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An Efficient Algorithm for Roadways Obstacles Detection using Smartphone in Infrastructure-less Environment

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Abstract**: *Apart from having smart systems in modern vehicles, roadways traffic positions in infrastructure-free environment are in various ways not suitable for driving which causes roadways accidents. Smart systems are costly, training and maintenance is not practiced by all, hence they are not useful for vehicles running in infrastructure-less environment. Modern days Smartphone are multifunctional, easily operated and consists of numerous sensors, can be utilized for roadways obstacles detection in infrastructure-less environment. In this study, we proposed an efficient algorithm depth learning approach for roadways obstacles detection using Smartphone which is useful for planned as well as unplanned roads. In this, road information is collected using Smartphone accelerometer sensors, data normalization take place using Euler angle method and location determination of obstacles take place using space interpolation method. In comparison to other same type of approach, our algorithm is efficient and cost-effective.***

Keywords**: *Roadway obstacles, Smartphone sensors, infrastructure-less environment, obstacle detection.***

I. INTRODUCTION

In infrastructure-less environment, driving is complex, and roadways vehicle driver must continuously to be aware to protect themselves from accidents. Researchers have designed smart systems, having multiple sensors, which help to handle various traffic situations [4]. Most of the R&D approaches is adding smart sensing features to the roadways vehicles, mainly in high range vehicles, but these systems are costly and not easy to use.

Modern Smartphone are advanced, rich in capacity and capability. Therefore Smartphone can be used for computer vision based driver support system. Some researchers have been developed some methods to identify road conditions using Smartphone sensors [6-10]. The Smartphone based techniques don't need to install special type of sensors in roadways vehicles. Such techniques also have high level scalability benefits as Smartphone users increasing at very fast rate. The existing Smartphone based approaches can be optimized to develop efficient algorithms for roadways obstacles detection and tracking using Smartphone. Some Smartphone based driving support system applications developed are iOnRoad, Drivea, SpeedBump and Movon FCW.

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II. BACKGROUND

The most useful method for identifying roadway obstacles is using numerous sensors to identify the vibration patterns of roadways vehicles causes through obstacles on the road. Most of the work is carried out using Smartphone sensors for gathering road uneven data to identify road obstacles. Due to Smartphone user increase, Smartphone sensors based algorithms are being developed. Smartphone based methods uses two most useful sensors, accelerometer and GPS, to gather the roadways data for further analysis. In following segment we are going to discuss some of the Smartphone sensor based methods used for identifying roadways obstacles:

Nericell [6] Smartphone application uses to monitor roadways and traffic situations. It identifies bumps, potholes, honks, and braking events through Smartphone accelerometer, GPS, microphone and GSM radio sensors. Braking events are identified through analysis of y-value of Smartphone accelerometer sensor. Bumps events are identified using analysis of z-value of accelerometer. Using microphone data of Smartphone it also identifies honks. An Android OS based Smart system proposed by Mednis et al., [7] uses accelerometer sensor to identify roadways potholes. It identifies events in automatic way and also gathers the obstacles data for passive post-operation. The obstacles data is gathered through Smartphone accelerometer sensor. In his approach total four algorithms have been developed for pothole detection. Wolverine [8] system is Smartphone sensors based application used for roadways bump detection and monitor traffic in real time. This system also utilize accelerometer sensor to gather the obstacles data (braking and bump event). Another approach which utilizes Smartphone accelerometer, microphone and GPS sensor is developed by Singh et al., [9] that identify roadways obstacles data and driver behavior in real time. As we can see that most of the above approaches is based on accelerometer and GPS sensor to gather the roadways data.

Some of the above methods are machine learning algorithms based whereas some or not.
Following table I summarize the above approaches based on some parameters.

Table-I: Summarization Of Some Of The Previous Approaches

Method	Sensors	Smart phone Used	Machine Learning Impleme-ntation	Accuracy
Nericell [6]	Accelero meter, Microph one, GPS, GSM	Yes	No	False-negative=11.1% False-positive= 22%
Pothole detection through Smartph one (android) [7]	Accelero meter	Yes	No	True-positive=90%
Wolverin e [8]	Accelero meter, Microph one, GPS	Yes	Yes	False-negative=10% (for roadways bump event detection) and false-negative =21.6% and false-positive=2.7% (for roadways braking event detection)
Driver behavior analysis using Smartph one [9]	Accelero meter, GPS, microph one	Yes	Yes	False-negative=10.5% False-positive= 19%

III. LIMITATIONS OF EXISTING APPROACHES

Some researchers have been given their best effort to detect roadways anomalies and for that some Smartphone sensors based methods have been developed but a most trusted and cost effective approach is still needed. The existing methods are useful but they have some limitations and no method can completely work alone for handling all types of obstacles situations.

- There are various events such as railroad crossings, door slams, expansion joints etc. which are not road anomalies and such events are to be treated as non-potholes events and therefore differentiation is required.
- It is not necessary that a road anomaly give same pattern of data every time during each drive. An efficient algorithm is required that handles all situations.
- Sometimes GPS gives error contained longitude and latitude data of anomaly location. There is chance to not collect exact GPS data due to various environmental condition such as tunnels, high building, shady trees etc. [11]. An efficient approach to reduce such types of error is not available.
- Sensor data is generally heavy as it contains graphical data, sometimes due to congestion in network it is possible to delay in saving sensor data or data may loss. Therefore it is necessary to improve the efficiency of algorithm that support to minimum use of network which can reduce communication cost.
- Sensor data contains location data which can be accessed by other users which may cause privacy breaches. Therefore it is necessary to enhance the security features in algorithm that protect user's data from unauthorized and illegal uses.
- Most of Smartphone based systems use threshold based classification only few algorithms have machine learning implementation. Machine learning implementation has better efficiency in handling roadway anomalies therefore existing algorithms should be updated with machine learning implementation

IV. SMARTPHONE BASED ROADWAYS OBSTACLES DETECTION: DEPTH LEARNING APPROACH

Our proposed mobile sensing based roadways obstacles detection approach consists of four steps: (1) data collection using Smartphone accelerometer (2) accelerometer data normalization, (3) roadways anomalies detection and (4) anomalies location determination.

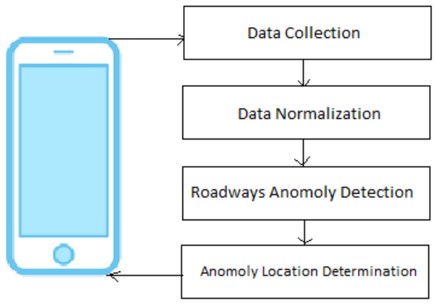

Fig. 1: Roadways Obstacles Detection Method

A. Data Collection

In our approach data collection take place using Smartphone accelerometer sensor using Smartphone app. The x, y and z values of accelerometer sensor are fetched by internal services of Smartphone and shown in fig. 3. Data collection takes place at the rate of 5 readings in a second. The Smartphone is kept on vehicle dashboard in the mode of portrait as displayed in fig. 2.

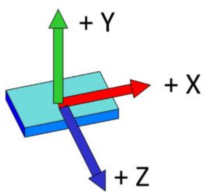

Fig. 2: Orientation of Accelerometer in Smartphone

In our approach X-axis denotes in forward direction, Y-axis denotes in upside and Z-axis denotes in sky perpendicular to down side. The recorded raw values using accelerometer sensor are kept in Smartphone's memory in a file .txt format.

Fig. 3: Data Collection User Interface

B. Accelerometer Data Normalization

Earlier *obstacles* detection approaches have following limitations: (1) The Smartphone should be kept in specific way and in specific angle. (2) While detecting obstacles, mostly high false positives are generated (3) the actual obstacles location is not investigated.

Therefore, we proposes a Smartphone sensing based anomalies detection approach which collects and normalize the accelerometer senor data on the establishment of free angle. We also propose an efficient algorithm for roadways anomalies detection which uses space interpolation technique to determine actual obstacle location. Our proposed approach uses Euler angle method to process and normalize three-axis data of accelerometer because Euler angle method helps in obstacles detection from any angle. Euler angles method represent the vector data in 3-D Cartesian coordinate three attributes and it represent a succession of 3 attribute rotations. For easy computation the 3-D Euclidean coordinate data can be represented in homogeneous coordinate system. The data of Smartphone accelerometer is represented as {x, y, z}. The Smartphone system rotated by angle ɵ about x-axis, now y-axis is at angle ɵ degree respect to y-axis and z-axis is at angle ɵ degree with respect to z-axis. According to Euler angle methods, the value of vector set data {x', y', z'} is calculated by taking the value of vector set data {x, y, z} and angle ɵ. Similarly, the vector of other two y and z can is calculated Euler angle methods when the Smartphone system rotates angle ϕ through y-axis and by angle α about z-axis.

In this study the baseline is referred when the vector of every axis with angle 0 degrees. The relationship of calculating baseline vector of rotation about x-axis can be represented in scalar form as:

$$\left.\begin{aligned} x' &= x \\ y' &= y*\cos\theta + z*\sin\theta \\ z' &= y*\text{-}\sin\theta + z*\cos\theta \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

In homogeneous coordinate system the above relationship can be represented as:

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & \sin\theta & 0 \\ 0 & -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \ldots\ldots\ldots\ldots(2)$$

The relationship of calculating baseline vector of rotation about y-axis can be represented in scalar form as:

$$\left.\begin{aligned} x' &= x*\cos\phi + z*(-\sin\phi) \\ y' &= y \\ z' &= x*(-\sin\phi) + z*\cos\phi \end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

In homogeneous coordinate system the above relationship can be represented as:

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\phi & 0 & -\sin\phi & 0 \\ 0 & 1 & 0 & 0 \\ \sin\phi & 0 & \cos\phi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \ldots\ldots\ldots\ldots\ldots(4)$$

The relationship of calculating baseline vector of rotation about z-axis can be represented in scalar form as:

$$\left.\begin{aligned} x' &= y*\cos\alpha + y*\sin\alpha \\ y' &= x*(-\sin\alpha) + x*\cos\alpha \\ z' &= z \end{aligned}\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

In homogeneous coordinate system the above relationship can be represented as:

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\alpha & \sin\alpha & 0 & 0 \\ -\sin\alpha & \cos\alpha & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \ldots\ldots\ldots\ldots\ldots(6)$$

C. Anomaly Detection Approaches

Our proposed approach is based on the applications of following three obstacle detection methods and our approach is a combined improvement of these approaches which are summarized as follows:

(i) Z-THRESH

It considers z-axis lowest value of Smartphone accelerometer collected data as threshold value to identify obstacles. When Smartphone is laid horizontally then z-axis value of accelerometer data is 9.8 m/s^2 but when accelerometer dropped off the z-axis value is lower than 9.8 m/s^2 which specifies obstacles. It generally detects potholes on road. The threshold value is obtained as:

$$\theta_1 = \max_{a=1,1\le p\le n,p\in N} \; \min_{e_p\le q\le l_p, q\in N} g_{a,p,q} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

And mathematically the function for obstacle detection is specified as:

$$f_1(g_{a,p,q}) = \begin{cases} 1, if g_{a,p,q} \le \theta_1 \\ o, others, \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

Where a= 1, 1 ≤ p ≤ n, p∈N, q ≥ 1, q∈N.

(ii) G-ZERO

This method accepts 3-axis data of accelerometer and chooses a lower bound of 3-axis data and upper bound of 3-axis data to identify obstacles. When a vehicle goes through an obstacle then 3-axis data is recorded and based on recorded data lower and upper bound is calculated. The lower bound and upper bound is represented using $\theta_{2,1}$ and $\theta_{2,2}$ and obstacle detection function is represented using $f_2(g_{a,p,q})$.

The lower bound value is:

$$\theta_{2,1} = \min_{a\in\{1,2,3\},1\le p\le n,p\in N}\ \max_{e_p\le q\le l_p,q\in N} g_{a,p,q} \quad\text{....................(9)}$$

The upper bound value is:

$$\theta_{2,2} = \max_{a\in\{1,2,3\},1\le p\le n,p\in N}\ \min_{e_p\le q\le l_p,q\in N} g_{a,p,q} \quad\text{....................(10)}$$

And mathematically the function for obstacle detection is specified as:

$$f_2(g_{a,p,q}) = \begin{cases} 1, if\ \theta_{2,1} \le g_{a,p,q} \le \theta_{2,2} \\ 0, others \end{cases} \quad\text{....................(11)}$$

Where a = {1, 2, 3}, $1\le p\le n$, $p\in N$, $q\in N$.

(iii) Street Bump System

It is an iPhone application based obstacles detection system. To locate roadways obstacle data it uses Smartphone accelerometer sensor and GPS sensor. In this method the roadways information is collected using 3-axis accelerometer sensor and GPS sensor. The mobile phone is kept near steering of vehicle in stable position and reads 3-axis accelerometer and GPS data. It marks a forthcoming obstacle as bump if speed of vehicle exceeds 8 km/hour and accelerometer sensor record 0.4 g or more in z-axis as an absolute value reading. After that it sends the identified obstacle location on central server for further processing.

Let δ (k) be actual accelerometer data a particular time k when a bump is approaching. Let ξ (t) is the amplitude difference recorded in two consecutive time steps:

$$\xi(t) = \delta(k) - \delta(k-1) \quad\text{..................................(12)}$$

To magnify the amplitude increments a differential signal is defined which is represented as Δ-signature filter.

$$f_3(g_{a,p,q}) = \Delta(t) = \begin{cases} \Delta(t-1) + \xi(t), if\ \xi(t)\xi(t-1) > 0 \\ \xi(t), if\ \xi(t)\xi(t-1) \le 0 \\ 0, if\ \xi(t) < c \end{cases} \quad (13)$$

Pseudo code for Proposed Roadways Obstacle Detection Approach

This study proposes Smartphone accelerometer based obstacle detection method which is combined version of above three approaches, i.e., Z-thresh, Z-zero and street bump system. In this approach the proposed algorithm reads inputs as three-axis accelerometer sensor data and output of algorithm is 1 when vehicle passes through an obstacle. The algorithm for proposed obstacle detection approach is given below.

Input: $g_{a,p,q}$, where a = {1, 2, 3}, $1 \le p \le n$, $p \in N$, $q \in N$

Output: When a vehicle passes through an obstacle then the output value of proposed obstacle detection approach is 1.

```
Set evaluate_function = 0
Set evaluate_period = 0
do
    if(t_p,q-evaluate_period) > ε seconds then
        evaluate_function = 0
        evaluate_period = 0
    end if
    if f1(g_a,p,q) = 1 then
        if evaluate_function = 0 then
            evaluate_function = 1
            evaluate_period = t_p,
        else if evaluate_function = 4 then
            return 1
        else
            evaluate_period = t_p,
        end if
    end if
    if f2(g_a,p,q) = 1 then
        if evaluate_function = 0 then
            evaluate_function = 2
            evaluate_period = t_p,
        else if evaluate_function = 1 then
            return 1
        else
            evaluate_period = t_p,
        end if
    end if
    if f3(g_a,p,q) = 1 then
        if evaluate_function = 0 then
            evaluate_function = 3
            evaluate_period = t_p,
        else if evaluate_function = 1 then
            return 1
        else
            evaluate_period = t_p,
        end if
    end if

while(q ∈ N)
```

In the above algorithm, the evaluate_*function* parameter is used to test whether the output value of $f_1(g_{a,p,q})$, $f_2(g_{a,p,q})$ or $f_3(g_{a,p,q})$ is 1. When any one of *Z*-THRESH, Street Bump System or *G*-ZERO approaches consider that the vehicle passes through an obstacle, the value of timestamp t_p is marked and make tally with the evaluate_*period* parameter. The output value is 1 if difference of $t_{p,}$-evaluate_period is less than ε seconds that means an obstacle is identified. After that, the evaluate_*period* parameter can be learned and trained using previous data from every practical run of vehicle.

D. Anomaly Location Determination

Our approach employs space interpolation technique to obtain exact obstacle location. In figure given below two locations L_1 and L_2 and their timestamps t_1 and t_2 obtained through Smartphone GPS and taken as input for space interpolation technique to obtain the anomaly location.

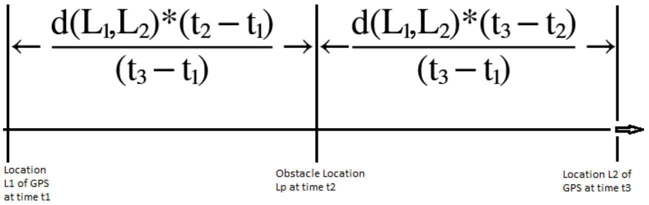

Fig. 4: Anomaly Location Determination Using Space Interpolation Technique

The function $d(L_1, L_2)$ specify the distance between location L_2 from L_1. Hence, the anomaly location L_p can be specified as:

$$d(L_{1,}L_p) = \frac{d(L_1, L_2)*(t_2 - t_1)}{(t_3 - t_1)}, \ldots\ldots\ldots\ldots\ldots\ldots(14)$$

$$d(L_{2,}L_p) = \frac{d(L_1, L_2)*(t_3 - t_2)}{(t_3 - t_1)}$$

V. EXPERIMENTAL RESULTS

In the present section we analyse the experimental results obtained by Smartphone accelerometer data normalization, obstacle detection techniques, and obstacle location determination.

A. Data Normalization Analysis of Smartphone Accelerometer

To perform data normalization analyses of Smartphone accelerometer, we considered two cases which include (1) The Smartphone kept on dashboard as flat having 0^0 angle for baseline (as display in Figure 5) and (2)the Smartphone with -30^0 angle ((as displayed in Figure 6). To proper verify the difference of baseline of case1 and case2 Smartphone z-accelerometer recorded data t-test method and f-test method [12] are used.

Fig. 5: A Case Study Of The Mobile Device As A Baseline With 0^0 Angles

In this approach we uses 2-tailed *t*-test to investigate significance of differences in mean value of Smartphone *z*-axis accelerometer recorded data of base 1 baseline (i.e., $\mu_1= -9.8489$) and mean value of Smartphone *z*-axis accelerometer recorded data after normalization of Smartphone accelerometer data in Case 2 (i.e., $\mu_2= -9.8463$). We have taken 60 sample sizes for Case 1 and 60 sample sizes of Case 2. Subsequently, we have also used f-test toinvestigate significance of differences in variance of Smartphone *z*-axis accelerometer data for case 1 baseline (σ_1^2=0.000077) and variance of normalized Smartphone *z*-axis accelerometer in Case 2 (σ_2^2= 0.000095).

Fig. 6: A case study of the mobile device as a baseline with -30^0 angles.

In table II result of t-test method and f-test method for population means and samples variance of case study 1 and case study 2 is shown.

The results of experiments show that the finding is *null hypothesis* (H0: $\mu_1= \mu_2$) in *t*-test is collected, and *null hypothesis i.e.* (H0: $\sigma 1 = \sigma 2$) for f-test is also received. Hence, we can say that to normalize Smartphone accelerometer recorded data Euler angle formula is best fit for angle free establishment.

B. Accuracy Analysis of Obstacles Detection Approach

To analyze the accuracy of obstacles detection approach, we select a roadways pothole having (length size: 58 cm; breadth size: 41 cm; and depth size: 7 cm) as an experimental case (displayed in Figure 7) and total 12 runs in testing environment. The G-sensor in Smartphone having the mean frequency value of accelerometer data recorded is about to 124 count/seconds. The *k*-fold cross-validation approach [12] is used to test the accuracy of obstacles identification approach. In our experiments, the process of training and testing have done 12 times (i.e., *k* =12). In repetition *i*, the value of accelerometer data in p^{th} run is taken as test corpus value, and the value of accelerometer recorded data in other iteration is in whole used to train the value of thresholds for each approach. The comparative result of various obstacles detection approach (*Z*-THRESH, *G*-ZERO, Street Bump System and our proposed approach) is shown in Table III. The results indicate that our proposed approach is most useful and can fairly detect obstacles without any false-positives and its accuracy is about 95%.

C. The Error of Anomaly Location Determination

To analyze the error of obstacles location finding, our method uses the Smartphone accelerometer recorded data and obstacles location data from 12 runs which test the SI (Space Interpolation) technique. The outcomes indicate that the obstacles location determination error is minimized from 16.57 meters to 10.73 meters when space interpolation technique is used.

Fig. 7: A Case Study Of The Mobile Device With −30 Degree Angle.

Following table-II shows standard deviation of Smartphone accelerometer of two baselines and table-III shows false positive of above considered approach.

Table-II: Test Results Of Normalized Smartphone Accelerometer Data

Baseline (angle degree)	Standard deviation of Smartphone accelerometer
angle degree=0	0.000077
angle degree=-30 (after normalization)	0.000095

Table-III: False-Positive Value Of Above Considered Obstacle Detection Method

Obstacles detection approaches	Approach 1	Approach 2	Approac h 3	Proposed Approach
False-positive	50	41	75	5

Following chart shows comparative results of some obstacle detection approach.

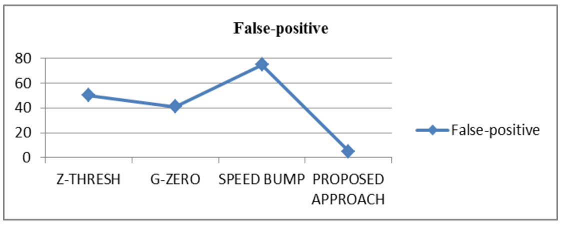

Fig. 8: False-positive of different Smartphone based obstacle detection approaches

VI. CONCLUSION AND FUTURE WORK

In this study a real time Smartphone obstacle detection method which is based on Smartphone accelerometer and GPS based sensing is proposed. To normalize the Smartphone accelerometer data we use Euler angle method which works in angle free establishment. Our approach is a combined version of Z-THRESH, G-ZERO and speed bump system which reduces the false-positives of obstacle detection. To precisely locate the obstacles we use spatial interpolation technique in our method which gives 95% accuracy. Our proposed approach is useful for Intelligent Transportation System because it improve the safety on road. Limitation of our approach is sample size. In future, to analyze and get more accurate results the sample size may be increased. Our proposed approach is Smartphone sensor based; hence limited battery capacity is another drawback. In future work we will produce a green obstacle detection approach which solves the issue of limited battery capacity and computation power.

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