Abstract—This paper proposes a novel dangerous driving report system using a smartphone platform. By collecting a stream of data through built-in GPS receiver, a time series of speed profile can be obtained for a given journey. An algorithm is proposed to detect anomaly in speed profile in order to detect whether a vehicle is speeding. As well as the ability to alert passengers in real-time in the case of speeding, the proposed system also records the journey data to be used as evidence when making a report. This is a feature which is not yet possible in the traditional dangerous driving report deployed in Thailand. A case study using three different smartphones in the proposed framework is performed. The findings reveal that the data from Smartphone is as accurate as the values from car’s speedometer with a speed offset of approximately 4km/hr.

I. INTRODUCTION

Road traffic accidents occur frequently in our everyday life. Recent studies have shown that it is one of the biggest cause of death in many countries around the world [1]. One of the major causes is human factors where speeding is one of the biggest factors contributing the risks of road accidents [2]. In many countries different authorities have set up a call centre where motorists and public transport users are able to report dangerous driving behaviour and make a complaint. Traditional dangerous driving report system is usually carried out by telephone calls, SMS, emails and websites in order to report or make a complaint regarding bad driving behaviour. This might not be sufficient as more accurate evidence might be required to prosecute a particular operator when reporting for an incident for a formal complaint or when the case goes to court as the only information being recorded is usually in the form of word of mouth.

For the past couple of years, the recent growth in the use of smartphone is rapidly increasing making them easily accessible to the majority of people. Latest findings from Google reveal that at least 14 countries around the world, such as the UK, USA and Australia, have more than 40% of their population on smartphones [3]. Technological advances coupled with cheaper cost of hardware have enabled modern smartphones to become well equipped with many different on-board sensors. Recent smartphones, such as the Apple iPhone 4S and Smartphone A, have significantly raised computational power in comparison to previous devices. For instance, the iPhone 4S is fitted with an A5 chip with dual core 1GHz processor and 512 MB of RAM, a sort of specification that was found in a high-end laptop only a couple of years ago.

Moreover, the competitive nature of mobile device market has driven smartphone manufacturers to include a wide variety of sensors capable of acquiring vast amount of useful data. These include high resolution camera, compass, accelerometer, 3-axis gyroscope, GPS receiver as well as fast data communication capabilities via WiFi and 3G. This consequently enables application developers to determine the geographic location, heading and movement of users. The aforementioned powerful processing power, popularity, relatively low cost and especially the capability to acquire rich vein of data make smartphones a good candidate as a tool to be utilised in dangerous driving report system.

To address the aforementioned drawback in the lack of evidence using the traditional call centre approach for reporting dangerous driving, this paper proposes a novel methodology by using smartphones mainly due to their ability to collect, store and send data to be used as evidence in real-time while at the same time being easily accessible. Furthermore, the work in this paper focuses mainly on the speed domain where public transport passengers are alerted automatically when the driver violates the specified speed limit in real-time as they travel in the vehicle through our mobile application. After that users have the option whether to report the incidents via our mobile application where a data log containing data related to the journey is sent to relevant agencies for a formal complaint. In addition to the proposed system, a set of experiments are carried out in this paper in order to investigate the accuracy of onboard GPS receiver on different smartphones with varying conditions.

The paper is organised as follows. Related work in the literature is reviewed in section two. The third section describes the framework of the proposed approach. The investigation of GPS receiver accuracy of different smartphones as well as the evaluation of the speed detection algorithm are presented in section four. Furthermore, an investigation to the effects of GPS reception conditions on the sensitivity and accuracy of the recorded data is performed. Finally, the last section concludes this paper.

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II. RELATED WORK

Mobile devices especially smartphones have been deployed as floating traffic probes and sensors in many applications both academically and commercially [4]. These applications include road conditions survey, traffic conditions monitoring [5] and accident detections [7]. All of these abilities are essential to an Intelligent Transport System (ITS), which aims to reduce traffic congestion and enhance traffic safety [8]. The reason that smartphones are becoming more popular in ITS is that they can track vehicles, determine their speed and provide traffic conditions at a lower cost in comparison to the traditional approach using loop detectors. In addition, smartphones are readily available now with most road users meaning that no extra specialised detection hardware is required.

Mohan et al. proposed a system where smartphones are utilised as a means to monitor road and traffic conditions [5]. This was achieved by using sensors onboard smartphones such as accelerometer and GPS sensor to detect potholes, bumps as well as vehicles braking and honking. The system has been implemented and tested where promising results in terms of the effectiveness of sensing functions have been reported.

Johnson and Trivedi proposed an approach in order to classify different driving styles based on data collected from smartphones [6]. In their approach, driving styles can be in the form of normal, aggressive and very aggressive. The results from their work reveal that various sensors on smartphones can provide good source of information for an accurate measure and classification of different driving styles.

The work presented in [7] discusses about the use of smartphones to report and detect car accidents. Similar to [5], the approach in [7] also utilises GPS receiver and accelerometer data in order to detect car accidents. The approach in [7] is different to our work in that the work that is proposed in this paper focuses on the speeding aspect of the driver where a speeding detection algorithm is presented. In addition, factors effecting the accuracy and sensitivity of data obtained from GPS receiver are investigated.

III. PROPOSED FRAMEWORK

The proposed framework consists of two major components, namely the smartphone module and data processor module. Figure 1 shows the overall framework of the system. The main function of the smartphone module is to collect related GPS data during a journey to be sent to the data processor module. The second module of the system, the data processor module, takes a stream of data from the smartphone module and detects whether the vehicle has been speeding.

A. Smartphone Module

In the proposed framework a smartphone is utilised as a front end to users as well as a tool to measure and record all necessary data to be used in the system. This is realised through our mobile application which is supported in two major mobile operating systems, iOS and Android. Collected data is in the form of GPS data where the following items are gathered.

- Speed - a measurement of instantaneous speed at which the vehicle is travelling at for each data sample.
- Position - a geographical location of the vehicle described by the latitude and longitude for each instance of a data sample.
- Heading - a measure of direction of travel in degrees East of True North.

Data is measured and recorded at a sampling rate of one sample per second. The fine sampling frequency of 1Hz creates a time series of measurement in speed and position over a period of time which is stored in a database in the data processor module. The stored data for each journey will be passed through our speeding detection algorithm which will be described in the next section.

In this work, Android SDK based on Java and Apple’s Xcode based on objective-C were utilised as a tool to create the relevant mobile applications to collect and process data onboard.

B. Data Processor Module

GPS data collected from users smartphones are sent to the data processor module to be stored in a database. The benefit of this is that public transport users are able to use the recorded data as evidence when reporting for dangerous driving.

Speeding Detection Algorithm

A stream of data is sent to the data processor module when the mobile application becomes active. This data stream produces a time series of speed and location over a length of the journey. In this work we define a plot of speed against time as a speed profile. In this context, speeding is defined as a time series of instantaneous speed with irregular speed profile. As
beginning by taking the first sample in the time series to check how the value of the instantaneous speed compares with the specified speed limit. If the speed of the current sample $s_i$ is lower or equal to the specified speed limit then the algorithm goes back to the starting point and takes the next sample to be processed. On the other hand, if the speed of the current sample is larger than the value of the speed limit then the value of the time over limit, denoted by $t_d$ is evaluated. In this context, the time over limit is defined as the duration at which the instantaneous speed $s$ has been over the speed limit. In other words, it is the time duration which the vehicle is speeding.

At this stage of the process, the algorithm checks whether to start a new timer by assessing $t_d$. The value of $t_d$ equals to zero indicates that this is the first instance at which the vehicle’s speed is over the limit. A non-zero $t_d$ indicates that the timer has already been started from previous samples and therefore its value will be incremented. In the final stage of the algorithm, the time over limit $t_d$ is compared with the value of time limit $t_L$. If the time over limit $t_d$ is more than or equal to the time limit $t_L$ then an anomaly is detected.

IV. EXPERIMENTS AND RESULTS

In this paper, the experiments are divided into three parts. The first part considers the evaluation of the speed detection algorithm described in the previous section where the validity of the algorithm is assessed. In the second part of the experiment, the accuracy of onboard GPS receiver of different smartphones is assessed with the data recorded from vehicle’s speedometer. Finally, the last part of the experiment the sensitivity of onboard GPS receiver is investigated by varying GPS reception conditions.

A. Experimental Setup

In order to perform all three experiments, a test route is chosen from Rangsit district in Pathum Thani province to Ayutthaya province in Thailand which is approximately 80 km north of Bangkok as shown in Figure 4. The selected route is a main highway from Bangkok to cities in the Northern region of Thailand. The reason that a highway is chosen for this experiment is that speeding violation seldom occurs in the urban zone due to heavy traffic congestions within the city of Bangkok. Hence, public transport vehicles are more likely to violate the speed limit on the highway. The test route is approximately 40 km long and the experiments are performed on both legs of the journey there and back. Our mobile application is installed on three Android devices to be tested. The make and models of smartphones are omitted in this paper and instead they will be identified as smartphone A, B and C. The selected smartphones are from different manufacturers with different hardware specifications. All devices are equipped with onboard GPS receiver and communicate with the system server via 3G. The vehicle used for the test was chosen such that it has a digital speedometer in order for the speed readings to be recorded as a reference as shown in Figure 5. The value of
the speed limit $s_L$ is set to 90km/h while the time limit $t_L$ is set to 45s.

TABLE I
SMARTPHONE PLACEMENT IN THE EXPERIMENT.

<table>
<thead>
<tr>
<th>Smartphone</th>
<th>GPS Reception Conditions</th>
<th>Outward</th>
<th>Return</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smartphone A</td>
<td>Good</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smartphone B</td>
<td>Good, Poor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smartphone C</td>
<td>Poor, Good</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The entire journey is divided into two legs, the outward journey from Pathum Thani to Ayutthaya and the return journey from Ayutthaya back to Pathum Thani. In order to investigate the effects of GPS reception conditions on the accuracy and sensitivity of the recorded data, the three smartphones are placed in different positions in the vehicle during the experiment to vary the GPS reception conditions. A summary of the set-up is presented in Table I. In this set-up, a *Good* reception condition is defined as a situation where the smartphone is placed on the vehicle’s console by the front passenger’s seat next to the windscreen to allow for a good amount of GPS signal. On the other hand, a *Poor* reception condition is a condition where the smartphone is placed inside a seat pocket in the back of the passenger’s seat near the middle of the vehicle. Less signal is expected to reach the onboard GPS receiver in comparison to the previous case.

**B. Evaluation of Speeding Detection Algorithm**

In this experiment, the speeding detection algorithm is verified. During the trial run of the entire journey the vehicle under test violated the speeding condition, i.e. travelling at more than 90km/h for more than 45s, three times on the outward journey and once on the return journey. Therefore, it is expected that 4 pop-up messages should be displayed during the journey to alert users that the vehicle is speeding.

**TABLE II**
EVALUATION RESULTS OF SPEEDING DETECTION ALGORITHM.

<table>
<thead>
<tr>
<th></th>
<th>Actual Alerts</th>
<th>Expected Alerts</th>
<th>Missed Alerts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outward Journey</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Return Journey</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Table II shows the results of the evaluation of the speeding detection algorithm where it can be seen that three messages have been alerted during the journey. The reason for the missing message is due to the connection error when data is transmitted to server from the smartphone via 3G as it was found that some data samples were received with a delay. As a consequence, the sequence of data samples did not appear in the correct order resulting in the algorithm detecting that the vehicle travelled above the speed limit for less than the time limit $t_L$. Hence, the pop-up message was not alerted.

**C. Assessment of Accuracy of GPS Receiver on Different Smartphones**

The main purpose of this experiment is to assess the accuracy of onboard GPS receiver of smartphones with different manufacturers. The recorded instantaneous speed obtained by the three smartphones is compared with the speed values from the vehicle’s digital speedometer.

Figure 6 illustrates the plot of speed versus time along the test route for the outward journey. It can clearly be seen from both plots that the speed profiles of all three devices and the vehicle’s speedometer follow the same pattern. However, a small discrepancies can be observed between the vehicle’s speedometer and the three smartphones. Hence, a speed offset, which is defined as the difference between the speed value from smartphone and our reference value from the

1234
vehicle’s speedometer, is calculated.

**Statistical Significance of the findings**

Figure 7 presents the histogram of speed offset of the collected data for both legs of the journey where the number of data samples is 7500. It can be seen from the graph that the samples are normally distributed with mean 3.86 km/hr and standard deviation of 3.99. A student’s T-test has been carried out and the results revealed that the 99% of the speed offset values fall in the interval of 3.73 and 3.99 km/hr with a p-value of 1. Hence we can be almost certain that the speed offset is between 3.73 and 3.99 km/hr. This invariability in speed offset means that data from Smartphone is as accurate as the values from car’s speedometer.

**Error Analysis**

In order to assess the accuracy of onboard GPS receivers, two metrics are deployed to estimate the deviation of speed values from our reference value from the vehicle’s speedometer. These metrics are Mean Absolute Percentage Error (MAPE) and Root Mean Squared Error (RMSE), which are shown in (1) and (2) respectively.

\[
\epsilon_{MAPE} = \frac{1}{n} \sum_{t=1}^{n} \left| \frac{s_o - s_p}{s_o} \right|, \quad (1)
\]

\[
\epsilon_{RMSE} = \sqrt{\frac{1}{n} \sum_{t=1}^{n} (s_o - s_p)^2}, \quad (2)
\]

where \(n\) denotes the number of samples, \(s_o\) denotes the speed values from vehicle’s speedometer and \(s_p\) denotes the speed values obtained from GPS receiver on smartphone. MAPE is a measure of relative size of estimation error in comparison to our reference speed value from speedometer. On the other hand, RMSE measures the deviation of the readings from smartphone from speedometer.

**TABLE III**

**Errors in the Measurement of Speed using Onboard GPS Receiver.**

<table>
<thead>
<tr>
<th>Smartphone</th>
<th>(\epsilon_{MAPE}(%))</th>
<th>(\epsilon_{RMSE})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smartphone A</td>
<td>2.308</td>
<td>4.397</td>
</tr>
<tr>
<td>Smartphone B</td>
<td>8.325</td>
<td>18.462</td>
</tr>
<tr>
<td>Smartphone C</td>
<td>5.698</td>
<td>5.104</td>
</tr>
</tbody>
</table>

The results of the estimation of errors are shown in Table III. It can be seen that the Smartphone A provides the most accurate data in comparison to the other two smartphones as it produces the lowest values of MAPE and RMSE. In addition, the measured error’s relative size is relatively small in comparison to the actual speed values from speedometer as only 2.21% and 4.5% MAPE are reported for the outward and return journey respectively. For all three smartphones, the errors in the journey where the GPS reception conditions are Good are lower than the case where the GPS reception conditions are Poor. These findings suggest that the GPS reception conditions have an effect on the accuracy of the
speed data for the chosen case of a highway connecting Bangkok to other cities to the north. However the error is relatively small and can be tolerated in this application as the speeding detection algorithm already allows for some discrepancies through the use of the time limit variable $t_L$.

D. Assessment of Sensitivity of Onboard GPS Receiver

In this experiment, the sensitivity of onboard GPS receiver is assessed with for the three smartphones with varying reception conditions. The accuracy of the geographical position is recorded from the three smartphones. The Smartphone A and Smartphone B were placed in a Good reception area while the Smartphone C was placed in a Poor reception area for the outward journey. For the return journey, the reception conditions of all smartphones were reversed.

![Comparison of Accuracy of Geographical Location by GPS Receiver](image)

(a) Outward Journey.

(b) Return Journey.

Fig. 8. Comparison of Accuracy of Geographical Location by GPS Receiver.

Table IV presents a summary of the GPS accuracy when detecting for geographical location for both outward and return journeys. It can clearly be seen that the accuracy of the geographical location detected by the GPS receiver becomes worse when the reception conditions is switched from Good to Poor. This demonstrates that the positioning of smartphones within the vehicle has an effect on the accuracy of the measured data.

V. CONCLUSION

This paper proposes a dangerous driving report system using a smartphone platform. By collecting a stream of data through built-in GPS receiver, a time series of speed profile can be obtained for a given journey. An algorithm is proposed to detect anomaly in speed profile in order to detect whether a vehicle is speeding where time series analysis and anomaly detection techniques are deployed. As well as the ability to alert passengers in real-time when the vehicle that they are travelling in is violating the speed limit, the proposed system also records the journey data to be used as evidence when making a report. This is a feature which is not yet possible in the traditional dangerous driving report deployed in Thailand.

Three sets of experiments are carried out in this work. The first experiment evaluates the performance of the proposed speeding detection algorithm where it was found that 3 out of 4 cases of anomaly in speed time series have been correctly identified. The findings from the second and third experiments reveal that, for the chosen route and the sets of data collected in this work, smartphones from different manufacturers produce a fluctuation in instantaneous speed measurements of approximately $+4$km/h due to GPS receivers with different capabilities. The constant speed offset means that data from Smartphone is as accurate as the values from car’s speedometer. Hence, it is a suitable choice for dangerous driving report system. In addition, experimental results in this paper confirms the fact that the reception condition effects the accuracy and sensitivity of recorded data.

Future work for this work includes using more runs for the experiments and also perform the tests on different type of route such as in urban areas. The use of other sensors available on smartphones such as accelerometer and gyroscope to provide data for the algorithm will also be considered. This will increase more dimensions to the model and therefore, a more accurate driving behaviour can be obtained.

TABLE IV

<table>
<thead>
<tr>
<th>Smartphone</th>
<th>Average Geo Location Accuracy (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Outward</td>
</tr>
<tr>
<td>Smartphone A</td>
<td>8.38</td>
</tr>
<tr>
<td>Smartphone B</td>
<td>5.82</td>
</tr>
<tr>
<td>Smartphone C</td>
<td>22.76</td>
</tr>
<tr>
<td></td>
<td>Return</td>
</tr>
<tr>
<td>Smartphone A</td>
<td>34.05</td>
</tr>
<tr>
<td>Smartphone B</td>
<td>38.48</td>
</tr>
<tr>
<td>Smartphone C</td>
<td>3.51</td>
</tr>
</tbody>
</table>

REFERENCES


