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A low cost, non-invasive method for detection and measurement of damaged roads

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***Abstract*— Road networks have been constructed to ease communication over long distances but this can be distressful if the road is damaged. Hitherto detection and maintenance of these is done manually. As time is consumed in carrying out these solutions, many automobile manufacturing companies have upgraded their vehicles with techniques which can supersede these issues. But due to this there is elevation in cost of vehicle; so to bypass this problem detection and maintenance of damaged roads is a necessity. This paper makes an attempt of using an accelerometer as a vibrational detector [4] and a GPS transmitter which can be clamped on the wheels of vehicle sending continuous data (vibrations along with location) to the main server. At the main server, vibrational and locational data thus collected are automatically analysed and categorised according to their intensities and sent to the main server where it is symbolised according to their magnitude. The data is then used to generate vibrational maps (VMaps).The VMaps report can be continuously analysed by engineers involved in maintenance of these damaged road and quick action can be taken. The methodology discussed over here is reasonably priced and can help in reduction or eradication of many problems caused by damaged roads.**

***Index Terms*— damaged roads, manual monitoring, sensors, intelligent systems.**

I. INTRODUCTION

Transportation can be considered as one of the important parameter in the growth and development of a region; among the various schemes of transportation by land can be considered the most important among the all. Road networks have been constructed all across the globe for trouble-free conveyance of resources and people from one place to another. But this may sometimes turn weary, take a while longer than usual or may result in accidents if these roads are damaged or full of abyss. And surveys form all around the world can show us that change in weather conditions(rainy season), occurrence of any natural calamity (landslide, earthquakes) or due to the load of the vehicles that passes contribute to damage of a notable portion of road network and is in constant need of maintenance. Recurrent monitoring of these roads are thus a necessity which is hitherto manually executed in developing countries i.e. experts appointed by local government or transportation agencies regularly audit all the networks and generate a maintenance report of different locations. This procedure is quite tedious and involves huge investment of time and money and is not even reliable. So to reduce the reliability on manual methods many research have been conducted. In most of these remote sensing techniques have been used in which a resolution camera captures images (using UAV) of damaged road and reads the features of the image (using image processing and filtering techniques) and identifies fissures on the surface [1] or a camera takes up a single image and identifies fissures by identifying difference in colour and texture using Gabor filter techniques [2]. Notwithstanding the efficacious methodologies, these are not cost efficient and are not affordable for government of developing countries to make them viable. So to recurrently audit such locations an innovative, efficacious and reliable alternative forms a prerequisite. In lieu of capturing image of road networks and scrutinizing different features using image processing techniques, parameter to be accounted can be changed. The problem with the image examining techniques is that it is not reliable at certain conditions, which can be framed as follows:

1) In stormy weather.
2) When fissure and abyss on road surface are surfaced by water due to superfluous rain water or any other reason like overflow of water from drain constructed beside roads in cities.

Figure I. Damaged roads

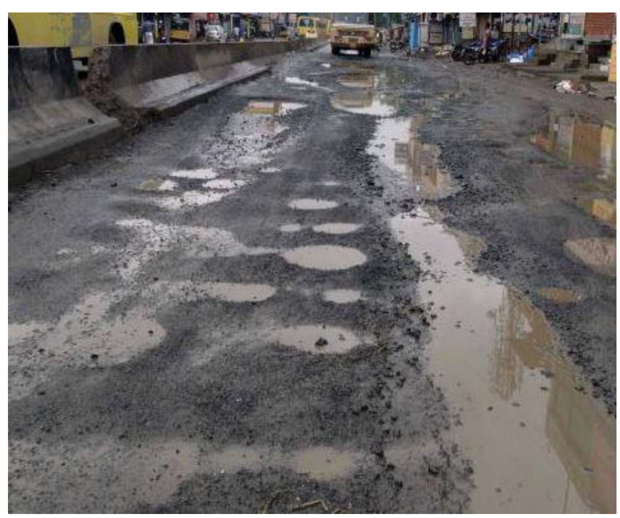

Figure II. Pits filled with water (damaged road)

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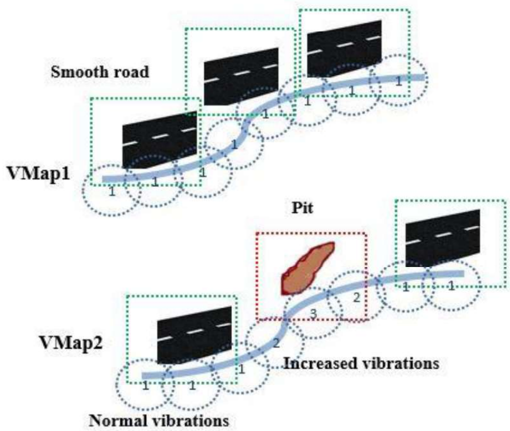

Figure III. Two VMaps showing damage of road

To vanquish above matter in question, a new but existing parameter can be examined and evaluated i.e. vibrations experienced by any vehicle while crossing over fissures, humps or potholes on road surface to determine severity of maintenance of road. The advent of this methodology works as a boon as it is not only reasonably priced but also efficacious and reliable in terms of its output. The methodology proposed in this paper can effectively detect damaged road and is intelligent enough to deduce the intensity of the damage from recorded data, thereby reducing manual labour incurred in collecting data and making record, thus saving time and extra expenditure.

II. METHODOLOGY

Whenever any four or two wheeler vehicle bypasses any damaged road then there are vibrations produced in the vehicle which can be used as a tool or variable to differentiate in according to its magnitude between damaged and smooth road and severity of need of maintenance thus can be easily determined. This paper puts forward a new technique in which MEMS accelerometer is used to detect vibrations. Here accelerometer in conjunction with GPS module is employed to lessen the work of audit and report generation. In this module accelerometer along with GPS transmitter is clamped to the rim of the wheels. The work of accelerometer here is to not only measure the velocity but also detect the vibrations in the vehicle when crossing pits or damaged roads. In the overall system adxl335 accelerometer has been used which can easily detect the rate of change of momentum in x, y and z direction. The intensity of vibration is recorded along with the current location which is then send to a common server where different locations are segregated automatically in three categories, namely:

COLOUR	SEVERITY OF NEED OF MAINTENANCE
RED	High
YELLOW	Mild (can stand for few more months)
GREEN	Ok

Table I. Colour coding of damage intensity

During ideation and adaption of this methodology following protocols are followed, namely:

1) No changes are made in the assembly or working mechanism of the vehicle and vehicle can carry both accelerometer and GPS transmitter effortlessly.
2) The overall mechanism of operation is automatic and needs no human intervention.

The overall system works on generation of waveforms by the accelerometer which initially helps in deduction of a threshold value for a smooth or undamaged road then whenever vehicle is made to travel over a damaged road the abrupt or instant increase in magnitude of vibrations can be used as a factor in determining the need of maintenance. GPS module continuously sends the current location along with velocity of the vehicle to the main server where it is monitored. The server then follows a procedure similar to that described by Huang-Chen Lee and Huang-Bin Huang [3].

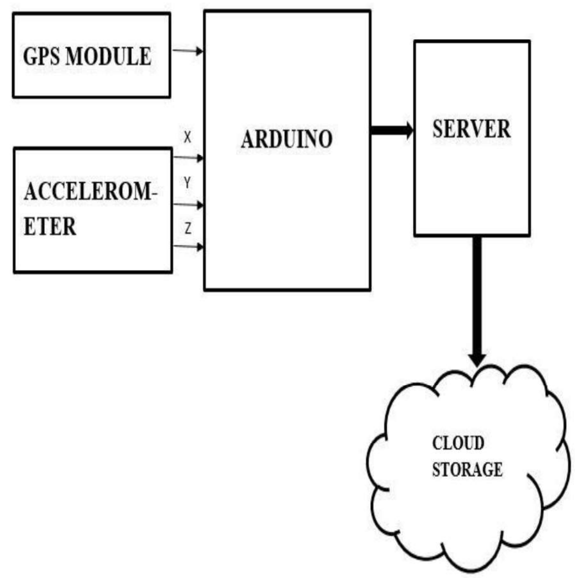

Figure IV. Block diagram of system

III. RELATED RESEARCHES

There have been many methods being deduced using unmanned aerial vehicle which takes up the snaps of different locations of roads and then different features on road surface with location of the road is monitored by using GPS[1]. In this a helicopter rovers over all the road networks and captures images using a high resolution camera, which is further processed using different filtering techniques to detect different features of road especially pits, fissures and humps. Next is the simple image processing technique which employs taking up a picture and differentiating different features of road on basis of colour or textures. This paper mainly implements use of Gabor filter technique to detect various features of road and detect damaged or gravelled roads [2]. In order to make these techniques viable in developing world huge amount of capital investment is required so these methods can't be considered as feasible and affordable for developing nations.

Comparative study of various techniques:

METHODS/COMPARISON PARAMETER	**Auditors**	**General road detection from single image**	**UAV based photogrammetric mapping system for road condition assessment**	**Application of accelerometer in detection of damaged roads**
Installation cost	N/A	□2000 for a single camera	□10000	N/A
Hardware cost	N/A	□1500 for accessories	□15000 UAV with Camera and accessories	□1500
Total cost	Salary = □30,000 per month	□3500 for a single sector	□25000 plus maintenance cost	
Advantages	Can report correctly	Time efficient	Time efficient and can report correctly	Time efficient, cheap and can report correctly
Disadvantages	Costly and not time efficient	Costly	Costly	Only the path travelled can be monitored

Table II. Comparative analysis

IV. SYSTEM ARCHITECTURE AND DESIGN

The following part describes the system's architecture and the design considerations that were taken during the course of the project. An overview of this can be seen from the figure. The main components of the system are 1) Sensor module (consisting of the accelerometer, GPS and the Arduino), 2) Server (in this case a laptop with Intel core i3 processor). The sensor module is just an embedded system that can be clamped to the vehicle whose main function is to read the vibrations that come along the way and to transfer this vibrations to the server. All the data that is recorded is sent to the server for further processing and analysing.

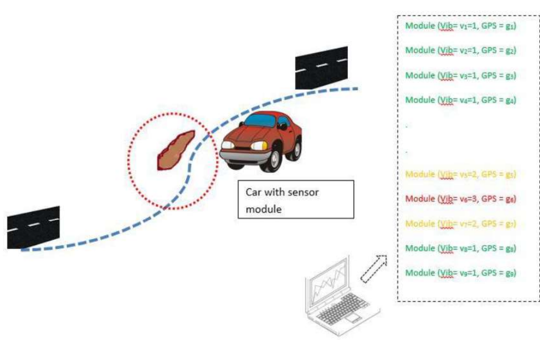

Figure V. System architecture

A. Sensor module

The main idea for using this sensor module is to take advantage of the existing vehicle to carry out the designated task. Huge amount of data is read by this module in the process. All of this data is stored in a database in the server. The module uses Arduino as its power source which gets power from a 12V LiPo battery.

The system components of the module consists of adxl335 accelerometer and a GPS receiver MT3333 chipset from Media Tek Inc. The GPS has 66 channels for GPS tracking and uses a baud rate of 9600bps. The adxl335 has a minimum full scale reading of ±3g.

The speed of the vehicle is calculated from both the GPS data and value of accelerometer so that the effect of the speed and acceleration on the readings of the vibration can be nullified. The equations for determining the speed and acceleration is given below:

$$acc_{avg} = \frac{\sqrt{(lat_k - lat_{k-1})^2 + (lon_k - lon_{k-1})^2}}{t^2} \quad (1)$$

Where,

lat_i, lon_i = readings from GPS

t= time elapsed between k and (k-1) moment

Acceleration is also read from the accelerometer as

$$acc = \left|\overrightarrow{a_x} + \overrightarrow{a_y}\right| \quad (2)$$

Where,

a_x, a_y= reading from the accelerometer

By deducing the vibrational component from them in the z direction a better and error free reading is taken.

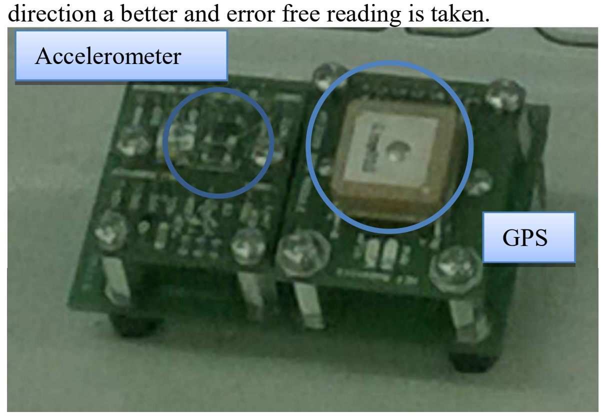

Figure VI. Sensor module

B. Server

The server used in this project is a laptop working on Intel core i3 processor. Matlab 2014b is used as the programing tool for the whole process. The server was connected to the cloud using high speed internet.

V. DESIGN REQUIREMENTS

To ease installation of this equipment different protocols have been kept in mind, which are as follows:
1)Installation of this equipment must not require any remodelling in structure or assembly of the vehicle.
2) The equipment must work without any human intervention i.e. must be autonomous.
3) Any error detected in the equipment must not hamper the functioning of the vehicle in any situation.
4) Cost of installation and maintenance must be within feasible range such that government of developing countries can easily afford this.
5) This equipment must be error free and must be as accurate as possible and must not be affected by changes in the weather conditions.

VI. PROCEDURE

In the experimental part of this project the accelerometer and the GPS module was fixed in a car and the car was driven on a particular path. First of all the car was driven over a smooth road for getting the proper calibration data. After calibrating the device over a smooth road the car was then driven over normal traffic road.
In the overall process an Arduino was used as a communicating interface between the accelerometer and GPS and the server. This accumulated data via serial communication network was sent to a laptop in the vehicle which in this case acted as the server. The values received by database(laptop) are x,y,z (by accelerometer) and longitude, latitude by GPS module. Of these five sets of data values an automatic comparative analysis and optimisation was done at the server. The acceleration in x and y direction were too accumulated at the database as they give information about vibration caused by moving vehicle over a smooth road or rugged road (as they contribute marginal effect in vibrations detected in z-direction). With value of z-direction, the analog data is converted to digital data before it is send at the server, a 10 bit conversion was used in the process and thus its value fluctuated within 0 to 1023 levels. This fluctuation in values is optimised in various other levels to define severity of the condition, namely: high, mild and ok. The maximum fluctuation in magnitude of vibration in z-direction are thus recorded to define need of maintenance of road with minimum of delay. The variations in value of z are marked as 1, 2 or 3 as per severity and are sent to the database.
The algorithm present in the server then picks up all the five variables and marks with designated colours different locations on map of that area according to severity.

Number	**Colour**
1	Green
2	Yellow
3	Red

Table III. Optimised value according to intensity

The laptop in the vehicle is connected via a high speed internet connection which then uploads the overall map on the cloud which can be easily accessed by designated personnel without doing any manual effort. The map thus produced after periodic audit of roads provides guidance for maintenance of damaged road with minimum of delay to Personnel appointed by local government.

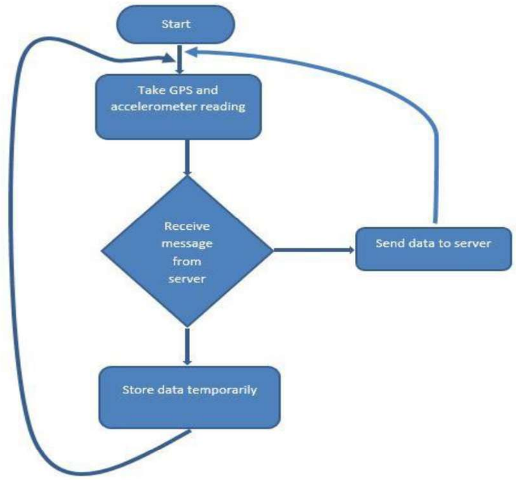

Figure VII. Working flow diagram

VII. ALGORITHM

The algorithm used in the above project is described below:

Algorithm used in the Arduino

1	Start up the serial communication with the server
2	Initiate timer
3	**while(true)**
4	Get the values of accelerometer $\mathbf{a_{xk}}$,$\mathbf{a_{yk}}$, $\mathbf{a_{zk}}$
5	Read GPS $\mathbf{lat_k}$, $\mathbf{lon_k}$
6	**if (Serial.available())**
7	Send the values to server
8	Send the timer value of $\mathbf{t_k - t_{(k-1)}}$
9	**end if**
10	**endwhile**(Return to 3)
11	Stop

Table IV. Algorithm 1

In the Arduino the analog input ports have been used for reading the value of the accelerometer, the analog value received is first digitised in 10 bit level thus giving us a decimal value from 0 to 1023 (1024 levels). The quantisation procedure follows the following procedure:

$$a_i = \frac{v_{in} \times 1024}{v_{ref}} \tag{3}$$

Where,

$a_i = a_{xk}$, or a_{yk} or a_{zk}

v_{in}= Input voltage in the analog pin 1 or analog pin 2 or analog pin 3

v_{ref} = 2.56V

The timer has been used in the Clear Timer on Compare (CTC) Mode. In the CTC mode the timer is continuously run on the background and whenever its value reaches that of the value defined in the OCR pin it resets itself to 0 and a counter counts this change. This helps to keep the track of time between two successive data values sent which is useful in deducting the speed and acceleration of the vehicle. The waveform frequency is given by the equation:

$$\frac{1}{T} = f_{OCnA} = \frac{f_{clk}}{2 \cdot N \cdot (1 + OCRnA)} \tag{4}$$

Where,

N= prescaler (1, 8, 64, 256 or 1024)

Algorithm in the server for plotting graph

1	Start up the serial communication with the Arduino
2	**if (Calibration not available)**
3	Take the reading of accelerometer on the various positions
4	Calculate **$gain_{accx}$, $offset_{accx}$,$gain_{accy}$, $offset_{accy}$,$gain_{accz}$, $offset_{accz}$**
5	**end if**
6	**while(true)**
7	Get the data of the accelerometer
8	Set up an array **g[]={g_{xk}= $gain_{accx}$(a_{xk}- $offset_{accx}$); g_{yk}= $gain_{accy}$(a_{yk}- $offset_{accy}$); g_{zk}= $gain_{accz}$(a_{zk}- $offset_{accz}$)}**
9	Plot the graph**g[]** vs. **k**
10	**end**

Table V. Algorithm 2

In the server for calibrating the accelerometer, the gain and the offset is determined. For calculating the gain and the offset. The accelerometer if first put in such a way so that z-direction points up and the values are written as:

$$[gz\_x \quad gz\_y \quad gz\_z] = [a_x \quad a_y \quad a_z] \tag{5}$$

$$offset_{accz} = \frac{gz\_x + gz\_y}{2}$$

$$gain_{accz} = gz_z - offset_{accz} \tag{6}$$

After the calibration process is completed the results are used for creating the g [] matrix as:

(7)

$$g[\ \ ] = \begin{bmatrix} g_{x0} & g_{x1} & \cdots & g_{x(k-1)} & g_{xk} \\ g_{y0} & g_{y1} & \cdots & g_{y(k-1)} & g_{yk} \\ g_{z0} & g_{z1} & \cdots & g_{z(k-1)} & g_{zk} \end{bmatrix} \tag{8}$$

(5)

After creating this matrix the values are categ... ...d given proper colour coding. And is then plotted according to the following matrix

$$data_{col} = \begin{bmatrix} vib_0 & \cdots & vib_k \\ col_0 & \cdots & col_k \end{bmatrix} \tag{9}$$

$$GPS_{data} = \begin{bmatrix} lat_0 & \cdots & lat_k \\ lon_0 & \cdots & lon_k \end{bmatrix} \tag{10}$$

Algorithm for cloud

1	Get the readings of the **g[]** matrix
2	**if (g_k lies in the value of green zone)**
3	**Vib_k=1; col_k = 'g';**
4	**if (g_k lies in the value of yellow zone)**
5	**Vib_k=2; col_k = 'y';**
6	**if (g_k lies in the value of red zone)**
7	**Vib_k=3; col_k = 'r';**
8	**end if**
9	Get the values of GPS **lat_k, lon_k**
10	Create a map of matrix min_val<**lat_k**<max_val and min_val<**lon_k**<max_val
11	Plot (**lat_k, lon_k,'col_k'**)

Table VI. Algorithm 3

VIII. RESULT

This equipment results in various parameters which are well studied and examined to fulfil the required objective of identification of location of damaged roads without using manual efforts. The overall procedure gives various outputs such as acceleration in x and y direction, jerks over pits, fissures on damaged road in z direction along with the location. From given waveforms it can be easily differentiated between normal, smooth and damaged road whereas the Vmaps provide us with an overall track of surveying vehicle travelling over normal smooth or damaged road. The waveforms that were received during the various periods of the experiment are shown:

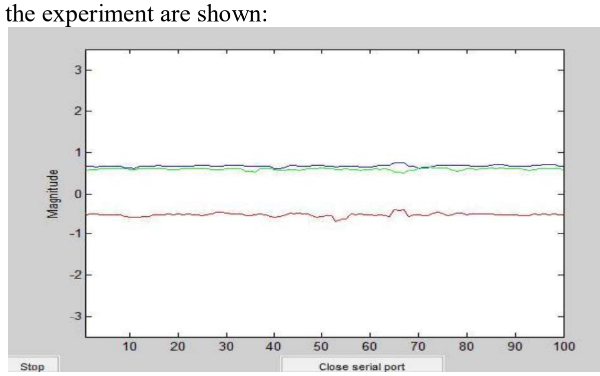

Figure VIII. Normal road (For calibration)

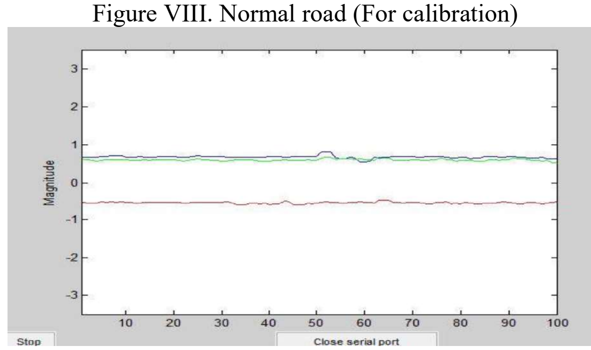

Figure IX. Normal road

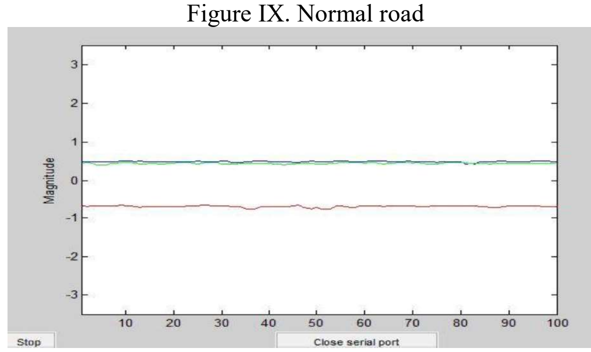

Figure X. Smooth road

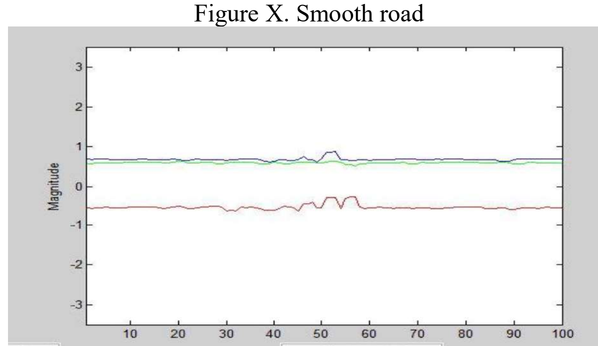

Figure XI. Bumps

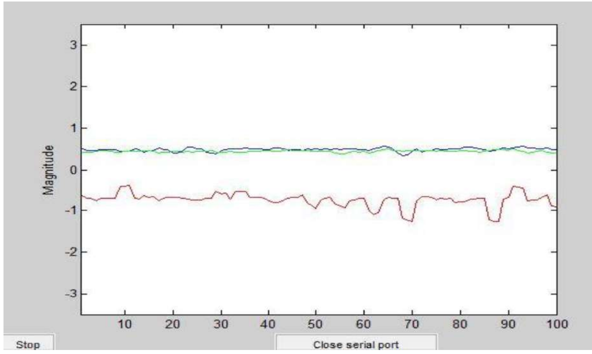

Figure XII. Pits

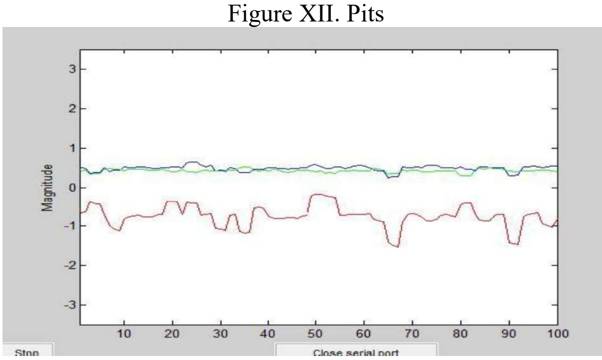

Figure XIII. Damaged road

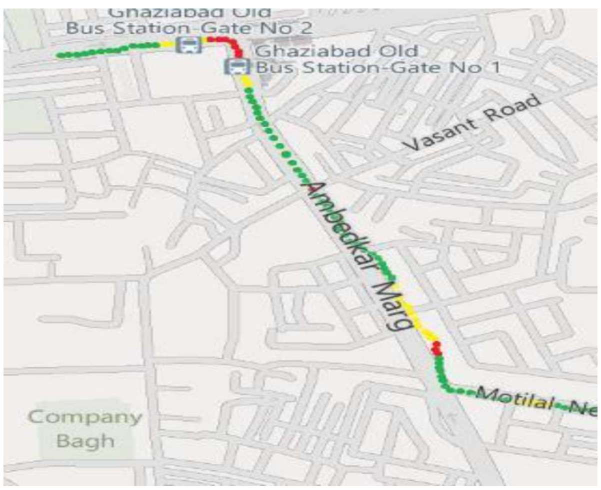

Figure XIV. VMap(1)

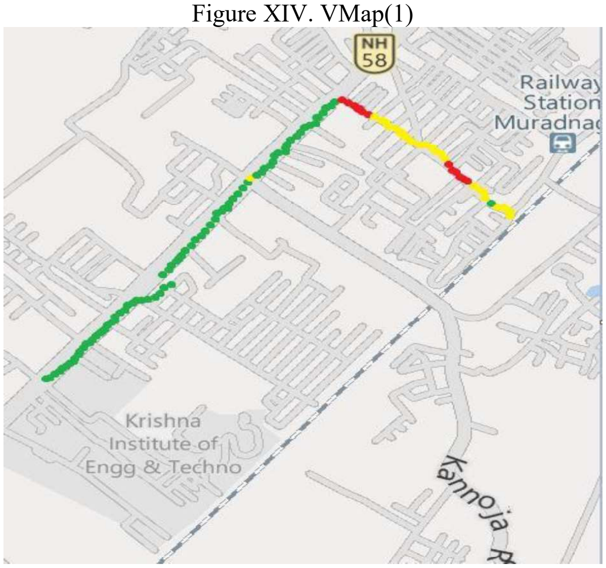

Figure XV. VMap(2)

IX. CONCLUSION

It can be inferred from this paper that accelerometer can be utilised to detect dynamic force like vibrations due to its high sensitivity to a very small change too. This method is not only feasible but flexible i.e. can be used in any environment(on any vehicle) just by changing the sensitivity of the device. The overall system is cost effective and highly reliable in terms of accuracy. It forms an intelligent system which operates without any human intervention and reduces reliance on manual methods for maintenance of record and detection. Accelerometer in conjunction with GPS module is an innovative approach to design an efficient system to map all the damaged roads all across the globe (just by accounting all the jerks experienced by vehicles while travelling over these roads). This equipment looks forward to various advantages like:

1) Reduction in time consumption invested by personnel in monitoring damaged roads.
2) Dwindle number of accidents and deaths occurring per year due to damaged roads.
3) Diminish economic stress over officials involved in monitoring of damaged roads, as its installation is too cost efficient.
4) Yields a reliable and efficient result, and can be implemented in any vehicle without causing any change in the mechanism of the vehicle.
5) It can function effectively and efficiently in any weather condition.

To conclude we can say that this equipment provides an easy, safe and cost effective solution or alternative to problems faced by personnel appointed to monitor these damaged roads.

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