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Road surface condition monitoring system utilizing motorcycle (ROCOM) – System development, validation and field test

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Abstract. Motorcycles are the riskiest mode of travel in Malaysia, however motorcycles are also very sensitive to the road surface condition. Thus, by taking advantage of this, a system of applications that analyses motorcycle motion and mapped out risky road sections was developed, i.e. ROCOM. The system consists of three major components, i.e. acceleration data logger smart phone app, risk mapping web-based app and a visual tracking app utilizing the phone. ROCOM is able to detect adverse acceleration (> 2g) on the road surface similar to the High Accuracy GPS Data Logging for Vehicle Testing (VBOX). Risk mapping validation along a section of the motorcycle lane along Federal Route 2 shows that ROCOM have the similar risk-mapping pattern, but superior tracking capability that the VBOX. The pilot and field test results showed that ROCOM works best when mounting the smartphone on the motorcycle handle bar or basket, and with successful detection rate of 62% of various road anomalies. In the future, once the system is fully developed, ROCOM intends to give road authorities cheaper and faster alternative to inspect road surface condition and also through crowdsourcing, motorcyclists can be warned of risky road condition ahead of their path.

1. Introduction
According to the World Health Organization (WHO), almost to a quarter (24.1%) of the world’s road traffic deaths occur among riders of powered-two-wheelers (PTW) [1], or commonly identified in Asian region as motorcycle [2]. Of these motorcycle fatalities, the South-East Asia region (i.e. mostly low- to middle-income countries) has the highest rate of 49.9%, compared to only up to 10.9% motorcyclist fatalities in high-income countries in the European region. Malaysia is a good example to study motorcycle safety, as it typifies the countries with safety problems for motorcyclists and in Malaysia, the risk of a motorcycle rider of being fatally injured about 3 times higher than the risk of a car driver, 6 times higher than pedestrian and nearly 50 times higher than of a bus passenger [3].

One of the contributing factors to PTW crashes is the condition of the road surface. Road surface anomalies, such as potholes, speed bumps, railroad crossings, joints, can cause problems for passing vehicles and can affect road users safety [4]. Road defects such as rutting, water ponding, potholes, corrugation, etc. affect the safety of motorcycles [5-8]. In Malaysia, motorcycle single-vehicle fatal crashes are almost four times more likely than those motorcycle involve in multi vehicle fatal crashes to occur on road with rutting and corrugation [2].
To ensure that roads are free from defects, road maintenance activities have to be done systematically and cost-effectively by the road authorities. Municipalities around the world spend millions of dollars to maintain and repair their roadways [9], thus road quality assessment plays a key role in optimizing infrastructure management and road maintenance operations [4]. At the same time, informing drivers on road real conditions, in terms of the presence of bumps, potholes, or other anomalies, has a great importance in order to make the transportation system more safe, efficient and comfortable. In addition, informing drivers of hazardous road conditions [4] especially at night or when lighting is poor would be a useful for motorcyclists.

In the last few years, mobile sensors and computing systems have been developed to collect data on road quality with the final aim of giving real-time information to road users [4]. The monitoring of road conditions can be done by means of several sensors embedded in the mobile devices and nowadays, most of these smartphones/tablets use a three-axis accelerometer to collect acceleration data due to their motion on road anomalies and a GPS receiver to obtain location information of the road segment in question [4,10]. In this way, each event can be located allowing to create a database of road anomalies by means of a central server to which data can be collected by road users, e.g. such as motorcyclists [11].

Motorcycles are the riskiest mode of travel but on the flip side, it is very sensitive to the road surface condition. Thus, by taking advantage of this characteristic, we aim to develop a system of software applications that analyses motorcycle motion and mapped out risky road sections for motorcyclists.

2. Literature review

Applications for road surface defect detection are not something new. These intelligent transportation system (ITS) technologies have been well documented by Vittorio et al. [10], Vittorio et al. [4], Eriksson et al. [9] and Alessandroni et al. [12]. This ITS tech are beneficial to drivers navigation system when informing of hazardous road conditions especially at night or when lighting is poor [12]. However, these currents developed ITS devices for road defect detection; services and applications are usually designed for four-wheeled vehicles [13] and rarely for motorcycles.

Earlier studies, Vittorio et al. [10], Vittorio et al. [4] and Eriksson et al. [9], used accelerometer sensors on the phone purely to detect extreme values (x, y and z axis g values) during vehicle movement over road anomalies and they compared those to a normal driving conditions along a well-maintained road. The outcome of this technology would help road authorities to map the information of road defects efficiently as proven successfully by Alessandroni et al. [12]. This tech however is design for cars, while motorcycles are still at risk without this similar ITS tech.

As explained by Vittorio et al. [4], the accelerometer is a sensor that can detect linear accelerations along 1, 2 or 3 axes, by measuring the inertial forces, which can be represented with a 3-dimensional Cartesian frame with fixed x’y’z’, embedded in the mobile device. The accelerometer provides acceleration values in three directions: longitudinal (ax), lateral (ay) and vertical (az). When the vehicle is in a stationary condition, the only acceleration registered is along the z axis, and it is equal to gravity:

\[ a_x = 0 \text{ m/s}^2 ; \ a_y = 0 \text{ m/s}^2 ; \ a_z = 9.81 \text{ m/s}^2 = 1g \]  

Previous studies such as in Vittorio, et al. [4], Kitani [13] and González, et al. [14], relied on the orientation of the accelerometer sensors so that the x-axis identified the longitudinal direction, the y-axis the transversal one and the z axis the perpendicular direction to the xy plane.

3. Method

This research project requires the team to develop a system of application, which comprise of a mobile, a web-based application and a stand-alone software. After the development of ROCOM, data validation and field test was carried out in order to test and evaluate the system. Once the system has been developed, the system undergoes data validation and field test.
3.1 System development
Conceptually, a mobile app (ROCOM Data Logger) in the smartphone records the acceleration of the motorcycle’s motion and also video of the ride when placed correctly on the motorcycle. The acceleration data is transferred via Internet into a web-based application (ROCOM Risk Mapping) for risk mapping, while the video data is transferred into a stand-alone software (ROCOM Visual Tracking) for visual tracking analysis (see Figure 1). The development of video tracking capability requires us to integrate the smart phone’s camera function with the GPS and built-in map software. This capability was suited as a stand along software components of the system.

![Figure 1. Schematic diagram of ROCOM](image)

3.2 Data validation
The data validation was carried out utilizing the High Accuracy GPS Data Logging for Vehicle Testing (VBOX) as the baseline equipment. The location of the field test was along a section of the exclusive motorcycle lane along the Federal Highway (FR2). The data validation is based on two aspect, i.e. risk mapping validation and acceleration data validation.

3.3 Pilot and field test
Before the field-test being conducted, a pilot tests were conducted on 15th November 2016 (9.30 am), in the city of Kajang in the Kajang district. The objective of the pilot test was to test the capability of ROCOM to detect the road defects depending on the way of mounting the device on the motorcycle. The way of mounting of the phone on the motorcycle were as follow:

1. On the handle bars
2. In the motorcycle basket
3. In the rider’s backpack

This test requires us to control the road environment (based on the selected sites) and also the rider. Thus, the pilot test employed two selected riders with good riding fitness and experience and also two well-maintained motorcycles. During the tests, they were required pass along the test route, which consisted of various road defects objects demanding abrupt braking and weaving.

The field tests were conducted on the 25th November 2016 (9.00 am) at Jalan Seksyen 2/15, Kajang Utama, Kajang, Selangor (see Figure 2). The objective of the tests was to test the capability of ROCOM to obtain the acceleration values for each object of interest. Fifteen qualified riders passed through a 400 m test route containing eight obstacles with their motorcycles equipped with a mobile smartphone. To obtain variations in the data collected the type of riders and motorcycles were varied. The riders were not familiar with the test route. This was in order to maintain the Naturalistic riding behaviour – the riders to perform the test rides with their usual riding behaviour without anticipating the obstacles ahead. The tests required us to control the road environment the best possible by fixing the road environment and road obstacles. The eight obstacles along the test route were as follows: 1) weaving area, 2) road hump number 1, 3) uneven surface number 1, 4) abrupt braking area, 5) road hump number 2, 6) uneven surface number 2, 7) road hump number 3, and 8) pothole (see Figure 2). The riders were told to pass
through obstacle 1, 2 and 3 without stopping until obstacle 4, where they had to perform an abrupt breaking and then proceed to the rest of the obstacles until reaching the end of the test route.

**Figure 2.** Field test route of ROCOM

**Figure 3.** Photos at field test – obstacle 1 and 4

### 4. Result

The subsection below shows the results of the developed applications, field test and data validation results.

#### 4.1 ROCOM Data Logger

The mobile application software development was done using Apple’s IOS system software. The ROCOM Data logger app developed and designed in such way that the rider would not need to have the smart phone to be in exact orientation of x, y and z, i.e. in order to detect high or extreme acceleration or g-force with respect to the road defects or anomalies. Instead, in other words, the motorcyclists would just mount the phone on the motorcycle (e.g. on the handle bars or place securely in the basket) in any position.

**Figure 4.** Screen capture of ROCOM Data Logger app

In principle, the app would detect and record a vertical acceleration when passing a bump, or an undulating road section, or a horizontal acceleration when abruptly weaving past a pothole or object. For the high or extreme acceleration, we have set the ROCOM minimum threshold of 2g, which is
equivalent to 19.62 m/s². This threshold is based on previous findings such as in eCall and Wreck Watch as seen in [15, 16].

Our system was designed in such a way that the mobile app would automatically collect the data once it is activated, and at the end of the ride, the data will be saved into a text file, ready to be transferred via email, Bluetooth, cloud, etc.

4.2 ROCOM Risk Mapping
ROCOM Risk Mapping application is a web-based system that was developed as a tool to analyze the data (i.e. acceleration forces) from ROCOM Data Logger and display the location geographically of high threshold acceleration or road anomalies on a dedicated map.

The web base it consists of three interfaces: Overview, Map and Data display (see Figure 5). The Overview interface displays some details about the rider’s travelled distance, his or her average speed, total data collected and number of accelerations exceeded the susceptible limit of 2.0g. The Map interface reveals the risk mapping or the route that the rider has travelled (indicated by the green line) with the location where the occurrence of acceleration exceeded the susceptible limit of 2.0g. Lastly, the Data display section reveals a more detail information in terms of the acceleration figures and graph, and each GPS coordinate with respect to the sequential timestamp on when and where the data was logged by ROCOM.

4.3 ROCOM Visual Tracking
Video tracking is one of the value-added functions the ROCOM system user can observe their route and verify the risky location and to view the road surface condition with respect to the high acceleration obtain from ROCOM Data Logger and ROCOM Risk Mapping app. The video, maps, and line chart panel run according to video timestamp and raw data point (see Figure 6).
Data validation was carried out utilizing the VBOX as the baseline. The location of the field test was along a section of the exclusive motorcycle lane along the Federal Highway (FR2), from the Jalan Templer – Persiaran Narayanan interchange to the LDP interchange. The total distance traveled was 6.11km with the average speed of travel along the exclusive motorcycle lane of 22.7km/h. During the validation, ROCOM and the VBOX was synched and run together for three times along the same road section, same motorcycle and same mounting procedure.

4.4.1 Acceleration data validation
Validating each and every point from ROCOM and VBOX is a strenuous task. Moreover, not all of the points for each trial run are the same due to the fact that different rider goes on a different path despite the constant type of motorcycle. Thus, we have chosen one location that has similar coordinate for both devices in order to validate the acceleration readings.

Table 1 shows the acceleration data comparison between ROCOM and VBOX. The single data on the same location has shown that all of the x-axis acceleration value for both ROCOM and VBOX exceeded the 19.62 m/s² threshold for each trial. The acceleration differences are between 3.0m/s² to 9.7m/s² compared to the VBOX data. This shows that ROCOM is able to detect adverse acceleration or vibration on the road surface similar to VBOX.

| Trial | 1       | 2       | 3       |
|-------|---------|---------|---------|
| Latitude | 3.0851  | 3.0851  | 3.0851  |
| Longitude | 101.6236| 101.6233| 101.6237|
| Device  | #1 VBOX | #1 iPhone| #2 VBOX | #2 iPhone| #3 VBOX | #3 iPhone|
| Acc. on X (m/s²) | (20.1) (2.05) | (29.8) (3.04) | (27.6) (2.81) | (22.2) (2.26) | (21.7) (2.21) | (24.7) (2.52) |
| Acc. on Y (m/s²) | (11.9) (1.21) | (-4.4) (-0.45) | (-20.7) (-2.11) | (-10.1) (-1.03) | (0.8) (0.08) | (-7.9) (-0.81) |
| Acc. on Z (m/s²) | (11.9) (1.21) | (13.3) (1.36) | (-20.7) (-2.11) | (-0.1) (-0.01) | (0.8) (0.08) | (5.7) (0.58) |

( ): The value in the brackets are the value of the equivalent g value
Acc.: Acceleration
The red italic number indicate that the value of the acceleration (m/s²) exceed the 19.62 m/s² threshold
4.4.2 Risk mapping validation

Figure 7 shows the risk mapping comparison between ROCOM and VBOX for each trial. From the figure, we can see that both ROCOM and VBOX have the similar risk mapping pattern, i.e. most of the red markers are located similarly between trials. However, the VBOX route mapping (the green line) is inferior to the ROCOM, by which the VBOX route does not coincide with the map compared to ROCOM (see Figure 7). This may be due to the low accuracy of the standalone VBOX GPS system where else the iPhone has several complementary technologies on board that work in conjunction with the GPS chip to master the phone’s location, i.e. accelerometer and gyroscope, Wi-Fi Tracking, compass, Barometer and M10 Motion Coprocessor.

![Risk mapping comparison between ROCOM and VBOX for each trial](image)

**Figure 7.** ROCOM Mobile and VBOX risk mapping comparison for each trial

4.5 Pilot and field test results

The pilot test results showed that mounting the smartphone on the motorcycle handle bar and fasting it on the motorcycle basket with the ROCOM activated had the highest success rate of detecting the obstacles compared to placing the smartphone in the backpack.

To evaluate the detection capabilities of ROCOM, data of each individual trial was recorded with a frequency of 0.01 Hz and for each obstacle its acceleration readings were observed and match (see Figure 8). Those exceeding acceleration readings exceeding 2g were counted and compared with other rider.
Figure 8. The acceleration graph matched with the location of the obstacles

Results from the field test indicated that ROCOM is able to detect various obstacles with the average of successful detection rate of 61.9% while the highest successful detection rate (80%) occurred when riders passed through uneven surface and road humps.

5. Discussion
The aim of the work described in this paper was to develop mobile- and web-based application software that analyses motorcycle motion data gathered from a mobile app and mapped out the hazardous road sections for motorcyclists. We have developed a system that consists of three major components, i.e. ROCOM Data Logger app, which utilizes a smart phone to collect acceleration data, ROCOM Risk Mapping app, which is a web-based application, and ROCOM Visual Tracking, which is a stand alone software.

Data validation results shows that ROCOM is able to detect adverse acceleration (> 2g) or vibration on the road surface similar to the High Accuracy GPS Data Logging for Vehicle Testing (VBOX). Risk mapping validation along a section of the motorcycle lane along Federal Route 2 shows that not only ROCOM have the similar risk-mapping pattern, but its route tracking capability on the map is far superior that the VBOX. The pilot and field test results showed that ROCOM works best when mounting the smartphone on the motorcycle handle bar or basket, and it can detect various road anomalies with successful detection rate of 62%, with high detection rate when passing through uneven road surfaces.

The results from our test experiment show that ROCOM has similar capabilities as software developed by [17], [10] and [9]. For example, [17] and [4] has developed a dedicated sensing unit for the system and have evaluated the availability of a smartphone as the sensing device with the system, which resulted that the sensors on the mobile phone were enough to sense the motions as similar to the dedicated sensing unit. On the other hand, many literatures have suggested that filtering equation be embedded in the software algorithm such as in [10] and [11]. However, ROCOM adopts a simpler approach by detecting any road defects or obstacles only when the threshold of 2g is reached.

Further tests and calibrations of ROCOM are needed in terms of finding the ideal condition (e.g. appropriate speed) for accurate detection. Although we have found that mounting on the handlebars is suitable for a better detection rate, the mounting equipment must be placed so that it is close to the handed in order to mitigate the effects of vibrations. Thus, we recommend that ROCOM should have custom made mounting equipment.

6. Conclusion
The results from our data validation and field test show that ROCOM has similar capabilities as software developed by [17], [10] and [9], that could record road surface condition and map out the risky location.
The study also finds that ROCOM Visual Tracking app was able to proof the accuracy of road surface detection from raw data taken by ROCOM Data Logger. While the ROCOM Risk Mapping application shows that not only ROCOM have the similar risk-mapping pattern with the High Accuracy GPS Data Logging for Vehicle Testing (VBOX), but its route tracking capability on the map is far superior that the VBOX.

Once ROCOM is fully develop, it intends to give road authorities a cheaper and a quicker alternative to inspect road surface in the future. Road authorities can form an inspection team consist of motorcyclists mounted with ROCOM and inspect their road on a regular or schedule basis without breaking their yearly budget. Risk mapping in ROCOM can give an accurate risky location for motorcycle and allow road authorities prioritized their road maintenance. Most important of all, ROCOM can be upscaled for mass usage and crowdsourcing among motorcyclists so that they can be warned of potholes, cracks or corrugation ahead of their destination.

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