Indian Institute of Information Technology
Allahabad

Road Roughness Analyzing System

(For Rural and District Roads)

Project Report for 5th Semester Mini Project

Submitted

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Abstract- A working model was prepared to analyze the roughness of road in terms of *cracks and potholes*. Depth of potholes/cracks was used to express the roughness of the road segment. This depth was measured with the help of ultrasonic sensors mounted on the bottom of the vehicle model. Total 6 ultrasonic distance scanner sensors were used in pairwise combination of left-right along with a tilt sensor.

Error can occur in determining possibility of a roughness due to sensors used. To reduce probability of error sensors were used in pairwise manner along with a tilt sensor. The system detects the roughness with a *probability of 80%*.

Error in the depth of the roughness which in none other than pothole or crack was observed to be <0.3cm that is much close to the measurement error by ultrasonic sensor used which comes to be <0.2cm [1]. An alternative strategy can be there to use laser sensors instead of ultrasonic sensors which can provide accuracy up to 1mm as suggested in the paper by X. Yu and E. Salari [2]. That much accuracy doesn't provide much benefit for rural roads and using lasers increases the cost as well.

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1. Introduction

India is a nation with the Second largest road network of the world with over 5,472,144 Kilometers network [3]. A good quality Infrastructure, services and transportation are of utmost priority for a developing nation. The road network contributes to any economy in a significant way. The gigantic Indian road network significantly contributes to the economic growth, i.e. the strength of the road networks determines the strength of the economy. Indian road network is constituted by Expressways, National Highways, State Highways, Major District Roads, Rural and other roads [3].

From the past decades, we have seen a significant growth in the vehicle population of the country in urban as well as the rural areas. Increase in vehicle population had adversely affected the condition of the roads, and also the gigantic network of roads is responsible for the poor-quality maintenance of the transport network in roadways. In today's world time is more precious than anything else, the poor quality of roads limits the speed of the national growth. Roads are differently built for different terrain and are made up of different material depending upon the characteristics of the place it is being built.

The roughness of the road refers to the distortion of the quality of the ride. It can be due to potholes, cracks, ruts or bad orientation of the roads. The poor road condition affects the quality of the movement on them. The project aims for rural and district roads as there are already pavement surveying system for highways and expressways. These are rural and district roads which are not properly monitored. For these kinds of roads road super elevation, ruts and minor cracks are not big contributors when analyzing roughness. These are low quality roads, so the accuracy of measurement is not much critical as that in case of highways and expressways as well as small ruts and cracks being ignored is not a big issue. Thus, we'll be determining the roughness in terms of potholes and cracks only that will be sufficient enough. The term roughness used anywhere further in the report will refer to potholes and cracks only. In numeric terms, depth of potholes and cracks will be used to identify a road segment as poor.

Figure 1: Sensor equipped vehicle

Figure shows the customized vehicle equipped with sensor which was created to demonstrate the working of the proposed system.

The project aims on making a cost efficient IOT (Internet of things) based project in which the device will detect and analyze the roughness of the road.

IOT (Internet of things) refers to the network of interconnected devices which have internet-enabled. A paper by V. Sharma, *et al.* [4] defines IOT as "IOT is a sort of universal global neural network in the cloud which connects various things". IOT extends the internet connectivity from laptops and mobiles to range of devices making the devices smart. IOT includes smart machines which can interact and communicate with other devices, collect data from working environment and then share that data over internet.

Proposed model implements a low cost IOT based approach, model shares the collected data over internet thus requires internet connectivity. Data is collected through various sensors which are mounted on the bottom of the vehicle and then further shared over internet to the administrator for further analysis. Since the proposed model is low cost, system can be used on the vehicles like police vans, fire brigades and other government vehicles in order to more accurately analyze the condition of the roads. This will help the Government to fulfill their responsibilities and competent authorities to effectively and efficiently maintain the quality of the roads.

2. Literature Review

A number of recently published articles and research papers related to road condition analysis are enough to show the increasing interest in this particular area.

A recent publication [5] proposed a model which employs pothole detection using ultrasonic sensors, and notifying the driver for the same. Ultrasonic sensors were used for the detection of the humps and potholes. This project works on the data produced by the ultrasonic sensors only. That can be erroneous also. Model works fine for notifying drivers. But since the data recorded is not that much reliable, it can't be used for road maintenance.

S. Kathane, *et al.* [6] proposed a model which includes vehicle accident detection and pothole detection. Data provided by the system only includes the locations where the pothole was detected. Detection is made by measuring the change in vertical and horizontal component of the acceleration. That much information is not sufficient to analyze the condition of the road.

A. Danti, *et al.* [7] developed a model using Image Processing. Haugh Transformation was used for detecting the lane. For detection of potholes, clustering based algorithm was used. For precise analysis, high end camera was used which increases the overall cost with a big factor.

G. Chugh, *et al.* [8] developed a system in which analysis of road condition was done using smartphone sensors. Smartphone sensors do not meet the accuracy level required. Overall model was cost effective but in terms of reliability and accuracy it lacks.

T. Kim, *et al.* [9] proposed in their paper, classification of potholes. Potholes classification was performed according to the location, shape and depth. From this kind of detecting methods, need of a guideline for classification of potholes appears.

K. Chen, *et al.* [10] proposed a model using three-axis accelerometer and GPS. Data collected by sensors consists of velocity, time, location and three directional accelerations. System also provides error correction facilities for GPS and transmission errors. Potholes are detected by measuring the change in directional component of acceleration. System doesn't measure the depth of pothole detected.

I. Kertes, *et al.* [11] proposed a model which uses two industrial cameras, 20 laser sources and Inertial Measurement Unit (IMU) to collect road profilometry data and further analyzing road condition through image processing and additional data collected. Use of industrial camera and laser scanner sensors increases the accuracy along with exponential increase in cost.

3. Problem Definition

The aim of the project is to prepare a cost-effective model which will provide the analysis of the road condition in terms of roughness on the surface, record that data and further update that data on a database server for administrator as well as generate a map marking to the locations of the detected roughness for quick review.

For analysis of road condition, a vehicle mounted with sensors required needs to run over the surface of the road for which analysis needs to be done.

After collecting data through sensors mounted on the analyzing vehicle, analysis of that sensor data needs to be done and a decision needs to be made whether there is roughness ahead or not and driver of the vehicle needs to be notified for the same.

When roughness is guaranteed, the depth of roughness along with it's location needs to be updated on the database server and a custom map having markers to the roughness locations needs to be automatically generated for the quick review of overall analysis.

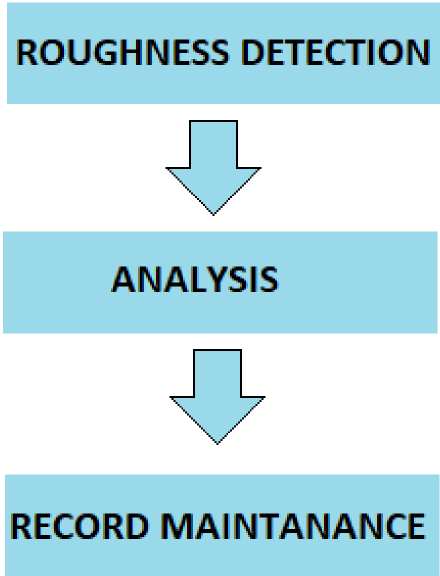

Figure 3: Flow chart of process

Figure shows a flow chart indicating step by step process which needs to be followed for the roughness analysis of a road.

4. Methodology

The whole process is divided into two phases. First is hardware implementation which includes the interfacing of sensors which are used to collect data for roughness analysis and building of a demonstration vehicle mounted with these sensors and the second part is implementation of software part which will read the sensor data and after analyzing the data, perform the decision-making job. Process is partially automated means the movement of the vehicle needs to controlled by the user. Vehicle will detect the roughness on the path on which it is moving.

4.1. Hardware Implementation

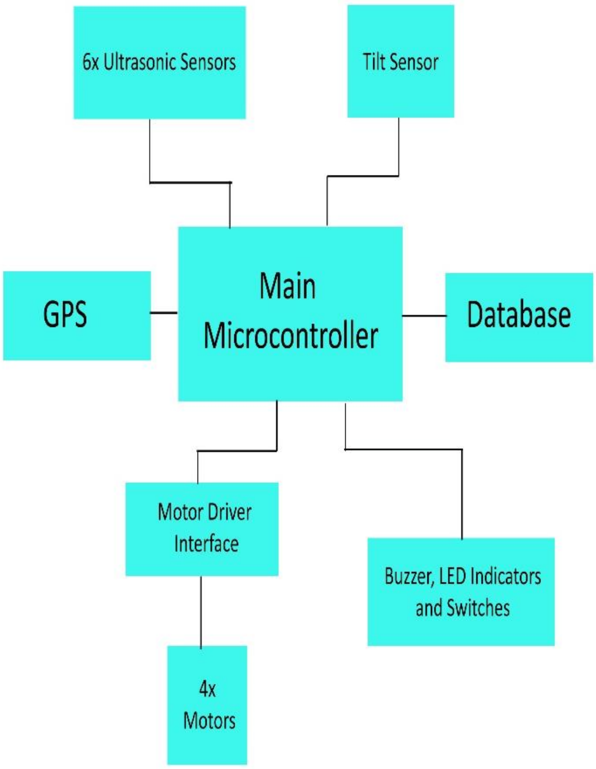

Figure 4.1.1: Block Diagram of Unit

Figure shows the block diagram of the unit. Six ultrasonic sensors and tilt sensor are directly interfaced with the microcontroller. GPS module is useful in determining location, this is also directly connected to the microcontroller. Database server is connected through the internet connectivity of microcontroller. Motors driving the vehicle are connected to the microcontroller through the Motor Driver Interface. Buzzer, LED indicators and switches provide a user-friendly interface.

A microcontroller is used for operating the sensors and controlling the movement of the vehicle through the signals given by operator. This microcontroller is mounted on the vehicle itself.

As shown in the figure 4.1.1, microcontroller is the heart of the unit. Job of this microcontroller is to operate the sensors and after collecting data from these sensors, perform the decision making. In mean time, this microcontroller is also responsible for the movement of vehicle.

Gear motors are connected with the microcontroller through Motor Driver Interface which provides facility of movement control in clockwise and counter-clockwise directions for two motors simultaneously.

Ultrasonic distance scanner sensors and tilt sensor are responsible for detection of roughness. Combined output data from these sensors is used in roughness detection.

Whenever roughness is detected, it's location is fetched through the GPS and checked in the database if not already there, record is added and database is updated.

As shown in Fig. 3, the whole process consists of three phases-

1. Roughness Detection
2. Analysis
3. Record Maintenance

Six ultrasonic sensors are used in pairwise manner along with the tilt sensor for shock detection.

Whole detection process consists of two phases-

a) Prediction of roughness
b) Confirmation

If there is a chance of roughness on the path on which vehicle is moving, it will be predicted through the data collected by ultrasonic distance scanner sensors. If data is sufficient enough to ensure the occurrence of roughness, vehicle will stop for updating the data and indicate the occurrence of roughness to the operator through indicators mounted on the vehicle. If occurrence of roughness is not assured, system will wait for shock detection for a period of time, if a shock is detected, then conformity of roughness is made, otherwise the prediction will be ignored. Shock detection will be performed through the tilt sensor mounted on the vehicle.

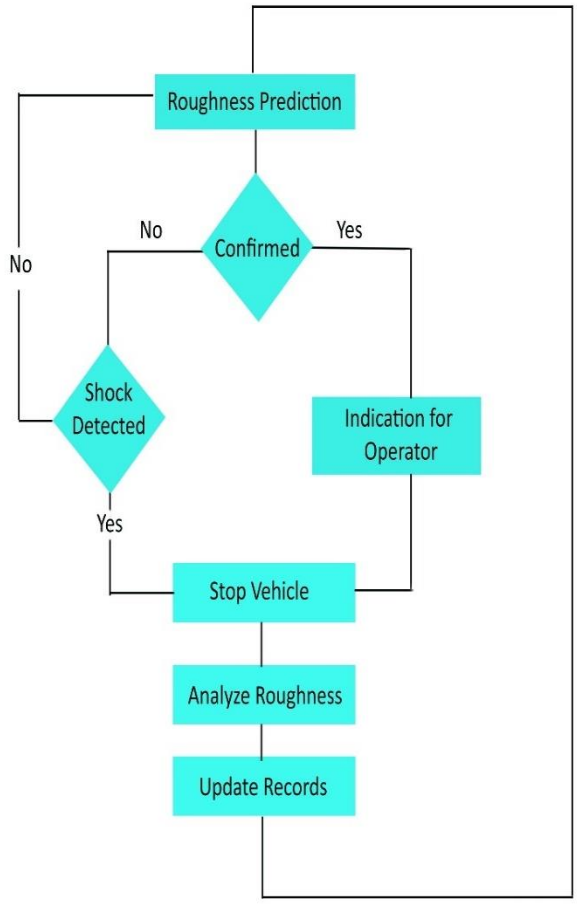

Figure 4.1.2: Flow chart of detection process

Figure shows the flow chart of roughness detection process. After prediction of roughness when confirmation is made the operator is informed and vehicle is stopped for updating the records.

The reason behind using ultrasonic sensors in pairwise manner was to increase overall accuracy. Since ultrasonic sensor uses sonar technology to measure the distance of an object. Distance is calculated by the time elapsed for the sound wave to return back. Chances are there that the wave gets reflected back in it's midway to the surface of the road.

Using the combined output of two parallelly mounted ultrasonic sensors and making the confirmation of roughness only if both of them detect roughness increases overall accuracy.

If either of them is not guaranteed about the roughness ahead, chance of roughness is predicted and system waits for detection of shock which is detected through the tilt sensor mounted on the surface of the vehicle. If a prediction of roughness was made earlier and tilt sensor detects change in orientation of the vehicle during a threshold time period then the confirmation is made otherwise the prediction is ignored.

A general ultrasonic sensor has 4 pins out – VCC, GND, TRIG and ECHO. These four pins are connected to the microcontroller as shown in the figure 4.1.3. Sensor requires 5V DC supply thus VCC and GND pin of the sensors are directly connected to the 5V VCC and GND out of the microcontroller respectively. TRIG works as input pin of the sensor while ECHO gives the output.

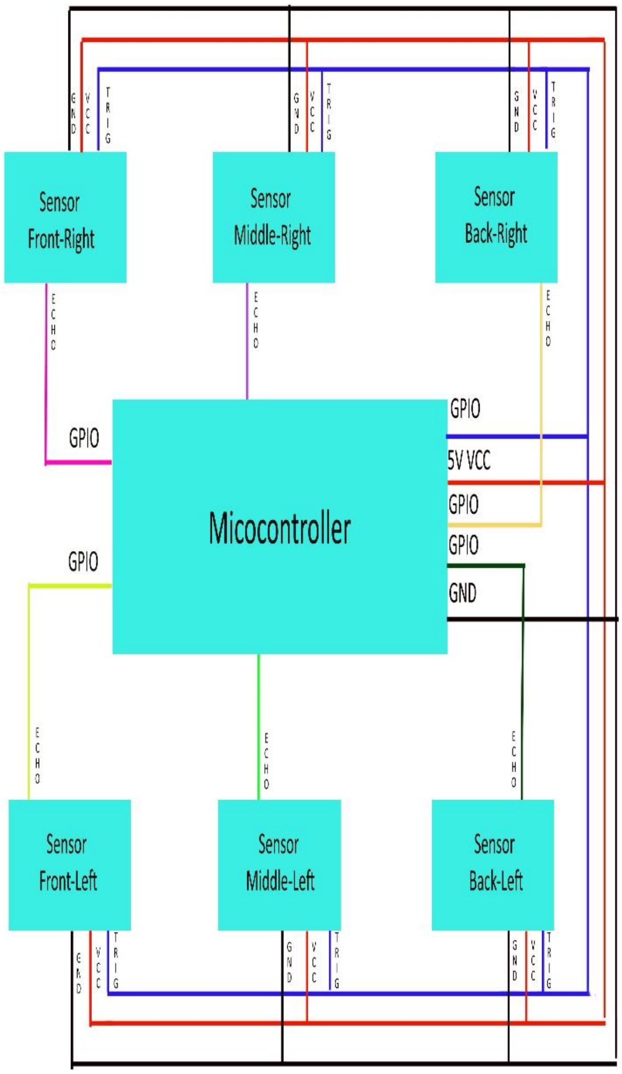

Figure 4.1.3: Interfacing of Ultrasonic Sensor

Figure shows the interfacing of ultrasonic sensors with the microcontroller. VCC and GND pin out from sensors are connected through 5V VCC and GND of microcontroller respectively. One GPIO is connected to the TRIG pin of all the sensors while one GPIO per sensor is used for ECHO pin out of the sensor for taking the output of the sensor.

General Purpose Input-Output is referred as GPIO. These pins out of the microcontroller are used to interface various peripherals with the microcontroller.

Mounting of ultrasonic sensor was done in such a way that vehicle detects the roughness before actually passing through that. Sensor pairs were mounted before front wheels, in between front and back wheels, before back wheels.

Ultrasonic sensor consists of a transmitter and a receiver. Transmitter sends a sound wave while receiver receives that wave reflected back from any object.

When the TRIG pin is logic-high, transmitter emits the sound wave. When the receiver receives the reflected wave back, ECHO pin goes logic-high. In this way, total travel time is recorded which is the time of sound wave to go to the object and return back.

The major issue that aroused while interfacing these ultrasonic sensors was that parallel working of these sensor was required and the sensors were catching the wave transmitted by other sensors when running parallelly. For successful parallel measurement of depth from sensors, common TRIG was used for all the six sensors which means emission of sound wave takes place at same instance of time for all the six sensors.

Velocity(V) = Velocity of sound at sea level at room temperature

Time(T) = Travel time of sound wave

Distance(DT) = (V* T) / 2

Velocity = 343 m/s or 34300 cm/s

*Distance(DT) = 17150 * time (in cm)*

Equation 1: Distance Calculation

Equation-1 shows the way of calculating distance of an object through the ultrasonic sensor. Temperature is also a factor in the velocity of sound wave. Since it's effect on distance calculated is negligible, temperature can be taken as room temperature considering the idle case. [12]

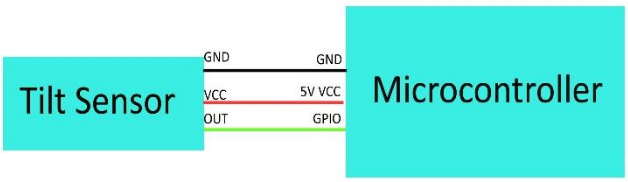

Figure 4.1.4: Interfacing of Tilt Sensor

Figure shows the interfacing of tilt sensor with the microcontroller. VCC and GND pin out from sensor are connected to 5V VCC and GND of microcontroller respectively, while OUT pin is connected to the GPIO.

Tilt sensor responds to change in it's orientation through the OUT pin. The application of tilt sensor which we've used in the approach is to detect the shock which results in the confirmation of the roughness detected.

Metallic ball tilt sensor was used in the proposed approach to catch the abrupt change in the orientation of the moving vehicle. This tilt sensor is unaffected by temperature, humidity, or mechanical misalignment.

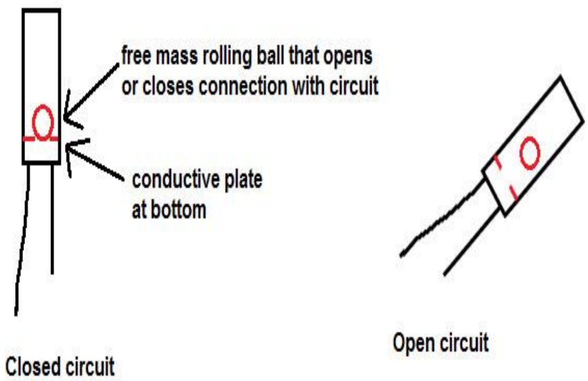

Figure 4.1.5: Working of metallic ball tilt sensor

Figure shows the working of tilt sensor. When the tilt sensor is at 0°, the metallic ball is in the center of the electrodes and output of sensor pin remains 0, as the distance between the electrodes and metallic ball increases the circuit goes open and output pin gives output as 1.

Tilt sensor is mounted on the bottom of the vehicle. When the vehicle goes into the pothole or crack, abrupt change in orientation of vehicle occurs which is captured by the tilt sensor.

4.2. Software implementation

After interfacing sensors with microcontroller, software implementation needs to be done which includes the analysis of sensor data and decision making.

Two type of sensor data is there in the proposed approach, one which comes from the ultrasonic sensors and the other which is taken from the tilt sensor. Based on this data, decision making is performed.

GPS data is used after the analysis part for updating the records. GPS data is also useful in pre-warning the operator from previously detected roughness on the same location. GPS data includes longitude and latitude of the location.

Movement of vehicle is simultaneously controlled through the signal provided by operator using the wireless keyboard.

Distance Calculation

```
GET_DISTANCE (SENSOR)
TRIG ← SENSOR.TRIG
ECHO ← SENSOR.ECHO
TRIG ← HIGH
sleep (SETTLE_TIME)
TRIG ← LOW
while (ECHO is LOW):
    start ← time ()
while (ECHO is HIGH):
    end ← time ()
Travel_Time ← end – start
Distance ←
    17150 * Travel_Time
return Distance
```

Above is the algorithmic approach for getting distance of road surface from the ultrasonic sensors mounted at the bottom of the vehicle.

When receiver starts receiving the sound wave reflected back from the surface, a rising edge occurs in the output of ECHO, when this wave ends, a falling edge occurs. Time duration between these two edges is calculated which is the total travel time of the pulse. Then Distance is calculated using Eq. 1.

The calculated distance is then compared with the maximum threshold distance which includes the height of sensor from the road surface and minimum roughness depth above than which device is going to respond.

If the distance calculated is greater than the maximum threshold distance, it means there is probability of roughness below this sensor.

Since there are chances that sound wave may reflect at critical angle and go away from the receiver. In that case also the distance will be greater than the threshold distance but this may not be the case of roughness.

To handle this, both the distances computed from parallelly mounted sensor are compared with the maximum threshold distance, if both of them come greater than the threshold, then only assurance of roughness is made, otherwise prediction is made for roughness which includes light indicators and system waits for the shock detection through tilt sensor for a period of time.

If output of tilt sensor goes high during this time period then only confirmation is made and vehicle stops for updating the record otherwise the prediction is simply ignored and vehicle moves on it's path.

Roughness Detection

```
GET_ROUGHNESS (SENSORS [])
LEFT ← SENSORS[LEFT]
RIGHT ← SENSORS[RIGHT]
TILT ← SENSORS[TILT]
OUT ← TILT.OUT
DIST-L ←
    GET_DISTANCE (LEFT)
DIST-R ←
    GET_DISTANCE (RIGHT)
DEPTH ←
    MAX (DIST-L, DIST-R)
DEPTH ← DEPTH - HEIGHT
MAX_THRESHOLD ←
    HEIGHT + MIN_DEPTH
if DIST-L and DIST-R both less
than the MAX_THREHOLD:
    return FALSE
else if DIST-L and DIST-R both
greater than the
MAX_THRESHOLD:
    return DEPTH
else
    for i in range (10):
        sleep (INTERVAL)
        if OUT is HIGH:
            return DEPTH
return FALSE
```

Above is the algorithmic approach for detecting roughness and measuring it’s depth through the combined output of two parallel ultrasonic sensors and tilt sensor.

Whenever roughness is detected, vehicle stops, indicators are turned on indicating the roughness detected to the operator. Location is fetched via GPS sensor. If this location is not already there in the database, then this location is added to the database along with the depth calculated using the discussed approach.

When analysis of a road segment gets completed and operator shuts down the analysis process, automatically a custom map is generated with the data recorded in the database.

Custom map includes markers to the locations where roughness was detected for a quick review of overall analysis process.

5. Working of model

Model requires two separate power supplies – 5V and 12V. Power bank is used for 5V supply while DC battery is used for 12V supply. 5V DC supply is for microcontroller while 12V supply powers the motors.

After turning on the power switches movement of vehicle is controlled through the external keyboard and vehicle detects roughness in it’s path as expected.

6. Results

The working of our model was tested on the Roads near the boys hostel premises of IIIT Allahabad, the Rural area beside IIIT-A premises and in the premises of IIIT Allahabad. Table and map shows the detected roughness on the way of vehicle model.

Figure 7.1: Map with markers to the roughness locations detected

Table 1: Data Collected

Longitude	Latitude	Depth
81.771910	25.429283	2.13
81.769917	25.432374	2.50
81.769824	25.432670	2.10
81.770078	25.432982	2.42
81.769696	25.432873	2.98
81.770083	25.432963	2.23
81.770728	25.432711	3.12
81.771220	25.432555	2.54
81.769398	25.432541	2.01
81.769302	25.432427	3.01
81.769288	25.432407	3.12
81.769014	25.432069	2.56
81.768888	25.431994	2.76
81.768695	25.431760	2.31
81.769049	25.429783	2.21
81.769201	25.429716	2.01
81.769701	25.429420	2.09
81.769851	25.429379	3.12
81.770079	25.429301	2.12
81.770089	25.429301	2.09
81.771009	25.428872	2.67
81.771201	25.428763	3.06
81.771468	25.428640	2.56

7. Conclusion

After analyzing the results and work done so far, we conclude that the model is a cost-effective implementation of the road roughness analyzing system for rural and district roads and provides a user-friendly interface. Model vehicle successfully detected the roughness on it's path with an accuracy of 80% and analyzed it's depth with error < 0.30 cm.

8. Future Work

Prototype can be extended to use a high-end camera for detecting the possibility of roughness several meters ahead which will surely increase the accuracy of the system as well as delay will be reduced.

Currently model focuses on four-wheeler vehicles which can be further extended to automatic drones which will automatically determine the roughest path ahead using the image processing technique and analyze that particular part of the road only. Data-Hub points can be made which will do the error checking and error correction as well for the generated data by analyzing vehicles and after that process only the data will be updated to database server.

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