Detection and Analysis System (PoDAS) which can be deployed in large cities in multiple fashions. We discuss two possible application methods in this study. The first application method is to enlist the assistance of radio cabs and mobile application based taxi aggregators (like Meru and Uber, respectively). The sensor module which is discussed in greater detail in the successive sections of the study is attached to the lower end of these taxis which practically traverse the length and breadth of the city, multiple times in a day. The sensor module takes advantage of the Global Positioning System (GPS) (Deepika and Usha, 2016) available in the taxi driver's mobile phone. One major hurdle observed in practical implementations is the lack of a GPS coordinates to label the captured data. Since, these taxi drivers are required to have their GPS (Deepika and Usha, 2016) modules switched on if they ply on the roads, the sensor system can latch on to that for data labelling.

Another application model can be used where the local authorities also control the public transportation of a city. In such cases these modules can be attached to the lower surface of city buses. As the buses ply in the city the sensor system can gather data and push it to the cloud as soon as it enters an internet zone which can be the Wireless Fidelity (Wi-Fi) (Lindqvist and Neumann, 2017; Su *et al*., 2012) at traffic lights in certain cities and the bus depots in others. This caching approach to uploading data on the cloud is explained in detail in the methodology study.

PoDAS does not use any excessive cost sensors like the Microsoft Kinect sensor (Nguyen *et al*., 2016) which significantly reduces the cost of the sensor modules when compared to other solutions. Our experimentation shows that as we use multiple sensors to collaborate during the data gathering phase and use them to validate the data gathered by individual components, our method achieves significantly better accuracy results. We also provide a very easy interface to the government authorities to understand and locate multiple potholes which does not

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require any technical knowledge to operate. This makes the proposed system particularly attractive for deployment in developing countries where the government has not necessarily caught up with technological advancements.

Some of the related work done with respect to pothole detection and road surface monitoring with the help of sensor networks are now discussed. Existing methods for pothole detection are very diverse. Following are the different approaches attempted to solve this problem.

A system called Pothole Patrol (P2) (Eriksson *et al.*, 2008) was introduced by Jakob Eriksson *et al.* which captures the data from mobility, vibration and GPS sensor of the participating vehicles and processes that data to access the road conditions. Potholes and other severe road surface anomalies are identified by applying a simple machine learning approach using X and Z axis acceleration along with vehicle's velocity data as input on accelerometer data. The proposed model (Mednis *et al.*, 2011) provides a mobile sensing system which helps in detecting road irregularity using Android OS based smart-phones. Microphone and accelerometer sensors are used to detect potholes and true positive rates obtained are 90%. The researchers use a tri-axial accelerometer for obtaining the readings of acceleration while riding a motorcycle (Vittorio *et al.*, 2014). Further the data is processed using various machine learning with respect to several aspects. Supervised and unsupervised methods are used to identify the road quality and road anomalies, Support Vector Machine (SVM) is used to identify respective position of the detected anomalies. With the help of these methods and using Kendall tau rank correlation coefficient, an accuracy of 78.5% is achieved when the comparison is done with the data obtained by actual human observation with the data obtained after applying the above machine learning methods.

Traffic Sense (Mohan *et al.*, 2008) and Nericell (Mohan *et al.*, 2008) are the systems developed by Prashanth Mohan *et al.* which uses various sensing components like accelerometer, microphone Global System for Mobile (GSM) radio and GPS sensor. Identification of pothole, bumps, braking and honking is done with the help of above sensors. The researchers build a network called BusNet which considers public transport system based sensor network to monitor road surface condition and environmental pollution (Zoysa *et al.*, 2007). Road Condition Monitoring App (Ghose *et al.*, 2012) developed by Avik Ghose *et al.* is a monitoring and alert system for the road conditions of a city. This app uses in vehicle smart-phone as connected sensors which are connected to the Internet with the help of internet of Things (IoT) (Tong and Koller, 2001). This approach is energy efficient as it reduces the data communication between the phone and back-end system and provides accurate road conditions as many users are used to authenticate them.

Microsoft Kinect and a high-speed Universal Serial Bus (USB) camera are used as sensing devices. Mednis *et al.* (2010, 2012) propose a methodology for detection of potholes with the help of mobile vehicles rigged with shelf microphone and global positioning devices connected to an on-board computer. Whereas metrological and visualization properties of a pothole are discussed by Moazzam *et al.* (2013) where a kinect sensor is used which helps in collecting pavement depth images roads to analyze the area of pothole with respect to depth. The estimated volume of pothole is measured using trapezoidal rule on area-depth curves through pavement image analysis.

CarMote (Mednis *et al.*, 2012) is a customized embedded device dedicated for monitoring of road surface using microphone and accelerometer sensors. A novel pothole detection system was proposed by Rode *et al.* (2009) which helps the driver in avoiding potholes on the roads with the help of prior warnings. The architectural design further proposes a low response time, minimal maintenance and deployment cost solution to this problem.

Most of the people who drive on roadways are the one who suffer from the presence of potholes. There are various problems These potholes affect them in many ways: first is the maintenance required due to a vehicle passing over these potholes. If potholes are detected and recorded at regular intervals, then the damage incurred due to these potholes can be reduced. If the municipal cooperation in charge of repairing potholes was made aware of potholes locations in a timely manner then they could be more quickly filled, resulting in less vehicle driving over them and causing further damage to the road and their vehicles. PoDAS aims to do this and provides the following aspects:

- We use an ultrasonic sensor which provides a high accuracy to detect potholes
- Real time data sent to the cloud where data is analysed
- Visual interpretation of the potholes and uneven roads on Google maps

MATERIALS AND METHODS

Proposed algorithm: The complete model proposed for detecting potholes in this study is shown in Fig. 1. Sensors given in the figure are a combined circuit with all the four components: ultrasonic sensor, Arduino Uno

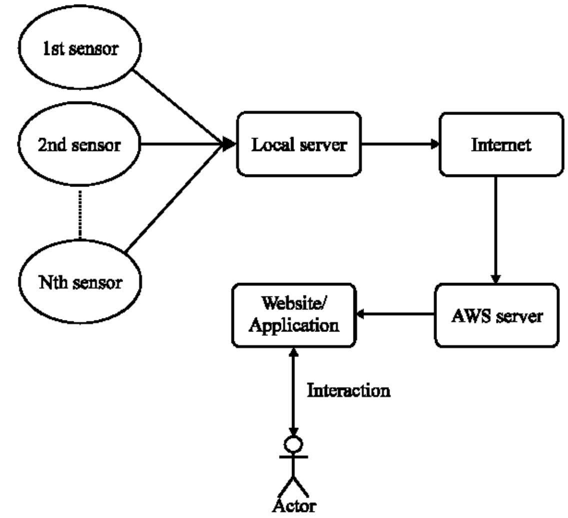


Fig. 1: Schematic representation of the proposed Pothole Detection and Analysis System (PoDAS)

GPS module and accelerometer. It interacts with the local server which communicates to the back-end server with the help of internet which acts as a transmission medium. Data computation is done on the back-end-server and processed data is passed to the front-end application. User interacts with this application and can get a visual idea of quality of the road. Entire process is divided into different segments which are narrowed down to two segments:

- Data acquisition
- Data processing

Data acquisition is the use of sensors to sense the environment and report the collected data values back to a host. Whereas data processing is the host consolidating the data and deriving meaning out of it. Later part of this section explains both segments in detail. In order to implement the proposed solution, the following sensors are used each working independently of the other and providing respective sensed values:

- Ultrasonic sensor: HC-SR04 Distance Measuring Transducer sensor
- Arduino Uno R3 Compatible with USB Cable
- GPS module NEO6MV2 NEO-6M
- GY-521 Mpu6050 Module+Accelerometer for Arduino

Data acquisition: The ultrasonic sensor is the first and primary source of pothole detection. The sonic waves are generated by the transducer which strikes with an object (in this case the road), gets reflected and comes back in the transducer. After having transmitted the sonic waves, the ultrasonic sensor will change to receiving mode. The amount of time taken between transmitting and receiving is proportional to the distance of the object from the sensor. Thus, we get the distance value which is converted into inches. A particular threshold value is calculated by taking some constant readings of a new road or well-maintained road. The threshold value computed is stored into the data set.

The secondary source of detection of potholes is the accelerometer which helps in case the Ultrasonic sensor fails to detect an approaching pothole. As soon as the vehicle encounters a pothole, it would inadvertently 1get displaced across its Z-axes. The accelerometer continuously records these displacements. Similar to ultrasonic sensor, a particular threshold value is calculated by taking some constant readings of a new road or well-maintained road and that values is stored in data set. Once the sensor sense the data for a particular point, corresponding accelerometer and ultrasonic sensor values of that point is pinned using geographical coordinates of the location and stored in the data set.

At regular intervals this information is then sent to the back-end server which all the data is processed where further analysis of the road can be done. If a sensor is not connected to the local server, it stores its value in the cache memory of the sensor and sends whenever it reconnects to the internet. Similarly if the local server is not connected to the internet, then the data is buffered by queueing it and sends it to the back-end server as soon as it gets connected to the internet. Circuit diagram of the sensors used to collect the data is shown in Fig. 2. Arduino Uno is connected to three sensors. First is ultrasonic sensor for keeping track of the ground clearance for a vehicle, next is accelerometer for keeping track of the movement and orientation of vehicle and last part is GPS (Deepika and Usha, 2016) module for saving location for detected potholes.

Proposed Algorithm for PoDAS: Now we proposed the new algorithm to detect the potholes with higher accuracy which is as given below:

```
function : DETCT_POTHOLE (Z_Coordinate, Ultrasonic Distance)
input    : Z_Coordinate, Ultrasonic Distance
output   : status←True if values are above threshold else status←False if
           less than threshold.
Initialize Utrasonic_Thres and Z_Thres←computed threshold values,
status←False
if Ultrasonic Distance > = Ultrasonic_Thres then
|          status ← True;
end
else if Z_Coordinate > = Z_Thres then
|          status←True;
end
else
|          status←False;
end
return status;
```

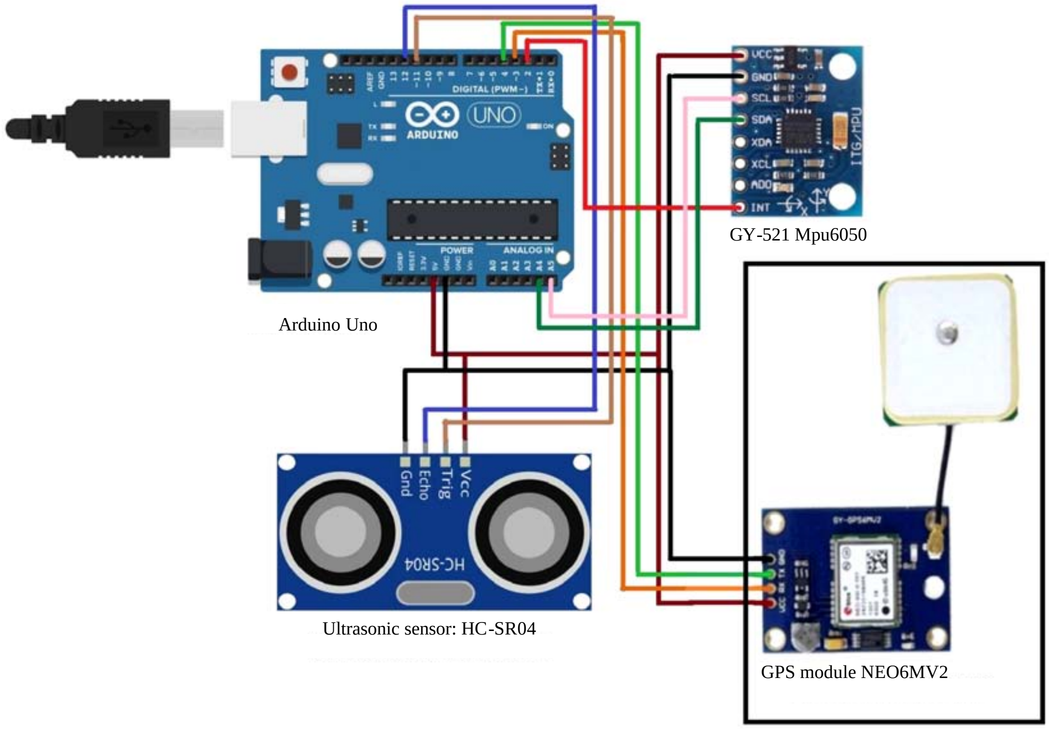


Fig. 2: Circuit diagram for data collection using Arduino Uno, ultrasonic sensor, GPS module and GY-521 Mpu6050 (accelerometer)

Data processing: The system follows a star topology architecture. Data is provided by the sensors to the server which in turn notifies its clients. The accelerometer threshold values for Z-axis and the ultrasonic threshold value are retrieved from the data set. Now the values of threshold for ultrasonic as well as accelerometer are compared to readings of all the points in the data set and hence they are classified as whether there is a pothole on that particular point or not. Also the threshold values are stored after the first computation and thus next time whenever the data comes, it doesn't need to wait for retrieving these values again from the data set.

Information retrieval and processing: The sensors send the detected values to the local server which communicates with the back-end server via the internet. Data is marshalled and transmitted as JSON (JavaScript Object Notation) (El-Aziz and Kannan, 2014). This reduces the size of the data to be transmitted while maintaining the intended structure of the data. The back-end determines if the detected readings are that of a pothole or not. Accordingly, data is sent to its clients. Clients can also query the server as the communication is bi-directional.

Using cloud facilities: As the server is hosted on cloud, classification of detection of pothole is done over there. All the computation and the purposed algorithm is implemented over here. It is the server's duty to detect if a pothole has been found or not by running the algorithm on the given data set. All the results are stored in the cloud itself so that it can be passed on to client.

Reporting information: Information is reported back to the client as JSON (El-Aziz and Kannan, 2014). This information can then be used to represent pothole locations through charts, graphs or interactive live maps. This helps the user to retrieve the processed information and take the desirable actions as per the requirement.

Applications: To apply PoDAS in real time, a feedback system can be implemented. This ensures that information with the access point is correctly and timely updated. Here are a few modes of applications we present for the deployment of sensor:

Rental cabs: In this case, the sensor is deployed in every vehicle. As the driver having kept the GPS (Deepika and Usha, 2016) and internet on the whole time, sensors can be connected to the internet by creating a Wireless Internet hotspot from driver's phone. Hence, real time data keeps on flowing into the server at any given time.

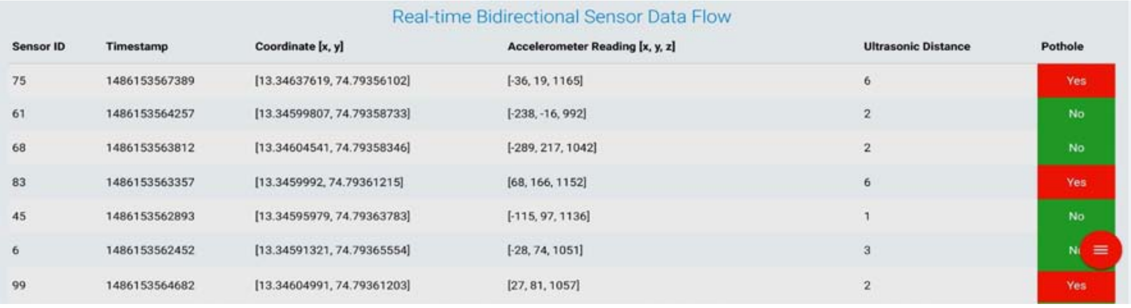
Public transport: This approach proposes the deployment of sensor in public transports like buses. Buses travelling the entire day can store the data into the cache memory of the sensor and as soon as it reaches the bus depot, it gets connected to the internet and all the data is transmitted to the server.

Pilot vehicle: Vehicles which are designed for purposes can be considered under this category. It moves through the roads at periods and aggregates data about potholes to the system. Internet connection must be provided as and when used.

RESULTS AND DISCUSSION

Experiment and result: To check the accuracy and efficiency of PoDAS we conducted a experiment. All the sensors were attached as a whole to the bottom of a vehicle and the power was supplied to the Arduino Uno with the help of USB. Readings were saved on a laptop which is connected through USB. Laptop acts as a local server and as soon as it gets connected to the internet the data is transmitted to Amazon Web Service back-end server where all the processing is done. For the sake of convenience we collected the data for potholes along the road which was around 1 km long and around 150 points were taken into consideration while travelling on this road. In order to compute the threshold values for ultrasonic sensor and accelerometer, another road which is high maintained and about 500 m long was taken in consideration. Constant threshold values for ultrasonic sensors and z-coordinate for accelerometer are obtained to be 6 inches and 1150 m/sec^2. It was found that a standard default distance of between 6-10 inches indicates the need for maintenance of the road. The reported distance of <10 inches indicates the presence of a large pothole that needs immediate attention by the authorities.

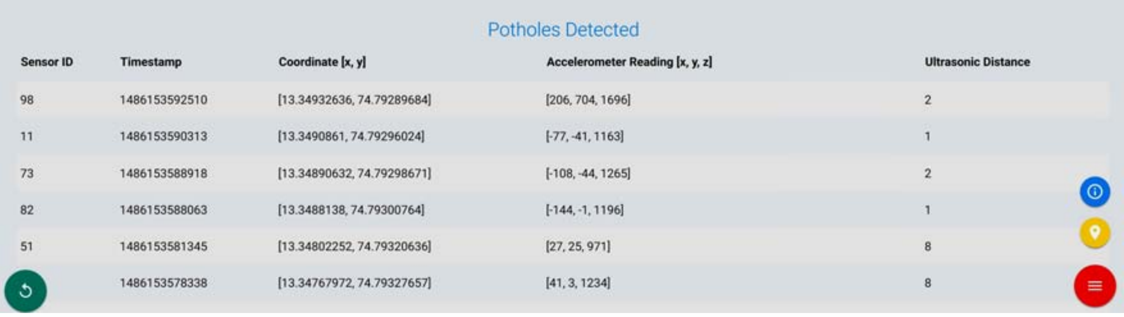
This information obtained as shown in Fig. 3 is viewed onto the system to issue the warning of an upcoming pothole or to initialize road maintenance. This makes it easy for keeping a track of quality of roads especially after heavy rains as the roads get damaged more during that time. To get a list of all the potholes in a particular place, a different web page was created which is shown in Fig. 4. With this information obtained from the



Real-time Bidirectional Sensor Data Flow

Sensor ID	Timestamp	Coordinate [x, y]	Accelerometer Reading [x, y, z]	Ultrasonic Distance	Pothole
75	1486153567389	[13.34637619, 74.79356102]	[-36, 19, 1165]	6	Yes
61	1486153564257	[13.34599807, 74.79358733]	[-238, -16, 992]	2	No
68	1486153563812	[13.34604541, 74.79358346]	[-289, 217, 1042]	2	No
83	1486153563357	[13.3459992, 74.79361215]	[68, 166, 1152]	6	Yes
45	1486153562893	[13.34595979, 74.79363783]	[-115, 97, 1136]	1	No
6	1486153562452	[13.34591321, 74.79365554]	[-28, 74, 1051]	3	N
99	1486153564682	[13.34604991, 74.79361203]	[27, 81, 1057]	2	Yes

Fig. 3: Real time data obtained from the sensors which is processed at the back-end server and output of whether a pothole is there at a particular coordinate is displayed



Potholes Detected

Sensor ID	Timestamp	Coordinate [x, y]	Accelerometer Reading [x, y, z]	Ultrasonic Distance
98	1486153592510	[13.34932636, 74.79289684]	[206, 704, 1696]	2
11	1486153590313	[13.3490861, 74.79296024]	[-77, -41, 1163]	1
73	1486153588918	[13.34890632, 74.79298671]	[-108, -44, 1265]	2
82	1486153588063	[13.3488138, 74.79300764]	[-144, -1, 1196]	1
51	1486153581345	[13.34802252, 74.79320636]	[27, 25, 971]	8
	1486153578338	[13.34767972, 74.79327657]	[41, 3, 1234]	8

Fig 4: Listview of detected potholes which helps to keep a track of all the detected potholes at a single place

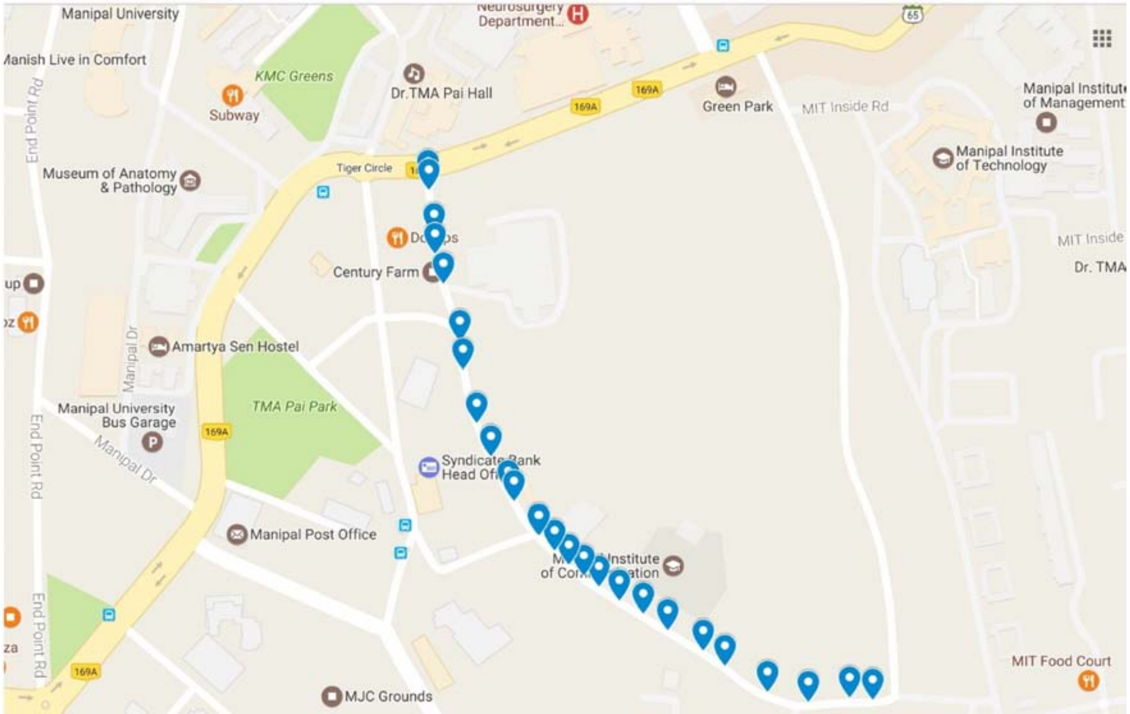


Fig. 5: Pinned location for all the detected potholes using PoDAS on Google maps (Li and Zhijian, 2010)

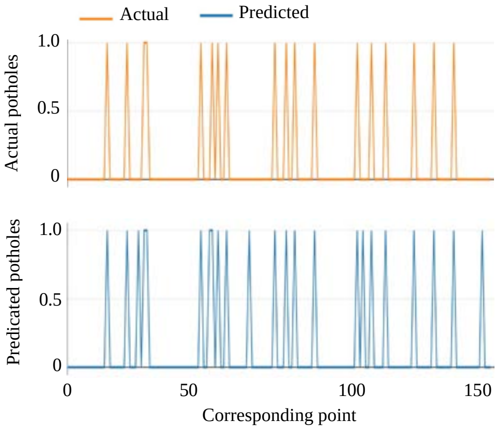


Fig. 6: Comparing the predicted potholes and actual potholes. PoDAS is successful in detecting 80% of the potholes present on the roads during our experimentation

detected pothole webpage, a time series can be obtained which can help the government to determine the budget for road maintenance. For better interpretation of the data, Fig. 5 is used which helps the road maintenance people to locate the approximate location on google maps. To obtain this representation, all the recent detected potholes are passed to the google maps API (Li and Zhijian, 2010) which pinpoints all the location provided to it via GPS coordinates (Fig. 6).

CONCLUSION

We obtained 25 potholes while performing the above experiment and out of 25 potholes, 20 of them are detected by our method. This suggest an accuracy of 80% which is very high as compared to other methods. Comparison of the predicted potholes and actual potholes can be seen. In conclusion, we aimed to address a problem faced by many local municipal authorities where they do not know the exact geographic locations of potholes on the roads. In seasons where there is a lot of precipitation the situation is more dynamic and it is much harder for the authorities to keep track of new potholes. In the past they have relied on citizen initiatives to gain such information. Given the economic ramifications of these potholes we have come up with a low cost technology alternative that will help the concerned government authorities. Our proposed PoDAS system can be deployed in multiple ways depending on the city's needs. We use low cost sensors which make the system economically attractive. We perform extensive experiments as well as real world testing which show that our system is able to detect potholes of all shapes and sizes with an accuracy of roughly 80%. In the future this setup could be bundled into a standalone devices for commercialisation. Different sensor calibration can be explored for further improving the accuracy obtained.

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