Fuzzy Inference System for Speed Bumps Detection Using Smart Phone Accelerometer Sensor

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***Abstract*—Recently, a significant amount of research attention has been given to monitoring the road surface anomalies such as potholes and speed bumps. In this paper, speed bump detection method based on a fuzzy inference system (FIS) is proposed. The fuzzy inference system detects and recognizes the speed bumps from the variance of the vertical acceleration and the speed of the vehicle. The proposed method utilizes the embedded sensor (accelerometer) in the Smartphone. The proposed method is tested and evaluated under different speed levels. The results show that the proposed method is promising for bumps detection.**

***Index Terms*—Fuzzy Inference System; Road Monitoring; Smartphone; Vertical Acceleration.**

I. INTRODUCTION

Road network represents the core of recent transportation facilities; it connects small villages, cities and even countries. The road surface condition is crucial for driving safety. In order to maintain safe conditions [1], monitoring the road surface anomalies such as potholes and speed bumps has received a significant amount of research attention [1]-[6]. The speed bump is a vertical deflection of the road used to reduce the vehicle speed. It is used for enhancing and improving the safety on the roads. They are designed according to standards to make the road safe for both drivers and vehicles. Speed bump detection and recognition help in many aspects such as: alerting the drivers before approaching the speed bump, building a speed bumps maps and helping the government in regular maintenance plans. Furthermore, it helps in classification of the type of the bump whether it is standard or not.

Mobile sensing technology can be utilized to enable the road users to participate in the road surface monitoring, which is considered as a crowd sourcing. Most of the smartphones are equipped with motion sensors such as accelerometer sensor. Accelerometer sensor reads the linear acceleration in the three perpendicular directions.

In the light of the aforementioned facts, a new approach is developed for speed bump detection using vertical acceleration signal. The approach relies on the fact that the vertical vibration of the vehicle crossing the speed bump differs from that at other parts of the road. Several methods in the literature have used the vertical vibration for the detection. However, the vibration magnitude highly depends on the speed of the vehicle. Therefore, it is vital to consider the speed along with the vertical vibration. It is difficult to find a mathematical model that represents the relation between the speed, vertical vibration and the detection. Due to the noisy sensors, uncertainty, and unpredictable factors that may affect the accuracy of the detection and due to the merit of the fuzzy logic, which can overcome the drawbacks, a speed bump detection method based on fuzzy logic is considered in this paper. The fuzzy inference system combines the effect of the vibration and the vehicle speed, which represents the main contribution of this paper.

The rest of the paper is organized as follows. The related works are all discussed in Section II. Section III shows the data collection setup. Then, the proposed approach is discussed in Section IV. In Section V, the design of the fuzzy logic system is presented. Section VI shows the evaluation and the results. Section VII concludes the paper.

II. LITERATURE REVIEW

Recently, road condition monitoring has gained a significant amount of research attention. Researchers have proposed different approaches in order to detect speed bumps and potholes. Many of these methods are relying on utilizing smartphones' sensors due to their pervasiveness[1]-[6]. Many of these approaches are threshold-based [1],[6]-[14].

In[1] , two sets of threshold were used for the vehicle moving at a high speed and a low speed. However, the determination of the threshold value is still unclear. An algorithm was developed based on the high-energy events analysis of the acceleration signal [2]. In [3], their approach relied on the relation between road anomalies dimensions and the acceleration peak values without considering the speed of the vehicle. In [4], authors adopted a model based adaptive threshold method to detect bumping events. They scanned the high pulse in the waveform then analyzed the following waveform for confirmation of the detection. The standard deviation of the vertical acceleration is calculated for different speeds and represented in a lookup table in advance. Thus, all of their results are completely depends on the conditions of their experiments.

In [6] and [7], the bump can be recognized if the speed of the vehicle is greater than a certain value and the acceleration is higher than a specific threshold along the z-axis. Then the bumps are classified into actionable or non-actionable bumps based on some features. Thus, the authors exclude the effect of the speed of the vehicle. In order to detect the potholes, an approach was presented in [8] using the data mining techniques. A pass band filter was used to remove the noise from the accelerometer data. After that, some features are extracted, such as mean, peak-to-peak ratio, root mean square, standard deviation, variance, power spectrum density, and wavelet packet decomposition. However, the computation complexity is the main drawback of this technique.

Z-Threshold, Z-DIFF, STDEV (Z), and G-ZERO techniques are presented in [9] to detect the pothole. Z-Threshold depends on the values of the acceleration of Z-axes. Z-Difference computes the difference between each two consecutive measurements above a specific threshold. STDEV (Z) computes the standard deviation of vertical axes acceleration. G-ZERO uses a tuple of the three axes acceleration which has value below a threshold level

In [10], some image processing techniques such as Gaussian filtering and Median filtering have been applied in order to detect the speed bumps. The approach depends on the image which is captured by the camera that is locating in front of the vehicle. The approach alerts the end users in real time before they reach the speed bumps. However, relying on the camera seems to be an impractical solution due to the lack of this camera in most of the cars.

It can be seen from the above that most of the existing techniques neglect the effect of vehicle speed. Some approaches considered the speed effect on the vibration of the vehicle, but their approaches lack of having an appropriate and simple model that represents the speed effect. In this paper, a speed bump detection method based on fuzzy logic is presented. The fuzzy inference system combines the effect of the vibration and the vehicle speed, which represents the main contribution of this paper.

III. DATA COLLECTION AND SET-UP

Acceleration data is collected from Android smart phone using MPU-6K application. The smartphone is mounted and oriented to the chassis of the vehicle. Thus, it is assumed that the information about Z-axis position of the accelerometer is known. The sampling rate of the acceleration data is 82 Hz. Data is collected for a one standard speed bump for different speeds using Toyota Prius Sedan car. The dimensions of the bump are as shown in Figure 1. Figure 2 illustrates the vertical component of the acceleration time series for different speeds. It is obvious that the peaks values of the acceleration depend on the speed of the vehicle. Thus, using the peak threshold technique to detect the speed-bump is inefficient as the peak threshold must be adaptive to the speed of the vehicle.

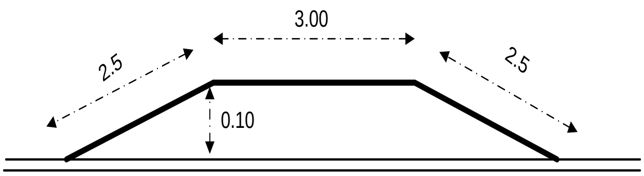

Figure 1: Dimensions of the pump: [all units are in meter].

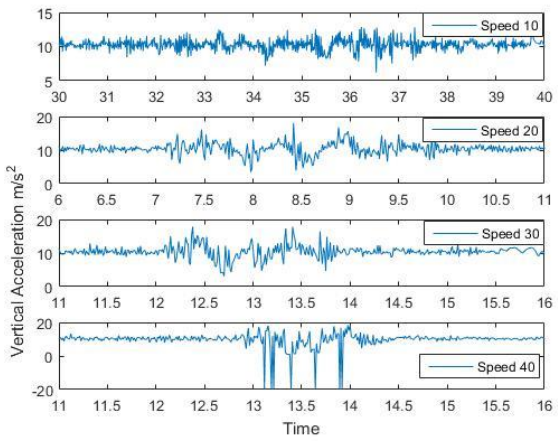

Figure 2: Vertical component of the acceleration time series for different speeds.

IV. THE PROPOSED APPROACH

This section presents the details of the proposed approach. Figure 3 shows the system architecture for the proposed approach. The system works as follows: the vertical component of the acceleration signal is derived from the Smartphone accelerometer sensor, and then a high pass filter is performed in order to preprocess the data and remove the noise and outliers. The system calculates the signal variance, which represents the first input of the fuzzy logic while the second input is the vehicle speed. The output of the fuzzy logic is the bump detection result.

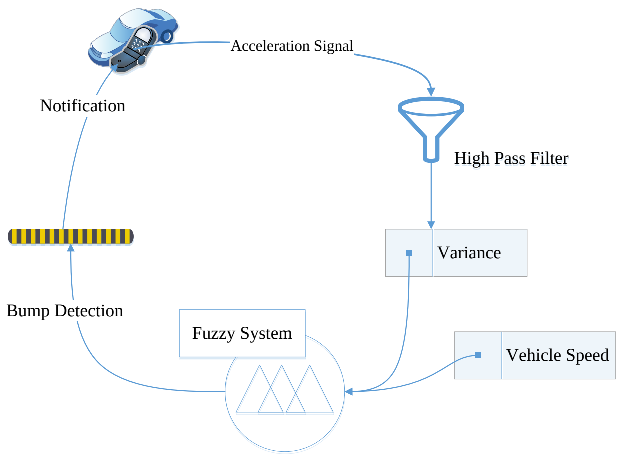

Figure 3: the system architecture for the proposed detection approach.

As the acceleration's variance depends on vehicle speed, which is shown in Figure 4. The figure shows how the variance is dependent on the speed. Therefore; bump event cannot be detected by measurements with variance value above a specific threshold level. According to this, the variance of vertical axis acceleration is combined with the vehicle speed in one system to detect the bump event. For more illustration, Figure 5 reflects the relationship between the maximum vertical acceleration variance at the bump with the vehicle speed.

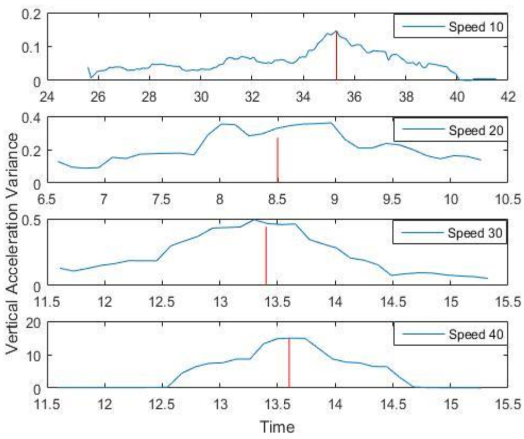

Figure 4: Vertical acceleration variance at different speed

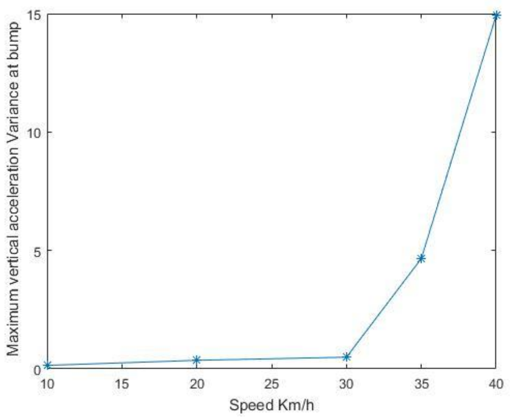

Figure 5: Relationship between the maximum vertical acceleration variance and vehicle speed

V. Fuzzy Inference System Description and Evaluation

Fuzzy logic is an effective way to represent, interpret, and compute vague and subjective information. Fuzzy reasoning provides an inference technique that derives conclusions from known facts and a set of fuzzy if–then rules. The structure of fuzzy system includes four components: Fuzzifier, Inference Engine, Knowledge Base, and Defuzzifier. The Fuzzifier translates crisp value inputs into fuzzy values. The Inference Engine is the part that controls the process of deriving conclusions. It applies a fuzzy reasoning mechanism to obtain a fuzzy output using rules and the fuzzy. The Fuzzy Inference System follows Mamdani fuzzy model. The Knowledge Base contains a set of fuzzy IF-THEN rules and a set of membership functions of fuzzy sets. The Defuzzifier converts the fuzzy output into a crisp value that best represents the out fuzzy set. The Defuzzifier uses the center of gravity scheme. The implication methods used in the proposed system are min (minimum), which truncates the individual output fuzzy sets, and max (maximum), which scales the resulted output fuzzy sets. The input to the implication process is a single number given by antecedent.

The idea behind this system is to utilize fuzzy logic to detect the speed bumps. The detection is based on the vertical component of the accelerometer sensor readings. The system consists of a fuzzy system where the output is either true or false. The inputs are the acceleration variance and the vehicle speed as shown in Figure 6.

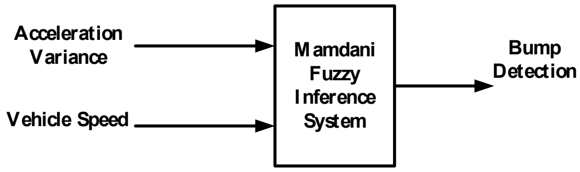

Figure 6: Block Diagram of the fuzzy inference system

The system consists of two inputs called vibration variance (VV) and vehicle speed (VS). The output is bump detection result (BD).VV is the variance of accelerometer data in the vertical direction over a specified window size. The corresponding membership functions of the input and output variables are shown in Figure 7, Figure 8, and Figure 9, respectively.

For each linguistic variable, a combination of membership functions is defined. Sufficient overlapping degree between the membership functions is ensured to obtain a smooth output relationship. The first input for the first fuzzy system is the acceleration variance. It has four membership functions as in Figure 7. The value of the acceleration is scaled according to a logarithmic function that is represented by Figure 10. The second input is the vehicle speed; it has three membership functions as in Figure 8. It is scaled by dividing it by the maximum speed.

The fuzzy system is evaluated for two different speeds and the results are shown in Figure 11. The fuzzy system detects the bump over the whole width of the bump. The detection of the bump event accuracy is high at the middle of the bump. However, the width of detection area shows some error for high speed. This can be mitigated by a proper tuning of either fuzzy membership function or the parameter of the scaling functions.

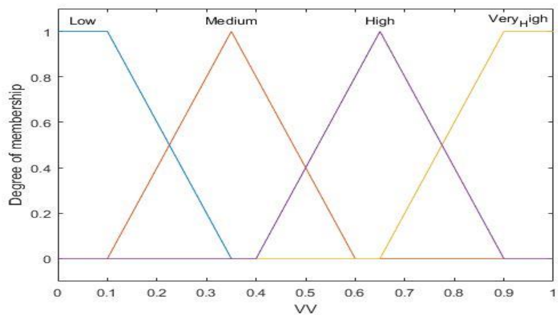

Figure 7: Membership Functions of the Vibration Variance (VV)

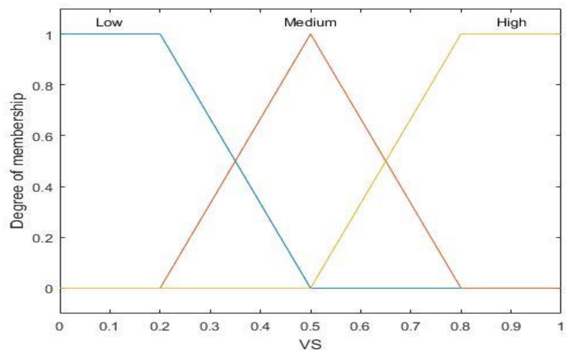

Figure 8: Membership Functions of the vehicle speed

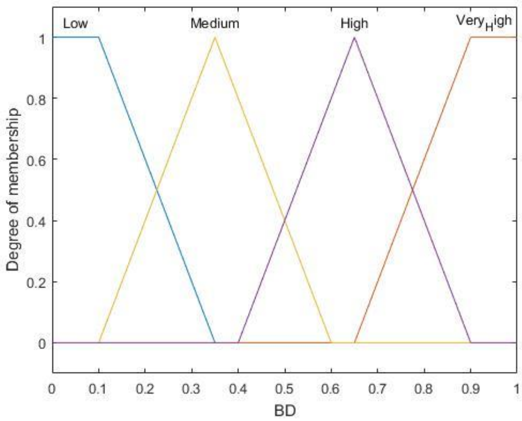

Figure 9: Membership Functions of the output of the fuzzy system which is the bump detection (BD)

VI. CONCLUSION

A fuzzy inference system has been proposed, described and evaluated to detect speed bumps using smart phone accelerometer readings. The proposed fuzzy inference system combines the effect of the vibration and the vehicle speed. Noisy data and uncertainty are all handled by the fuzzy system.

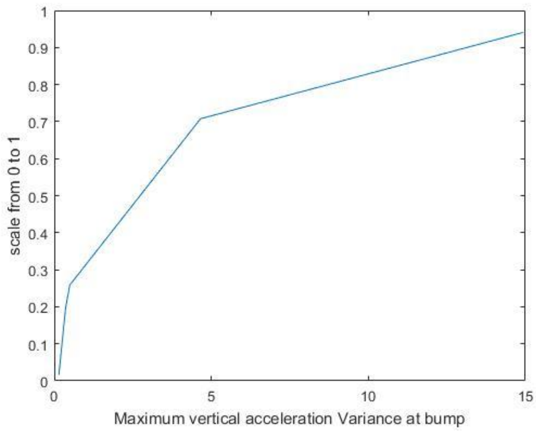

Figure 10: the value of the scaled acceleration

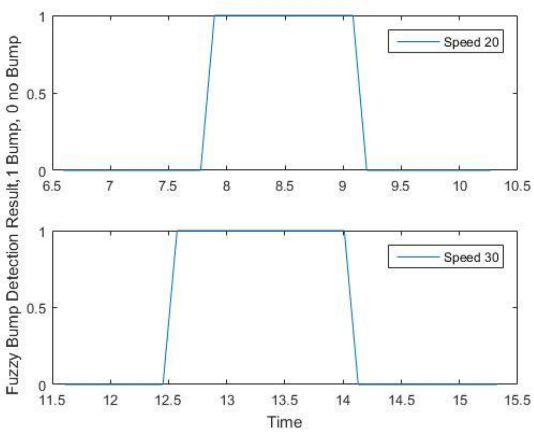

Figure 11: Bump detection output

The detection of the bump event accuracy is high at the middle of the bump. However, the width of detection area shows some error for high speed. This can be mitigated by a proper tuning of either fuzzy membership functions or the parameter of the scaling functions. As a future work, the fuzzy inference system can be improved by upgrading into a multistage system; this can be done by including other parameters such as the difference signal in the second stage.

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