MOBILE CLOUD COMPUTING SOLUTION FOR VISUALIZATION OF ROAD ROUGHNESS

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**A project report submitted in partial fulfilment of the
requirements for the award of Bachelor of Science
(Hons.) Software Engineering**

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April 2017

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : ________________________________

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"MOBILE CLOUD COMPUTING SOLUTION FOR VISUALIZATION OF ROAD ROUGHNESS"** was prepared by **LAM CHEN RIANG** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Science (Hons.) Software Engineering at Universiti Tunku Abdul Rahman.

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ACKNOWLEDGEMENTS

I would like to thank everyone who had contributed to the successful completion of this project. I would like to express my gratitude to my research supervisor, Dr. Tay Yong Haur for his invaluable advice, guidance and his enormous patience throughout the development of the research.

Special thanks to Lui Cai An, Soo Ching Pau and Ng Ching Yap that shared their vehicle or smartphone to conducting the experiment. Without their kind contribution, the progress of the experiment will be very slow and ineffective. My gratitude to them for sharing the resources.

Last, I would also like to express my greatest appreciation to my parents and friends who had helped and given me motivation and inspiration throughout the project. Without their support, I believe the project would not able to complete on time.

ABSTRACT

Nowadays, many road accidents occurs due to the bad road condition that does not fix immediately. Thus, road authorities are urged to obtain the latest road surface condition which will be helpful for them to plan and manage the road development ahead. An affordable and reliable mobile cloud solution that apply the crowdsourcing solution is proposed to solve this issue. In this paper, we will be discussing the design of mobile cloud solution, data pre-processing method, and road roughness calculation. A mobile application that used to collect data using the built-in sensor is developed. The collected data is then going through a data pre-processing process and send to the cloud server. The computation of the result will be using a server-less cloud service to minimize and prevent the waste of computation resources. Before the computation of road roughness, it will go through another stage of data pre-processing process. The processed data will be calculating through bump detection algorithm. After that, the result will be visualized under a heat map form.

KEYWORD – crowdsourcing, bump detection, Android, NDK, multithreading, DSP MQTT, cloud solution, AWS

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CHAPTER 1

INTRODUCTION

1.1 Background

“Road Roughness” is invariably known as the most vital road condition measurement in this world (Hunt and Jonathan 2001). Road roughness is the account of the flatness and frictional properties of the road and it is gaining concern over time as it used to indicate a road condition. A road with bad roughness condition may lead to uncomfortable ride experience, unexpected vehicle maintenance cost, extra fuel consumption and safety issue. Thus, having a good road infrastructure maintenance and management is an important task and responsibility that no country could deny. In developing country, Malaysia as an example, maintaining a good condition of road infrastructure is a challenging task for the road authorities like JKR, PBT, DBKL and MBPJ. This is due to the bad traffic congestion and most of the road is done in a hurry. Thus, the deterioration of the road is typically much faster than we expect. Besides, the weather in Malaysia which is usually humid and warm will also cause some damage to the road surface. So, the latest information about the road surface is what the road authorities urge to have. In order to get the road surface condition data for the maintenance and management planning, the three approaches mostly used by the authorities is by human visual inspection, using sophisticated profilers and optical profile meter which is used to measure the road surface shape (Darawade et al. 2016).

1.2 Problem Statement

- **The road authorities are not able to monitor all the road condition.**

According to the 2013 Malaysian Well-being report by Economic Planning Unit, the RDI increased from 0.75 in 2000 to 1.91 in 2012 and the total road length in Malaysia increased from 67,591 kilometers in 2000 to 182,628 kilometers in 2012 (2013). The road fixing and maintenance protocol applied by the authorities should aim to get the road fixed quickly and efficiently so the road users' safety is secured. However, with this huge size of road network size, it is a big challenge for the authorities to get the latest road condition data and send the road maintenance team to fix the road in a very short period of time.

- **Current road authorities' road fixing and maintaining protocol is passive.**

Road fixing and maintaining are a high expense for most of the road authorities. So, most of them will prioritize to repair the road that road users have lodged a report on it and the damaged road that without report normally will delay until someone lodged a report on it. JKR Selangor said they would able to repair a pothole within 24hours after the particular pothole is reported (Menon 2015). However, the problem comes in when there is no people report about the pothole and how long the JKR Selangor would take to notice and repair the pothole. Malaysia has a daily traffic level of 5 vehicles on a minor rural road to over 3,000vehichles the 2-lane. The two sites which located on dual carriageway have the traffic flows of 3,000 and 15,000 vehicles per day on the 4-lane road and 6-lane highway (Kwang, Morosuik and Emby 1992). With such heavy traffic in Malaysia, the longer the time taken to repair the potholes, the higher chances that the pothole to cause an accident. This will definitely put the road users at risk.

- **Direct measuring the road roughness is expensive and required a lot of human resources.**

The engineers have faced the problem of analysis and maintaining the road surface for many years. No doubt it is a big challenge that every engineer desire to solve. Although, detection of the road surface condition is important but the profiling method of using direct measurement of the road are typically expensive. The road authorities have limited road funding and they have to ensure the funding is spent wisely and efficiently. Thus, road surface detection that will require a lot of funding and resources normally will not take into consideration.

- **There is no platform to let the road user know the road surface condition in advance**.

Currently, there is no any platform that provides road surface condition information to the users. The road users would avoid these bumpy roads or be more careful of the bad road ahead if they able to get the latest road condition information in advance. Besides, the road surface condition information also will be very useful to the road authorities. To ensure the road funding used in the most competent and economical way, the road authorities require an efficient pavement management system to help in the decision-making process and the road surface information can be applied and take into consideration in this process. The continuously recorded road roughness data also allows road authorities to determine the roughness progression rate of the road. By this way, an appropriate action can be done by the road authorities (Hunt and Jonathan 2001).

1.3 Objectives

- To develop a mobile application that can collect the road roughness with the built-in sensors.
- To develop a framework that collects road surface information using crowdsourcing.
- To develop a backend server that collects a constant stream of data from various devices.
- To visualize the consolidated data that collected from the backend server.

1.4 Scope

The project aims to develop a mobile cloud computing solution that allows mobile devices to collect road roughness data on the road of Sungai Long area to a centralized storage for further data aggregation and visualization. This project is divided into 3 modules:

1. Data Acquisition:

An android-based mobile application will be developed. The mobile phone’s built-in sensor will able to collect the data about the road surface condition while the driver is driving. Simultaneously, the data will be sending to the cloud server. Thus, the mobile device used must have an active internet connection access.

2. Data Analysis

The data will be pass through several data filtration model. The data that sent to the cloud server will be process constantly by using the road roughness detection algorithm. The algorithm will be detecting the road bumpiness.

3. Data visualization

A web application will be developed to visualize the road surface condition on the map.

1.5 Significant of the project

- To visualize the road surface condition with a faster update rate.
- Provide a solution for the road authority to keep track on the road surface condition and faster reaction to the damaged road.
- Provide a platform for the road user to share the road surface condition safely and freely while they are driving.
- Enable road user to foresee the road surface condition and make a better road trip planning which can let them reach the destination safely.

CHAPTER 2

RELATED WORK

2.1 Introduction

There is no single definition for road roughness. The normal definition of roughness is a countenance of anomalies on the road surface that affects the ride experience of the vehicle (Pavement Interactive 2007).

ASTM E867 defines the roughness as “The deviation of a surface from a true planar surface with characteristic dimensions that affect vehicle dynamics and ride quality”

Besides road user’s comfort level of a ride on a specific road, road roughness is an important factor which related to vehicle’s vibration while it is moving, the vehicle’s moving velocity, wear and tear of the wheels with times and vehicle’s moving cost. Other than that, roughness index normally considered as a measured surface with high frequency and short wavelength component (Sayer, Thomas and William 1986). Roughness is significant to determine the interaction between a real object and its environment. As the road surface’s quantification evolves as a top interest to the engineers, examination of the performance of the wearing course of a road will be a good solution(Sayer, Thomas and William ,1986) . Although there are many methods for road roughness measuring, but in this review, we will covering the major methods that used by the road authorities and their strength and weakness as well.

2.2 Benkelman Beam

Benkelman beam is a device that works on the lever arm principle. It is used with a loaded truck which is generally 80kN (8165kg) with dual tires inflated to 480kPal to 550kPal on a single axis. To get the measurement of the road surface, the tip of the beam need to place between the dual tires and measure the road surface rebound as the truck is moved away at a creep speed.

Figure 2-1Benkelman Beam

2.2.1 Strength

The strengths of Benkelman Beam are:

- Simple. It is very simple to apply and does not involve very complex calculation.
- Quick. It can be applied in a very short time period as its operation is simple.
- Cheap cost. It does not require any expensive or special customized device to detect the road surface condition.

2.2.2 Limitation

The limitations of Benkelman Beam are:

- Inefficient. Benkelman beam can only apply in a single point of the road. For a single road, multiple time of measurement is needed.

2.3 Bump Integrator

There is two type of bump integrator which is the fifth wheel bump integrator and vehicle mounted bump integrator.

2.3.1 Fifth Wheel Bump Integrator

It is a device developed by CRRI which consist of a standard pneumatic wheel mounted within a rectangular with a single leaf spring on either side (CSIR, n.d.). The spring dashpots mounted on the leaf spring provide damping for the suspension. To get the measurement of the road surface, the bump integrator is towed by a pickup or jeep at a constant speed of 32kmph under standard tire pressure of 2.1kg/cm^2. The bump (cm) and corresponding road length are recorded on a panel board.

Figure 2-2 Fifth Wheel Bump Integrator

2.3.2 Vehicle Mounted Bump Integrator

This device consists of an integrating unit that mounted on the rear axle of a car or jeep. The bump integrator unit contains two sensors, one each for bump and distance measurement. To get the measurement of the road surface, the bump integrator is towed by a pickup or jeep at a constant speed of 32kmph. The bump (cm) and corresponding road length are recorded on a computer base data acquisition system.

Figure 2-3 Vehicle Mounted Bump Integrator

2.3.3 Strength

The strengths of bump integrators are:

- Simple. It very easy to apply and does not require the user to have depth knowledge in this area to use it.
- Fast. It can measures certain length of road in a very short time.

2.3.4 Limitation

The limitations of the bump integrators are:

- Speed limitation. It needs to be performing at the constant speed of 32kmph in order to get the accurate data.
- Sensitive. It will easily affect by the vehicle vibration(Tai et al., 2010).

2.4 Rolling Straight Edge

The rolling straight edge stimulates 3-meter rigid straightedge sliding along the road surface. It has rubber tyre wheels with the support of a rigid frame on arranged at the center and both end of the frame. A strip chart recorder or a computerized pointer is placed at the center of the wheel. In order to measure the road surface roughness, it is pushed at 1-2kmph. During the measuring process, the number of irregularities, length, and distance from the starting point is recorded. The depression on the road surface on an analogue scale measured by the rolling straight edge will the compare with the national specification for surface regularity.

Figure 2-4 Rolling Straight Edge

2.4.1 Strength

The strength of rolling straight edge is:

- Accuracy. The device is highly sensitive to the road roughness. It measures depression on the road surface on an analogue scale of 0-12mm +0.25mm.

2.4.2 Limitation

The limitation of the rolling straight edge is:

- The device is easy to be broken. As the device is very sensitive to the road measurement, thus a slight damage of this device will also affect the result. Thus, this device should be dismantled and handled with care to avoid any damage.

2.5 Road surface profiler

Road surface profiler also knew as a high-speed profiler. The road surface profiler is produced with the idea of a profiler under a van or heavy vehicle. This device is equipped with lesser height sensor, accelerometer, and GPS device. This device is capable of measuring a precise profile of one or more wheel paths while moving at speed 100kmph. To get the road measurement, it will capture every inch of the road profile and the data will then send to the computer database which places inside the vehicle and the speed of the vehicle usually operate on 70kmph.

Figure 2-5 Road Surface Profiler

2.5.1 Strength

The strengths of road surface profiler are:

- Straightforward. It is very easy to understand and operate. The road tester just needs to drive on the road and the calculation is done automatically by the computer.
- Efficiency. This device able to measure a very long range of an amount of road precisely per day. With this device, the road surface detection work can be done in very fast and efficient way.

2.5.2 Limitation

The limitations of the road surface profiler are:

- High cost. This device is expensive and the maintenance of device and vehicle would be a drawback that most of the road authorities cannot afford to apply it.
- Complexity. The procedures for conducting and controlling the device are relatively complex. The road surface profiler requires the tester to spend the time to understand the validation and control procedure of this profiler.

2.6 Walking Profiler

The walking profiler is a high-precision measurement instrument for collecting road surface condition information at true walking speed. The inclinometer between two support feet in this device is usually used to compute the road surface profile. To get the road surface measurement, the tester would have to push the walking profiler at the pace roughly 800 meters per hour.

Figure 2-6 Walking Profiler

2.6.1 Strength

The strengths of walking profiler are:

- Convenient. The size of the device is very small so it can be carried easily to every place to conduct the road roughness test.
- Efficient. The data collection can be very fast which around 4km per day.

2.6.2 Limitation

The limitations of walking profiler are:

- High cost. The cost device is expensive and it requires a frequent maintenance which also very expensive.

2.7 Waze

In the years of technology booming, everyone tends to become an active user of the internet that share some of their personal data toward the internet. This makes the concept “crowdsourcing” come in to solve the traffic congestion problem. Crowdsourcing is a method that engaging a huge group of people which have common goal to solve a problem. Waze, the traffic and navigation application that have the most community able to show the road traffic on the road real time.

Figure 2-7 Waze logo

They achieved this by using the concept of crowd-sourcing. By having the application open on their phone, users are passively contributing the information about their road trip to the whole community. Besides, the user also can report that specific the road condition. Then, Waze will analyze and stream the real-time report data to all the user.

Figure 2-8 Making report on Waze

2.7.1 Strength

- Near real time report. This is because the huge active crowd of the user that constantly updating the road condition. This makes the update rate become very fast.
- Convenient. The user only needs to make sure the application is open while driving in order to contribute data to the community.

2.7.2 Limitation

- High dependency of the crowd. Without a huge number of crowd, the accuracy of the result will not be accurate and will be biased to some false report from the user.
- Reliability of report. As all the data is contributed by the public and not a professional tester. This creates a big uncertainty of how the reliable of the collected data.
- Concentrate on the road traffic. Waze is currently concentrating on the road traffic condition but to the road surface condition.

2.8 Summary of existing method

Table 2.1 Summary of related work

Method of measurement	Principal of operation	Advantages	Disadvantages
Benkelman Beam	Lever arm	Simple, quick, and cheap	Inefficient
Bump Integrator	RTRRMS	Simple and fast	Speed have to be constant, result is affected by vehicle vibration
Rolling Straight Edge	Direct profile measurement	High accuracy	Easy to break
Road surface profiler	RTRRMS	Straightforward and efficient	High cost and the operation and control process is complex.
Walking profiler	RTRRMS	Convenient and	High cost

		efficient.	
Waze	Crowdsourcing	Near real-time report, convenient	Highly dependency to crowd, reliability of report, concentrate to traffic

CHAPTER 3

PROJECT METHODOLOGY

3.1 Introduction

In this chapter discuss the proposed solution and every technology involved in the solution.

3.2 Proposed solution

3.2.1 Introduction

In order to decrease the time needed for road fixing and maintaining, an affordable and reliable solution to collect the road roughness information on every road is needed. Nowadays, almost everyone has a smartphone and most of the phones are equipped with many useful sensors. The proposed solution is to create crowdsourced road surface monitoring application for the mobile phone that with active internet access. Then all the collected data will be filter and pass to the cloud server, AWS EC2 via a “lightweight” protocol, MQTT (Message Queue Telemetry Transport). In order to create an affordable solution, we used a cloud PaaS (Planform as a Service), AWS Lambda to periodically check for update and compute if there is a new data come in. Then, the result computed will be store into AWS S3.

The system can be separate into of four part:

- Android Data Acquisition application
- Data Analysis
- Data Visualization
- Cloud Web Solution

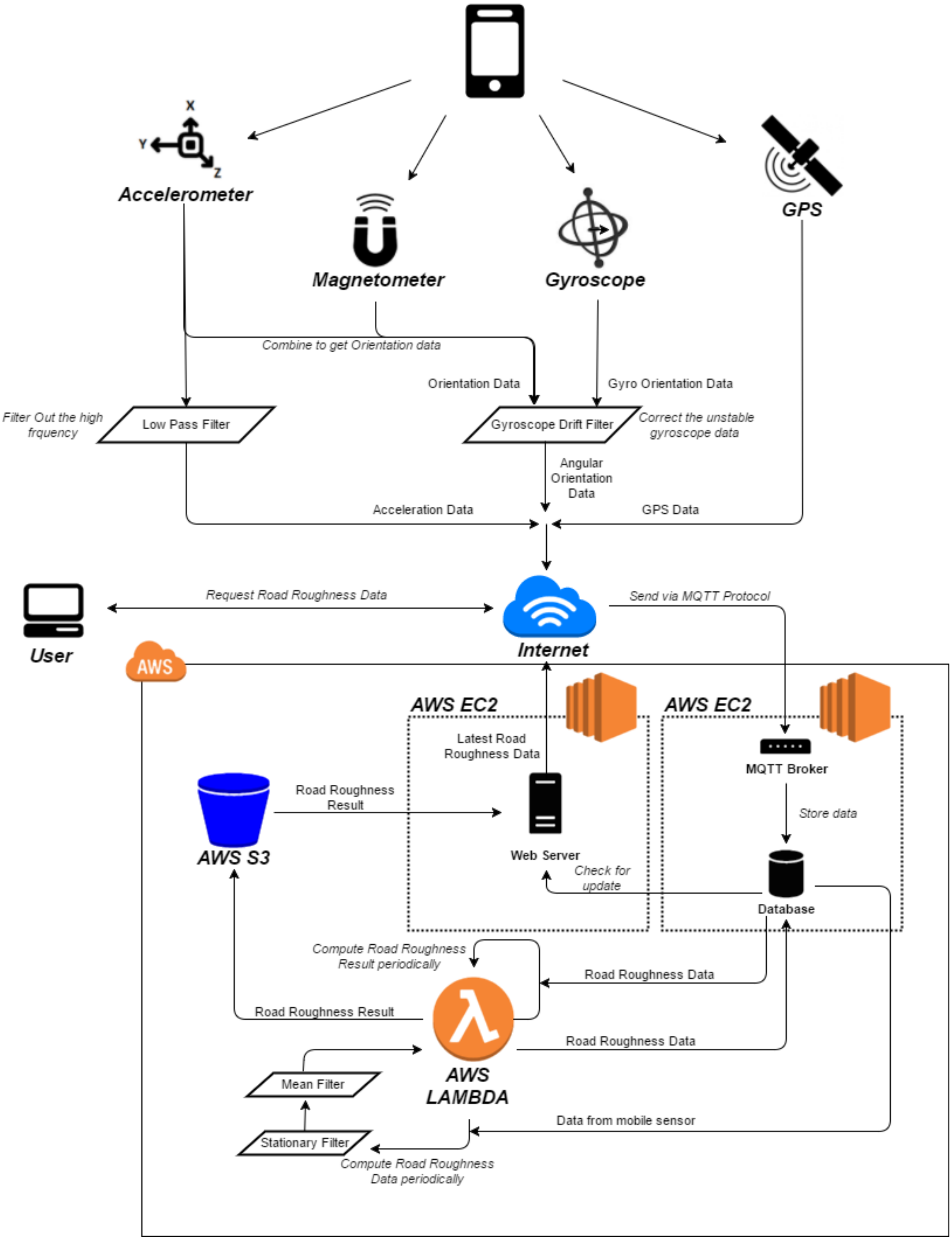


Figure 3-1 System Overview

3.2.2 Android Data Acquisition Application

To collect data from the user, we will be creating an Android application that placed on the car dashboard.

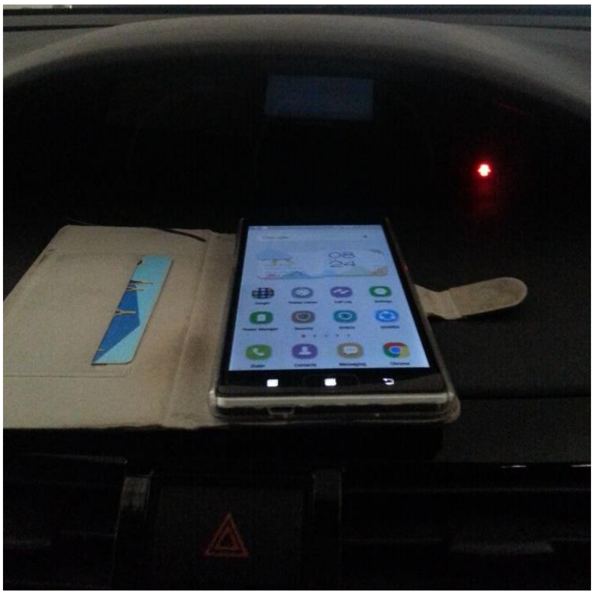


Figure 3-2 Phone position on the car dashboard

In this application, we will be accessing three motion sensors (Accelerometer, Magnetometer, Gyroscope) and a position sensor (GPS sensor).

The sampling frequency of the motion sensor we set it at 50Hz and position sensor is 1Hz. However, on the current software architecture of Android, there is an unpredictable time amount of delivery rate. The current architecture of Android sensor put a heavy polling and buffering to deliver data.

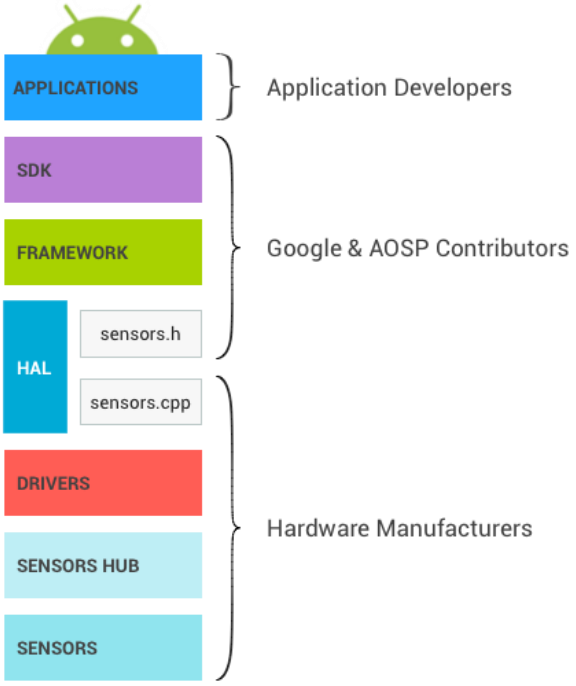


Figure 3-3 Android Sensor Architecture

So, in order to minimize the unpredictable delivery time, we decided to bypass the Framework and SDK level to have direct access to HAL level via NDK to obtain the physical sensor data. Then, we will have a first stage of pre-processing of data. We will use a low pass filter to filter out the high frequency on the accelerometer.

$$x = \propto \check{x} + (1-\propto)\bar{x} \tag{3.1}$$

where

$\propto$ = alpha

x = after filter sensor value

$\check{x}$ = past sensor value

$\bar{x}$ = current sensor value

The constant value of alpha is calculated as below:

$$\propto = \frac{\tau}{\tau\, dt} \tag{3.2}$$

where

$\propto$ = alpha

τ = time constant

dt = the sampling frequency

The time constant is calculated as below:

$$\tau = \frac{1}{2\pi f_c} \qquad (3.3)$$

where

τ = time constant

f_c = cut off frequency

In order to get a smoothing graph on the accelerometer, we will cut off the frequency above 40Hz which resulting us to have Alpha with a value of 0.89.

Then, the gyroscope will have a drift over time. The drift will produce a near constant-deviation (Johann, Lauro and Surat,2009). So, we can a correct and eliminate the drift value with a sensor fusion technique via a complimentary filter. This technique requires accelerometer, magnetometer, and gyroscope. We will be using Sensor library in Android to archive this filter. In order to filter out the drift error, the calculated orientation from accelerometer and magnetometer as a supportive information for the long-term interval while gyroscope for the short period of time. The overview of the filter design is shown below:

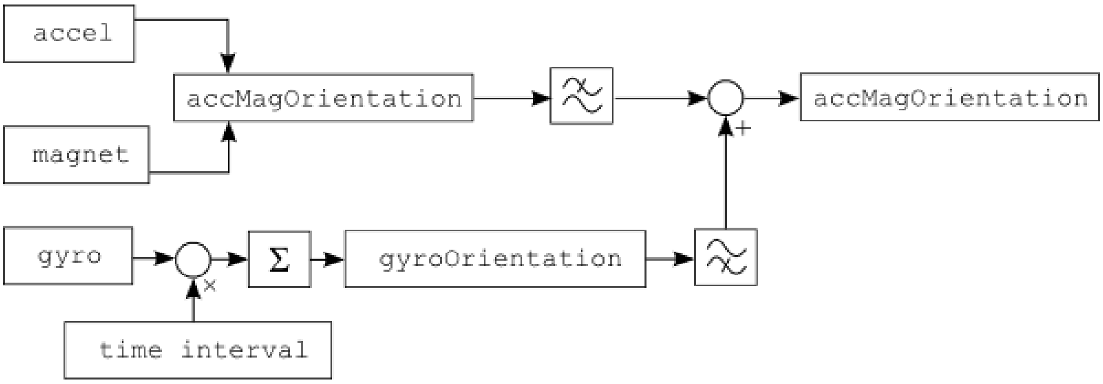


Figure 3-4 Gyro Drift Filter Design

After that, we will use an MQTT client library, Paho to send the data to the MQTT broker to the cloud server. In order to make the application fully utilizes the resources and efficient, thread and service are applied. Below is the overview of the system overview of the android application:

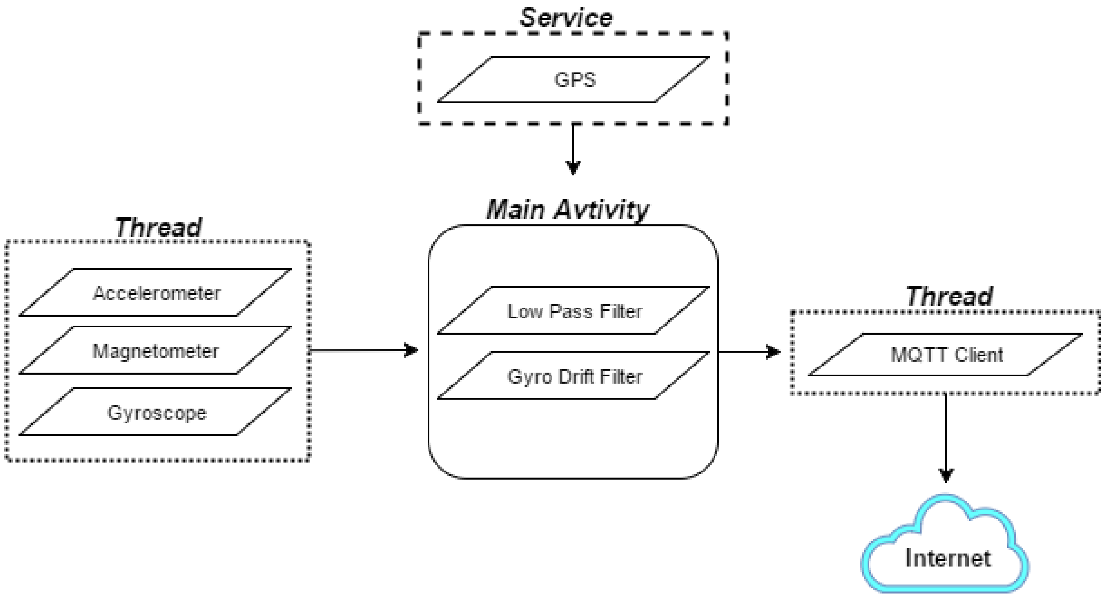
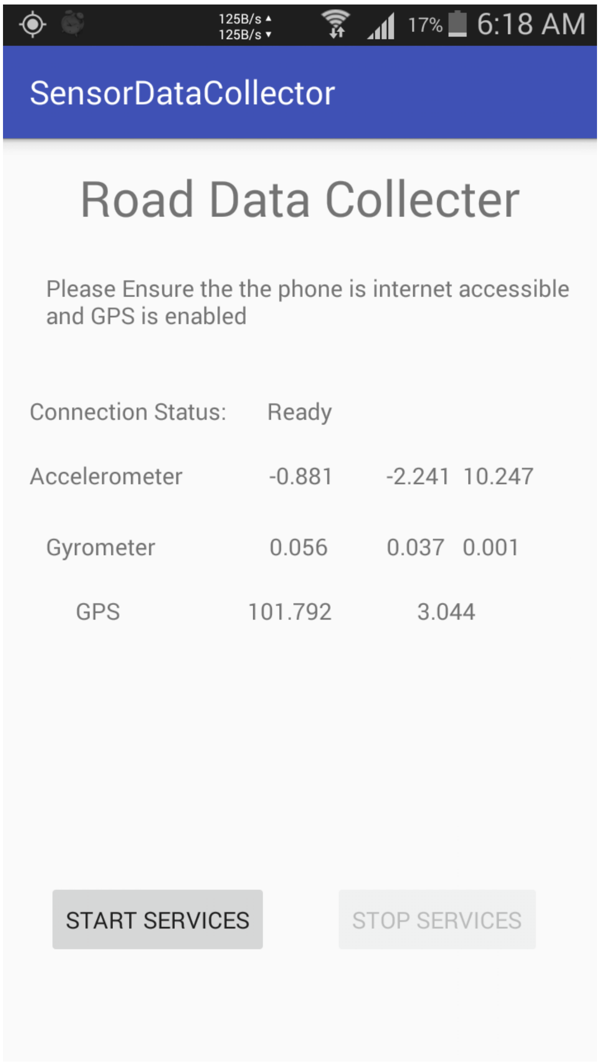


Figure 3-5 System Design of Android application



Road Data Collecter

Please Ensure the the phone is internet accessible and GPS is enabled

Connection Status: Ready
Accelerometer -0.881 -2.241 10.247
Gyrometer 0.056 0.037 0.001
GPS 101.792 3.044

Figure 3-6 Data Collection Application

3.2.3 Data Analysis

For data analysis part, firstly we will pre-process the data and make it clean and suitable for the calculation. Then, we will calculate the distance traveled per second using Haversine algorithm. Lastly, we will calculate the bump index which represents the roughness of the road.

The process of data analysis can be separated it into three parts:

- Data Pre-Processing
- Distance calculation
- Bump Index calculation

3.2.3.1 Data Pre-Processing

This is the second stage of data pre-processing. This process is to filter out the noise and some unnecessary data that would cause the inaccuracy of the result.

First, the filter we use on data pre-processing process is a stationary filter. This filter intention is to filter out the acceleration peak when the vehicle is not moving. As these peaks can be caused by closing the door or boot of the car.

Lastly, we use a mean filter to reduce the noise and smoothing the graph of the dataset. We will label every data that within the 0.5 second as the same partition and take its mean value.

$$\bar{x} = \frac{\sum x}{N} \tag{3.4}$$

where
$\bar{x}$ = wheelbase, m
$\sum x$ = vehicle speed, m/s
N = recording cycle, Hz

3.2.3.2 Distance traveled Calculation

The calculation will be using the Haversine algorithm to calculate the distance between two points on a sphere (Earth radius) given their longitudes and latitudes.
The algorithm of the Haversine formula is shown below:

$$a = \sin(\Delta\emptyset/2)^2 + \cos(\emptyset_1).\cos\theta_1 \,.\sin(\Delta\theta)^2 \tag{3.5}$$

$$c = 2a\ \tan\left(\sqrt{a}\,,\sqrt{(1-a)}\right) \tag{3.6}$$

$$d = R \times c \tag{3.7}$$

where

d = Distance travelled

R = Earth Radius

$\Delta\emptyset$ = Radians of latitude

$\Delta\theta$ = Radians of longitude

$\emptyset_1$ = latitude

θ_1 = longitude

3.2.3.3 Bump Index Calculation

We will be calculating the bumpiness of the road by using the bump index calculation from Yagi (2010). He stated that it able to detect the road bump created during Niigataken Chuetsu-Oki Earthquake 2007. Other than that, Darawade et al. (2016) also mention that root mean square acceleration of the data would be able to show the roughness of the road.

First, we will need to calculate the standard deviation of Y-axis and Z-axis acceleration and X-axis orientation acceleration which will define as SDy(i), SDz(i) and SDz(i).

$$\sigma = \sqrt{\sum \frac{(x - \tilde{x})^2}{N - 1}} \tag{3.8}$$

where

σ=standard deviation

x=initial value

x=current value

N=total number of record value

Then, we will need to calculate the simultaneity index which is defined as SDyzx(i).

$$SDyzp(i) = SDy(i)\times SDz(i)\times SDp(i) \tag{3.9}$$

In order to get a better result, we will the cycle number of wheelbase time which includes the wheelbase, speed and recording speed. The cycle number of wheelbase time is defined as Nw.

$$Nw = \frac{Lw}{V}\times H \tag{3.10}$$

where

Nw= cycle number of wheelbase time

Lw= wheelbase, m

V = vehicle speed, m/s

H = recording cycle, Hz

The following formula will be using to calculate the bump index, *Byzx(i)*

$$Byzp(i) = SDyzp(i)\times SDyzp(i+Nw) \tag{3.11}$$

3.2.4 Data Visualization

For the data visualization, we will be using an open source python framework, Folium that enables us to display the data in a heat map form under the OpenStreetMap and then save it locally under HTML format. The bumpiness of the data will be auto scale by the framework. Below is the generated result:

Figure 3-7 Web Page Visualization

3.2.5 Cloud Web Service

In this part, we will be using few web service from Amazon to provide an efficient and affordable solution. There are 3 services we are using:

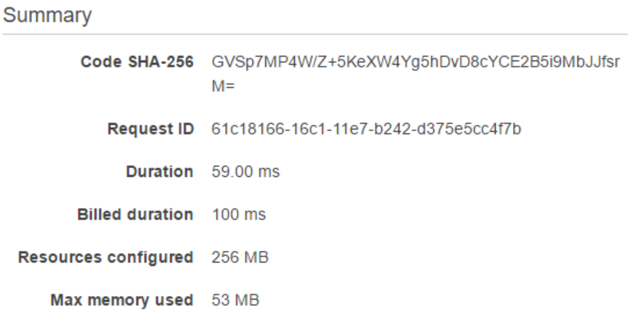
- Elastic Computer Cloud (EC2)
- Lambda
- Simple Storage Service (S3)

3.2.5.1 Elastic Computer Cloud (EC2)

In this solution, two EC2 instances will be using. One will act as a database that receives and store all the data and another one will be used to host the web server in order to displace the result of the road roughness. Both does not require a very high specification of computing power. By doing this, the cost to implement the solution can be reduced compare to use an own server do all the services.

3.2.5.2 Lambda

We also created a lambda function that constantly checks for update on the database. If there is an update, it will retrieve all the latest sensor data from the database and compute it into bump index. Then the bump index will be stored into database and a heat map that represent the bump index will be generated and put into another service storage S3. Lambda enables us to scale up and down the computation power easily. This will prevent from wasting the resources and compute the result with minimum resources.



Summary

Code SHA-256	GVSp7MP4W/Z+5KeXW4Yg5hDvD8cYCE2B5i9MbJJfsrM=
Request ID	61c18166-16c1-11e7-b242-d375e5cc4f7b
Duration	59.00 ms
Billed duration	100 ms
Resources configured	256 MB
Max memory used	53 MB

Figure 3-8 Lambda Executed Result

3.2.5.3 Simple Storage Service (S3)

All the result will be stored into the cloud storage after it computed by Lambda service. This storage service provides high scalability and reliability storage at a low cost.

3.2.5.4 Cloud Service Solution Design

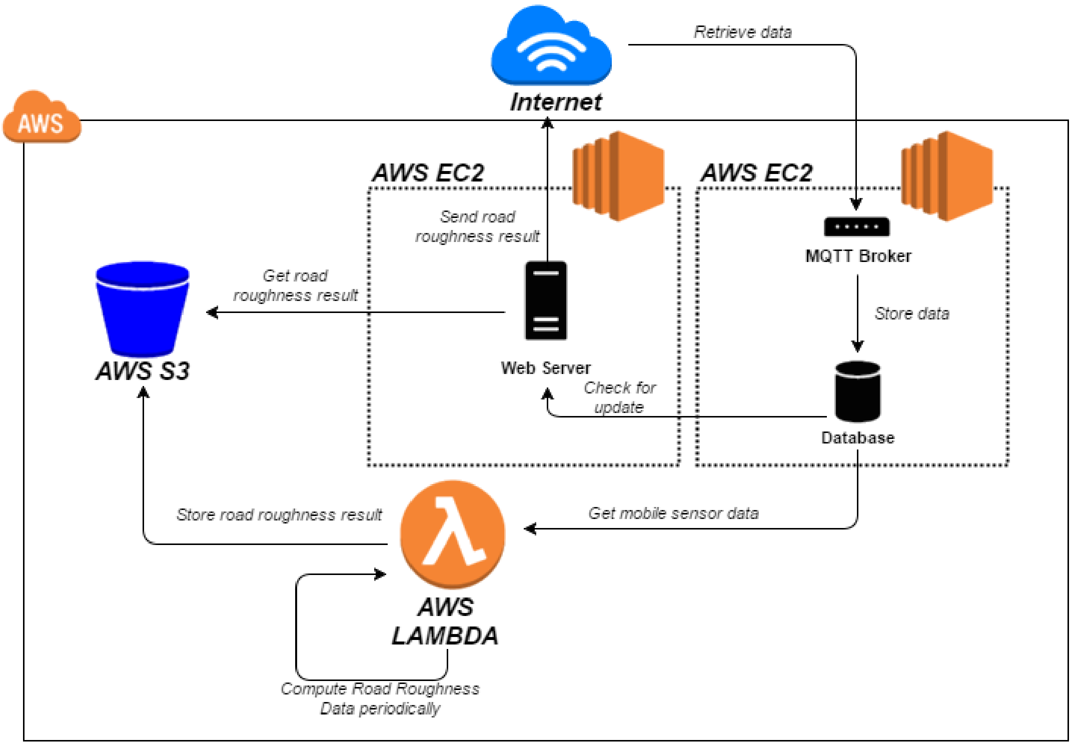


Figure 3-9 Cloud Solution Design

3.3 Technology Involved

3.3.1 Mobile Phone

3.3.1.1 Accelerometer

The accelerometer is a tiny mass on a tiny spring. The accelerometer is a sensor in the smartphone that used to measure the acceleration force. It allows the user to know their surrounding of the phone better. With the accelerometer, the user can determine whether the object is moving uphill or downhill. For example, by detecting how the user holds their phone, the smartphone would rotate their display between portrait and landscape mode. The sensitivity of the accelerometer is quite high. This is because they are intended to measure the tiny shift in acceleration(Goodrich, 2013). The responding unit of acceleration in Android is meter per second square (m/s^2) (Grey and Adam, 2012).

3.3.1.2 Magnetometer

The magnetometer is used to measure the magnetic field changes around the smartphone. The sensor creates Hall effect sensor with the modern solid state technology to detect the Earth’s magnetic field in three different perpendicular axes X, Y and Z. By simply passing a current through a wire make the hall effect sensor worked. A resulting voltage across the width of the wire which is corresponding to the polarity and strength of the magnetic field is produced due to the higher density of electron on one side of the wire. The reporting unit for the magnetic field changes in Android is microtesla. The accuracy of it might be bad as it affects a lot by the local environment (the present of nearby metal) (Grey and Adam, 2012).

3.3.1.3 Gyroscope

Gyroscope is tiny masses on a tiny spring that designed to measure the Coriolis force. The Earth’s gravity used by the gyroscope to get the orientation of the phone. Rotor, a freely-rotating disk which mounts onto a spinning axis in the center of the larger wheel is consisting in it. As the axis turn, the rotor remains stationary to indicate the central gravitational pull (Goodrich 2013). A gyroscope would able to use to measure the rate of rotation around the phone roll axis. When the phone rolls, it will measure the non-zero value until the platform level out. The reporting unit for the rotation force is radians per second (rad/s). However, the gyroscope will introduce large error due to the noise and offsets. This would make the integrated data to be useless within a second if the address is not addressed during the calculation of angle(Grey and Adam, 2012).

3.3.1.4 GPS

Among the sensors that that built-in in the phone, GPS sensor is the most frequently used and convenient sensor that used by the community. When visiting an unfamiliar place, the GPS sensor can locate your position and provide you turn-by-turn direction. The GPS reciever in the smartphone communicates with unit among the 30 global position satellites in the GPS system. The receiver will receive the phone position from at least 3 satellites and then determine the current location based on the intersection point of the overlapping sphere and the built-in GPS receiver of the smartphone (Gordon, n.d). Thus, to obtain the correct current location will take a substantial amount of time.

3.3.2 Message Queue Telemetry Transport (MQTT)

MQTT is a protocol for internet connectivity that used for machine-to-machine(M2M) and invented by Dr. Andy Stanford-Clark in 1999. As it is extremely simple and lightweight, so it is able to minimize network bandwidth and device resources requirement while at the same time ensure reliability and some degree quality assurance on the delivery (Mqtt.org, n.d).

Figure 3-10 MQTT logo

3.3.3 MongoDB

MongoDB is an open source NoSQL database. A flexible document model that is similar is used to store data in MongoDB. The document able to contain one or more field which includes array, binary data, and sub-documents. The advantages of using MongoDB is scalability, flexibility, and performance. It able to scale up depending on the needs and able to support thousands of nodes, petabytes of data and hundreds of thousands operation per second without rebuilding custom partitioning and caching layers (MongoDB, n.d).

Figure 3-11 MongoDB logo

3.3.4 Toolset, Framework and Library

3.3.4.1 Native Development Kit(NDK)

NDK is a toolset that let the developer implement native code like C and C++ into Android application (Google, n.d). With NDK, the developer able to use native code library. Android application is generally written in Java but it will have some limitation on memory management and performance. NDK enable the developer to directly program into Android native interface. Thus, this will boost up the performance of the application and increase the reusing of code.

3.3.4.2 Paho

Paho is an open source project that creates by Eclipse to provide client implementation of MQTT. It is aimed at application for Machine-to-Machine (M2M) and Internet of Thing (IoT) (Eclipse.org, n.d). Its intention is to include decoupling between devices and application and to boost the rapid growth of middleware and applications.

Figure 3-12 Paho Logo

3.3.4.3 Flask

Flask is a Python open source micro web framework. It is build that based on the Werkzeug toolkit. It also used and Jinja2 template engine as the core system engine. It is suitable for a small project that with only one or two functions as itself does not require any particular tools or libraries to run it. In order to provide a really simple framework that with no restriction to implement anything it minimize everything and thus there is no data access layer in it. In short, Flask is a good because it is simple, well documented and have an active community that continuous providing external module for it.

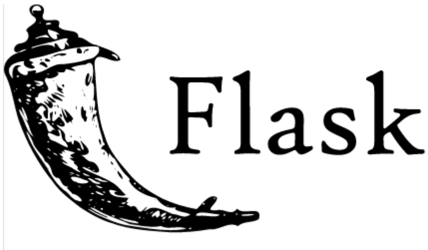


Figure 3-13 Flask Logo

3.3.4.4 Folium

Folium is a Python open source map visualization framework that mapping the strength of the Leaflet.js library. It allows the developer to manipulate the data in python and then visualize it on a Leaflet map. Folium has numerous of built-in tile sets from Mapbox, Stamen, and OpenStreetMap. It also supports GeoJSON and TopoJSON. In shorts, Folium is a very powerful framework that helps to generate interactive Leaflet maps.

Figure 3-14 Folium Logo

3.3.4.5 Pandas

Pandas is a python open source framework that provides high performance and easy to use a data structure for data analysis. It is sponsor by NUMFocus which ensure the quality and success of the framework. It built on top of Numpy and make a high level of the task is incredible to complete. As a conclusion, Pandas is a good data analytic framework that enables developer to speed up data analytical process.

Figure 3-15 Pandas Logo

3.3.4.6 Pymongo

Pymongo is a native Python driver library that used for interacting with MongoDB database.

3.3.4.7 Boto

Boto is a Python library that allows developer to write a program that makes use of the service of Amazon Web Service like Amazon S3.

3.3.5 Cloud Web Service

3.3.5.1 Elastic Computer Cloud (EC2)

EC2 is an IaaS (Infrastructure as a Service) cloud service that provided by Amazon Web Service(AWS) for a secure, resizable and computes capacity in the cloud. It allows the user to rent a virtual computer with complete control to run their own computer application. EC2 reduce the time amount require to build up a new server and the user only pay for the capacity they actually used.

Figure 3-16 EC2 Logo

3.3.5.2 Lambda

Lambda is a PaaS (Platform as a Service) cloud service that provided by Amazon Web Service(AWS) to run the code without managing the server. Lambda provides a continuous scaling on the resources. The uploaded code will run in parallel and processes each trigger individually. Lambda will also can be scaled precisely based on the size of each workload needed. The user will only charge with the compute time of the code consumed.

Figure 3-17 Lambda Logo

3.3.5.3 Simple Storage Service (S3)

S3 is an IaaS (Infrastructure as a Service) cloud service that provided by Amazon Web Service(AWS) for storage purposes. It is intended to make the computing become more scalability for the developer. S3 let developers store and retrieve any amount of data, at any time from any place on the internet. It is like a bulk data storage and thus it reduces the cost of having and maintain a data storage.

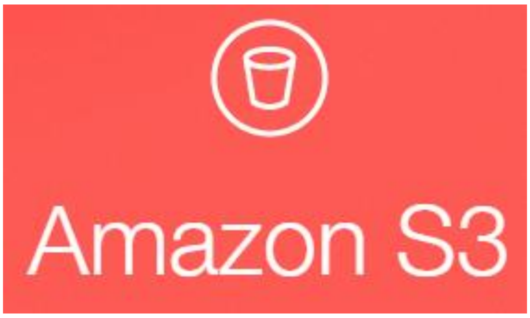


Figure 3-18 S3 Logo

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter will be discussing the experiment test to test the road surface detection algorithm and the effect of data filtration of the proposed solution in Chapter 3.

4.2 Experiment Specification

- The smartphone is stayed under the sky which means the test bed cannot have any tunnel or any building that cover the road. This is to make sure the GPS signal is clear and does not have any inference will affect its accuracy. So, we decided to carry out the test around Forest Green Condominium.

- The smartphone is placed on the vehicle dashboard that in front of passenger's seat statically and horizontally. The position of the display side of the phone is placed upright and the home button is point toward the back of the vehicle. This mean the running direction is Y-axis, X-axis is the width direction and the vertical direction is Z-axis. This is to control and prevent the result from being inaccurate due to the phone position.

- The phone that used in this experiment is Samsung galaxy Note 2. The motion sensors' sampling rate is 50Hz while position sensor is 1Hz.

- The vehicle that used is TOYOTA VIOS which has 2550mm wheelbase, 4285mm long, 1695mm width, 1435mm height and 990kg weight. The test is carried out around Forest Green Condominium and the vehicle is moving clockwise at a square course.

- The experiment is conducted 3 round and each round has 500m long. There are 9 bumps in the test road and 2 short distance of rough road in along the test bed.

4.3 Bump Index Calculation

4.3.1 Experiment 1

This is the first preliminary experiment, we tried to imitate the concept of Fifth Wheel Bump Indicator that measures the International Roughness Index (IRI) over Z-axis of its acceleration.

Figure 4-1 Z-axis Acceleration Result

From the result above, we able to see that it is almost impossible to recognize the road obstacle as the number of noise is high. So, we decided to include the Y-axis acceleration to calculate the simultaneity index of the standard deviation of the two axes (Y and Z).

$$SDyz(i) = SDy(i) \times SDz(i) \tag{4.1}$$

From the graph, in Figure 4.3 below we can see that it is some of the noise has been filtering and the graph become smoother compared to graph in Figure 4.2

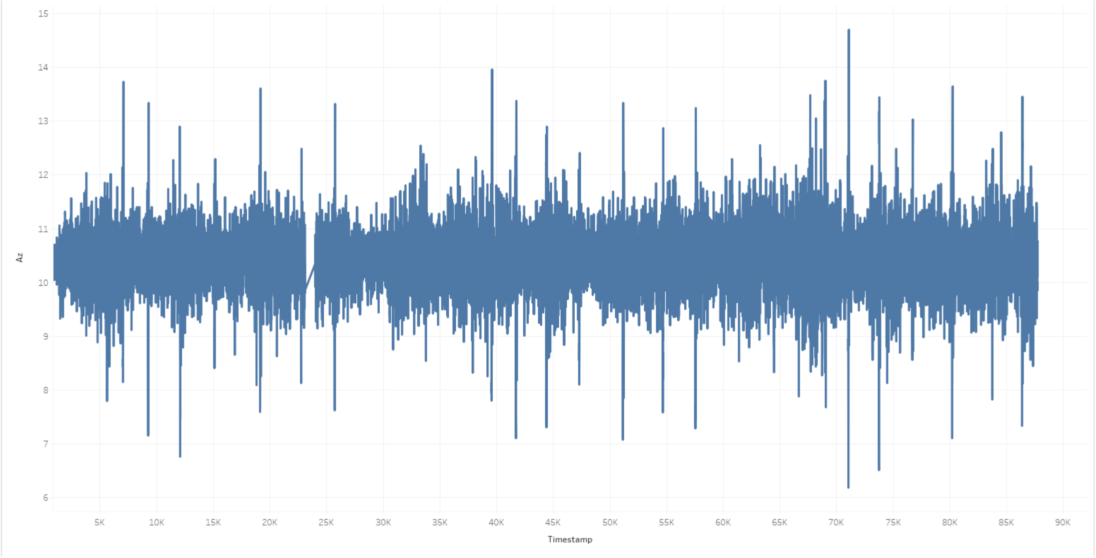


Figure 4-2 Frequency graph of Z-axis acceleration

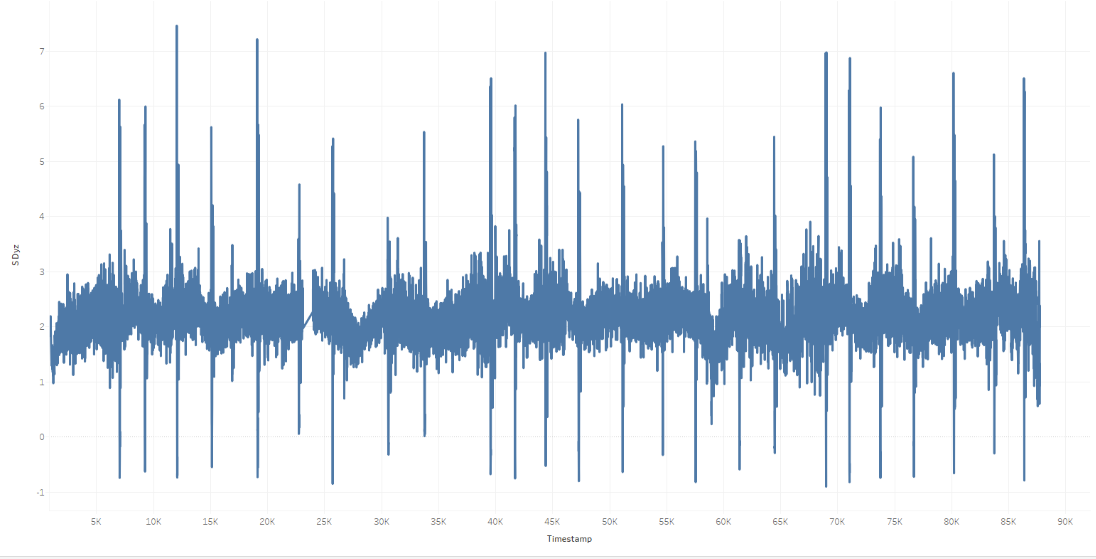


Figure 4-3 Frequency graph of Simultaneity Index of SDyz(i)

Then we will be calculating the bump index with the following equation

$$Byz(i) = SDyz(i) \times SDyz(i + Nw) \tag{4.2}$$

The Nw is the cycle number of wheelbase time and the equation is stated in Chapter 3. However, the result still does not really look very reasoning.

Figure 4-4 Result from Z and Y acceleration

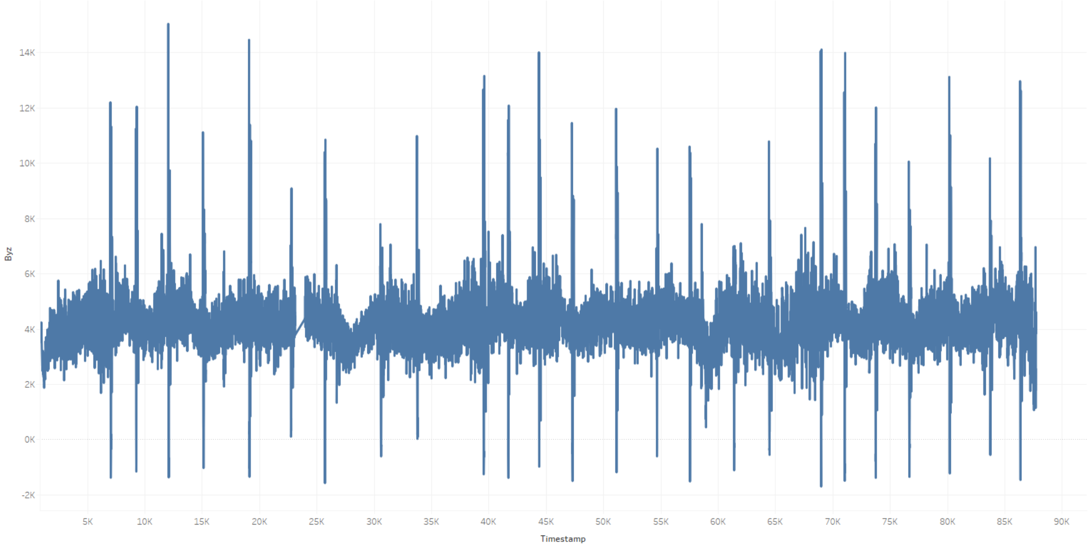


Figure 4-5 Frequency graph of Z and Y axis result

4.3.2 Experiment 2

To improve the result getting from Experiment 1, we decided to re-conduct the experiment with adding another sensor which is the gyroscope. This is because when the vehicle passes through rough road it will cause the phone to rotate around X-axis and generate the pitch data. We defined the pitch data as *p(i)*. Then, we will calculate the Simultaneity Index by getting the product of standard deviation acceleration along Y and Z axis and the pitch data.

$$SDyzp(i) = SDy(i) \times SDz(i) \times SDp(i) \tag{4.3}$$

Then follow by the calculation of bump index:

$$Byzp(i) = SDyzp(i) \times SDyzp(i + Nw) \tag{4.4}$$

After applying gyroscope, the frequency graph in Figure 4.7 shown there is an improved result and the some of the high peaks has been normalized. But the more new noise has been introduced into the dataset as a new sensor is implemented.

Figure 4-6 Result after implemented gyroscope

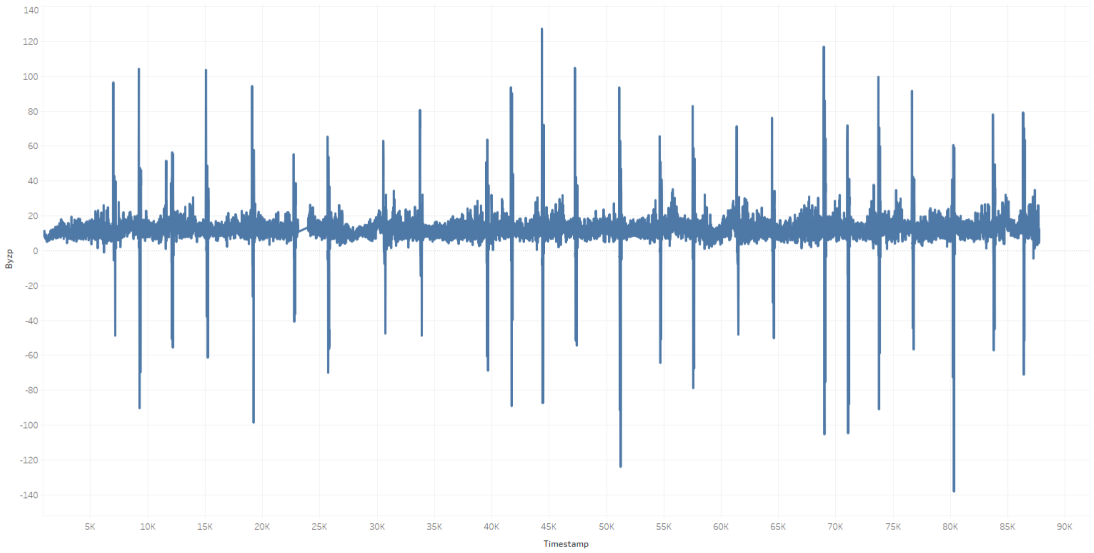


Figure 4-7 Frequency graph of the result after implemented gyroscope

4.4 Data Pre-Processing

We noticed that there are still a lot of noise that we should filter out from the data. So, we decided to have few data filtration model. We have two stage of data filtration. The first stage of it was implemented in mobile application and another stage is implemented at cloud server before the calculation of bump index. We decided to separate the pre-processing process is to prevent heavy loaded the server and decrease the computation resources required.

4.4.1 First Stage

First, we will implement the low pass filter on the accelerometer to filter out the high frequency. We cut off the frequency at 25Hz. The result is as below:

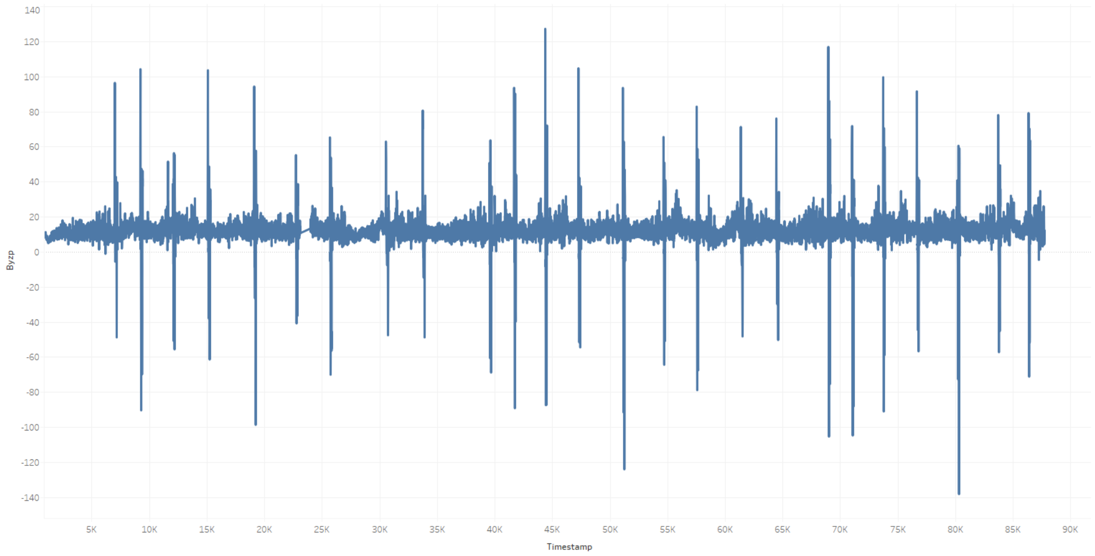


Figure 4-8 Low pass filter on acceleration

Then we realized that gyroscope will introduce a drift error over the time and it will be the reason the that caused the result to become unrecognize. As a result, we decided to implement magnetometer sensor into the application and fuse it with accelerometer and gyroscope to correct the data collected from the gyroscope. The data fusion is done through a complimentary filter. The result of it seems much more promising than the past 2 experiment.

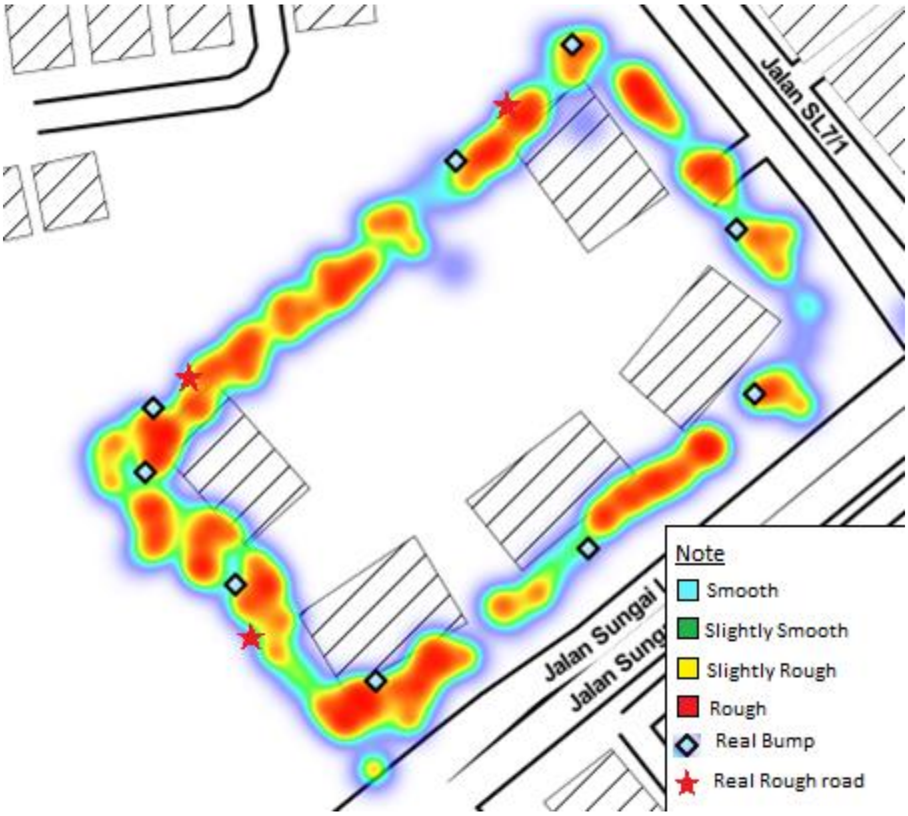


Figure 4-9 Result after stage 1 of data pre-processing

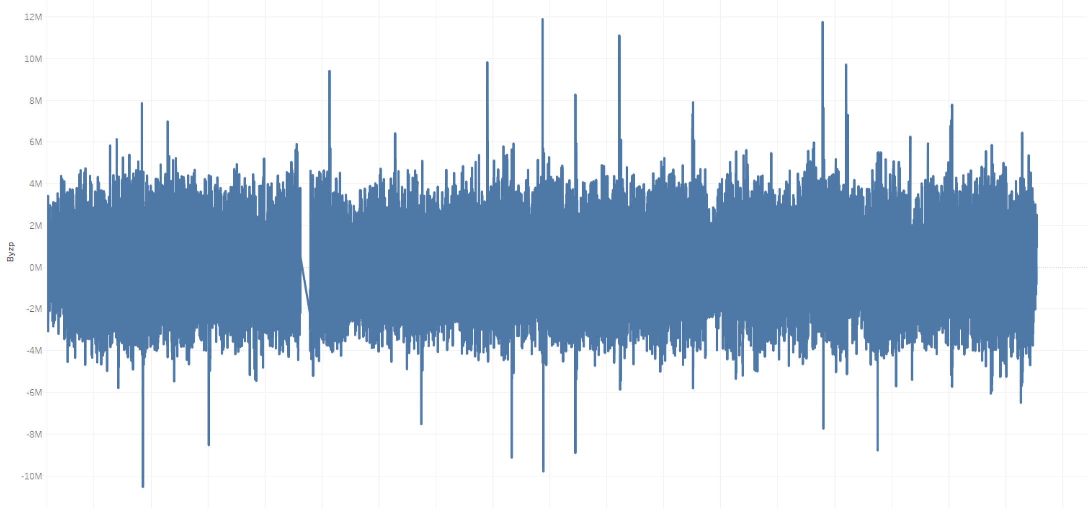


Figure 4-10 Frequency graph of data pre-processing stage 1's result

4.4.2 Stage 2

In this stage, we decided to implement a stationary filter to filter out some minor high peak acceleration when the car is not moving.

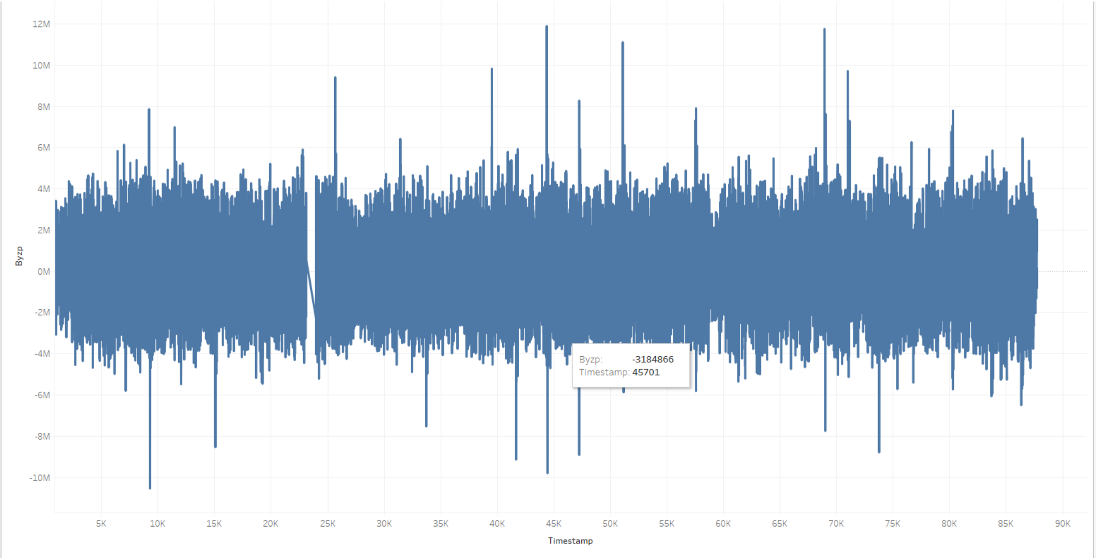


Figure 4-11 Frequency graph after stationary filter

Then, follow we will have a mean filter which will portion the data into every 0.5 seconds. The result has been filtered a lot of noise. It able to detect 7 bumps out of 9 and 3 short distance of the rough road. A bump sample is shown in Figure 4.13 and 3 short distance of rough road is shown in Figure 4.14, 4.15 and 4.16.

Figure 4-12 Result after data pre-processing

Figure 4-13 Road bump

Figure 4-14 Short distance of rough road at top position

Figure 4-15 Short distance of rough road at middle position

Figure 4-16 Short distance of rough road at bottom position

4.4.3 Result Evaluation

In this section, we will evaluate the different of the constant factors which are significant for the experiment.

4.4.3.1 Different Car

As every car will have different suspension condition which will direct affect the result. This is because a softer the suspension system of the vehicle, the less vibration will the driver feel. The another vehicle we used is Proton Wira which has 2500mm wheelbase, 4270mm length, 1680mm width, 1385mm height and 980kg. It has a stiffer suspension system compare to Vios. So, a lesser noise and more accurate result are produced.

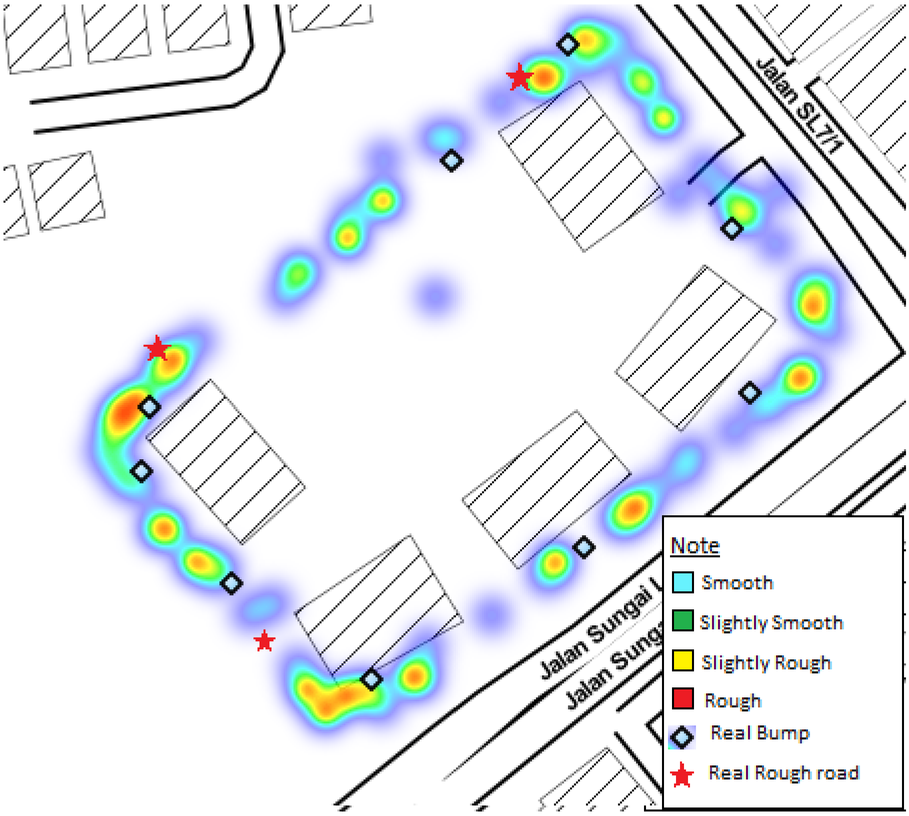


Figure 4-17 Result from another vehicle

4.4.3.2 Different Phone

As every phone might have different performance in term of the processor and better sensor it has which will affect the data collection result. In this experiment, we used another phone which is XiaoMi Mi3 to collect the data and the result is shown below:

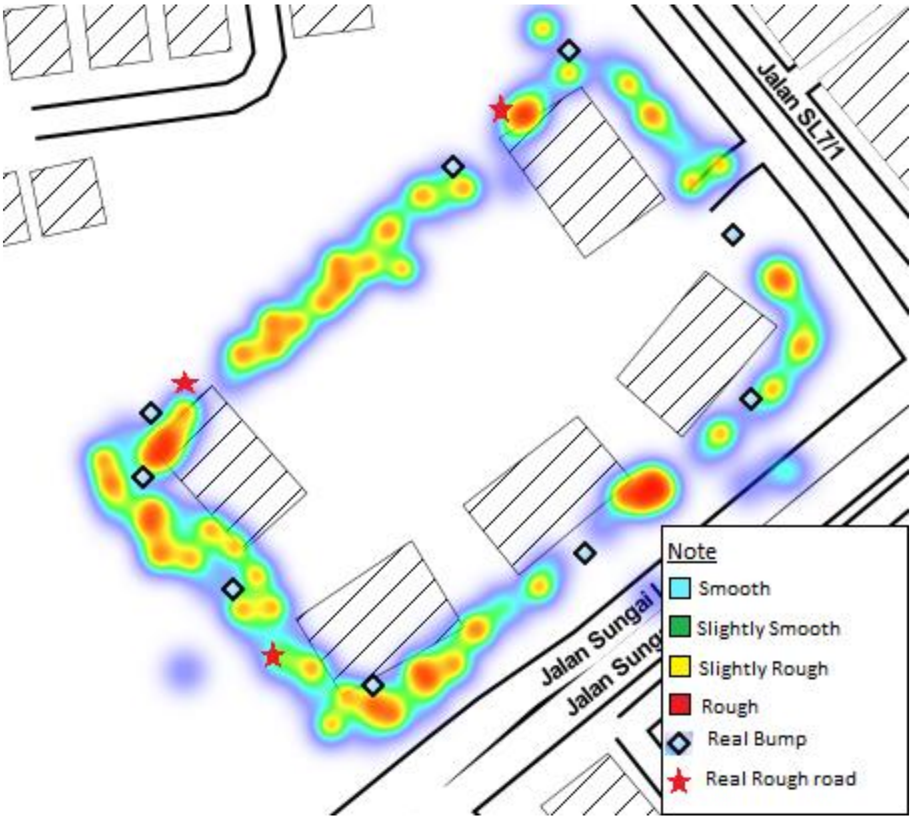
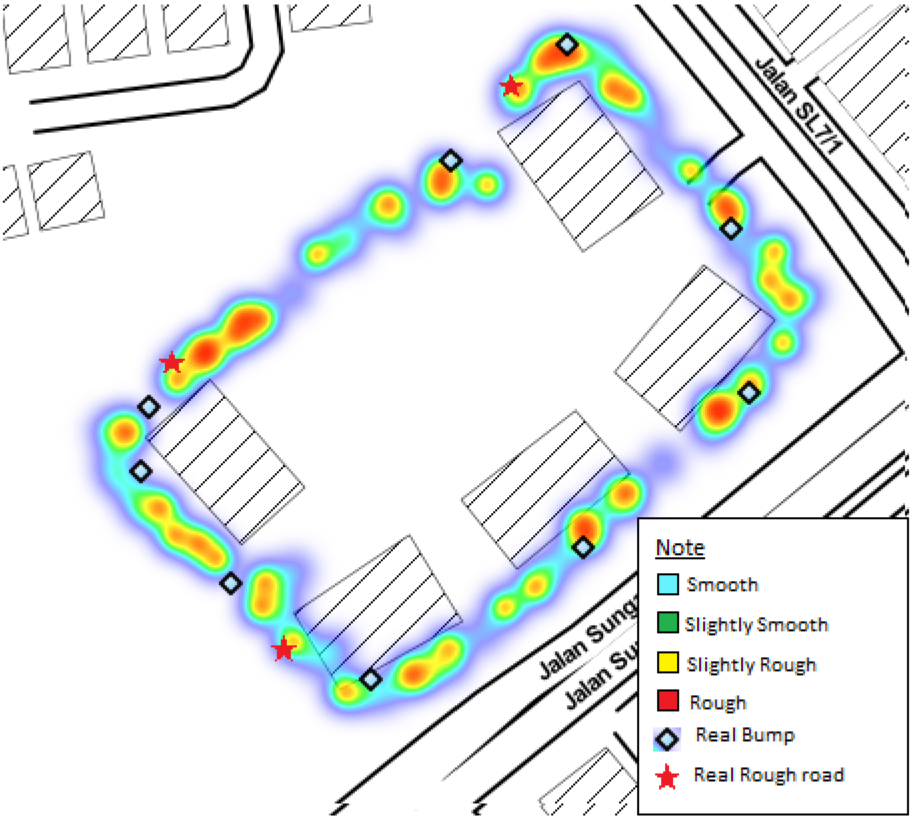


Figure 4-18 Result from another phone

The result getting from it is almost the same and able to consider as identical.

4.4.3.3 Multiple Data Entry

We conduct another experiment with two devices together instead of the only result from one device. This improved the result efficiently. As by averaging huge amount of data, able to eliminate the noise and enable us to obtain more accurate data to compute the roughness of the road.



4.5 Summary

As s summary of this chapter, we can see that by applying the crowdsources concept is able to improve the result. We can clearly see that the noise is dropped when we are collecting result from two devices compare to using only one device.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this project, we have presented and proven that a by applying the crowdsourcing concept into this solution able to produce a better accuracy of the result. We have designed an affordable mobile cloud computing solution which is also reliable and efficient to collect and monitor the latest road surface condition. We also discussed a basic calculation of road roughness and made it be more reliable by pre-processing the data with 4 data filtration model.

As road surface condition need to monitor continuously from time to time and when a damaged of the road does not be fix immediately, it might cause an accident which everyone does not it to happen. So, with our approach, we able to analyze the road condition in the shortest time compare to the solution in the market.

However, the result still is not able to identify the type of road obstacle which causes the road surface to be rough and bad as we detect the road bump or pothole based on the analysis of the high-energy event of the acceleration of the vehicle. Besides, we are using a basic bump index calculation that does not cover many factors that will affect the accuracy of the result. So, the result still has a lot of room for improvement.

5.2 Recommendations for future work

5.2.1 Vibration of vehicle engine

When the car is started, the will cause a tiny vibration to the vehicle and it will contribute to the signal and have a significant magnitude that would affect the accuracy of the result. These vibrations should be able to eliminate with a mathematical periodic filter.

5.2.2 Car suspension

Every car has a different suspension condition and this factor would directly affect the result’s accuracy. A better mathematical model should come out to cover this area.

5.2.3 Position of the phone

Currently the during the data collection period, the phone has to place upright facing to the sky on the car dashboard. In the future work, it should give the possibility to analyze the road surface without this limitation.

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