QUEEN’S UNIVERSITY

DrvieSafe: A Driver Safety Software System

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ABSTRACT

Driver profiling has been capturing increasing attention as a modelling objective for different driver behaviour models. Poor road conditions and anomalies can also have influential effect in endangering driving. This report aims at investigating and developing techniques for providing accurate driver behaviour models via the analysis of data collected using on board diagnostics (OBD) device installed in a car. Moreover, this report discusses a mobile application for Android phones that synchronously updates the driver behaviour and a web portal that displays the driver analytics derived from the driver behaviour models. The user interface, workflow and functionality of both the mobile and web applications are included in the end of this report. After test driving for more than 1000 kilometres, we have shown that the driver's behaviour can be accurately represented by a mathematical model, and the mobile application is effective in providing the drivers real-time updates in order to promote safer driving.

1. INTRODUCTION

The problem of traffic overcrowding is becoming more alarming every day as the number of vehicles constantly increase around the globe (Aleyadeh, 2014). With more vehicles on the road, road users are more prone to accidents. It has been reported in several studies that the major cause of accidents on roadway is highly attributed to human error. Driver inattention, unintended manoeuvres, reckless and aggressive driving are the primary cause of accidents according to these studies (Castignani, Frank & Engel, 2013). Incorporating driver behaviour models into advanced driver assistant systems to issue a warning to drivers ahead of time before performing unsafe driving manoeuvres and providing drivers with accurate reports of their driving behaviour could largely improve traffic safety and enhance the driving experience as a whole.

The main objective of this report is to implement a software system that detects hazardous driving situations. The profile of the driver in interest, road condition and profiles of the surrounding drivers are the three essential elements to detect hazardous driving situation. Driver profiling will be determined by analysing data of acceleration, braking, speeding, and turning. These variables can be detected using measurements collected from the vehicle's OBD system and the smartphone that runs the mobile application. Road conditions will be determined by analysing the data collected from different cars on the same section of the road. Profiles of the surrounding drivers will be collected from the cloud server. After collecting these three types of data, we modified a fuzzy algorithm to determine the driver's overall level of hazardous in driving due to the lack of precision of cell-phone collected location data (Castignani et al., 2013). In the end, a defuzzifier will be used to generate the numerical score to be sent to the driver via mobile and web application.

In order to show the analysed data and corresponding messages, we have developed a mobile application for real-time driving evaluation, and a web portal for post-driving data tracking. DriveSafe, the driver safety mobile application, provides drivers with forecasts, feedbacks and safety instructions to adjust their behaviour while they are driving. That includes warning the drivers with dangerous road condition and reporting the percentage of aggressive drivers in a particular road. It also contains functionality that enables the users to report potholes and icy road condition in a particular location to the cloud server, in order to warn other users once they are driving near that area.

Travel Viewer, the data viewing web application, provides drivers and any party in interest detailed information about the trips drivers made. Travel Viewer generates various charts that correspond the data, including speed, engine revolutions per minute (RPM) and Global Positioning System (GPS) bearing angle, with the geographic locations, so that the drivers are able to relate their behaviours with different segments of road. Providing the raw data inputs makes our decision making process more transparent. Since Travel Viewer shows the reasoning behind the segments that are classified as aggressive driving by our model, drivers are able to adjust their overall driving attitude by improving a particular score.

After developing and deploying the cloud server, web portal and mobile application, we tested the correctness of the algorithm by making trips in Eastern Canada for more than 1000 kilometres with 3 different drivers and various road conditions. During these trips, the effectiveness of the mobile application is tested and evaluated. Adjustments for the algorithm are made after these trips in response to the difference between collected data and the ones Castignani et al. presented.

2. RELATED WORKS

Due to the development of smartphone, they are now equipped with sensors which allow to detect any changes in its environment instantaneously. There are numerous mobile applications that are developed to share real time traffic condition and are able to detect driver behaviour. Furthermore, to have more accurate driving data from users, On-board diagnostics-II (OBD-II) can be installed on the vehicle for self diagnostics and report capability.

2.1 Waze Application

Waze application is a GPS-based geographical navigation application for smartphones which has the functionality to display information such as travel times, and route details, downloading location road information over internets. Different from GPS navigation software is that it is community-driven which may be gather traffic information and local road condition from users (Terdiman, 2009). Drivers can report accidents, traffic jams, and poor road conditions and can add friends while using this application. In addition to have real-time traffic and other road condition alerts, Waze simultaneously sends information back to its database to improve the service. Since Waze is updated continuously, it also has the ability to highlight the busy highway and look for the best routes to the destination by avoiding traffic jams, and poor road condition.

2.2 Inrix Application

Inrix application provides real-time traffic information, forecast and travelling details. It also has the functionalities to set up a notification for departure and save particular address and routes on cloud. Similar to Waze mobile application, it also has the ability to report roadway incidents such as road closures, accidents and arrival time to the destination. The data that affects traffic, including weather forecast, road construction and special events would be uploaded by mobile network to the database of Inrix, and it may turn the variable into traffic predictions. The improvable prediction may give us the fastest routes to the top destination and a safer routes by alert the driver of the poor road condition and traffic jam.

2.3 iDigi X-Trak 3 OBD Toolkit

iDigi X-Trak 3 is a compact tracking and telematics gateway for monitoring mobile and fixed assets. It can monitor and update predefined events such as current coordinates, temperature, route monitoring, over-speeding and in-vehicle parameters monitoring. This intelligent device is able to connect to iDigi Device Cloud which offers secure, scalable access to an unlimited number of remote assets and enables seamless integration into back-end office applications. Also, iDigi products are able to customize the application to do analyze by the industry standard scripting languages Python. However, X-Trak 3 is no longer been supported and developed.

3. DRIVER PROFILING

3.1 Input variables

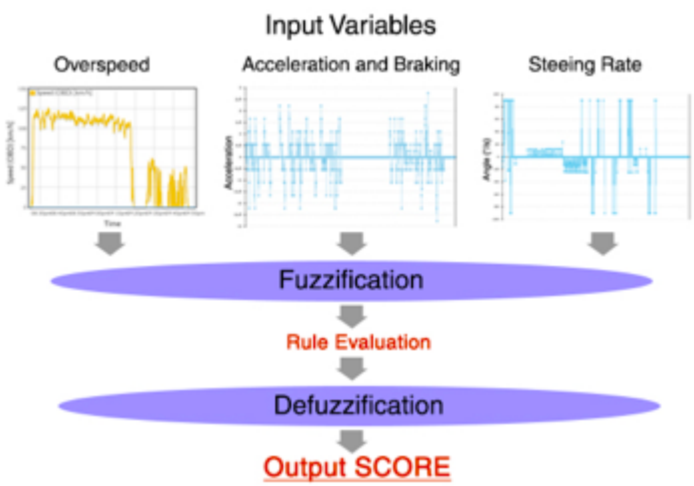


Figure 3.1: Fuzzy Inference System

In the application, the score is based on four measurements, over-speed, acceleration, braking, and steering rate. All types of measurements have same priorities for the scoring.We modified a fuzzy algorithm (Castignani, Frank, and Engel, 2013) to determine the driver's overall level of hazardous in driving. Due to the lack of precision of cell-phone collected data, most data used for analysis are collected by OBD. We used Torque, an OBD performance and diagnostic tool, to upload live OBD data and smartphone-collected GPS data to our Amazon Web Service (AWS) EC2 Ubuntu Linux server. Then, we use a fuzzy system combining input data and multiple evaluation rules to generate a reliable score. Figure 3.1 illustrates the flow of data through a fuzzy system. This fuzzy mechanism has been evaluated in around 30 trips with more than 1000 kilometres of different road conditions. The input variables for each measurement are described below.

1) Over-speed

Over-speed is an essential and useful metric to define the driver behaviour. Travelling with a high speed means driving dangerously and has high probability of generating related problems such as the loss of control during heavy braking. In order to compute the level of over-speed, we set the speed limit of local road to 50 km/h and the speed limit of highway to 80 km/h according to the Ontario Road Safety (Ontario Ministry of Transportation, 2016).

In order to have a measure of the over-speed level, we considered three input variables for it. First, the relative over-speed time OS_T is the normalized amount of time the driver incurs in over-speed. The value is in a range between 0 and 1. $OS_T = 0$ indicates no over-speed during the complete duration of the trip, and $OS_T = 1$ indicates that the driver has incurred in over-speed all the time during the trip. We also consider the average over-speed OS_A and the maximum over-speed OS_P to be the other two input variables.

2) Acceleration

Aggressive drivers accelerate faster and invoke more aggressive acceleration events. Such actions may be caused by start-up delay in intersections and during lane changing (Telogis Blog, 2014).

We define the acceleration as positive physical acceleration during a certain time period, in this case 1 second. The acceleration is calculated by the physics formula: $Average\ Acceleration = \frac{\Delta velocity}{\Delta time} = \frac{v_f - v_i}{t_f - t_i}$. Then, only positive acceleration values are selected. The speed and time are collected from OBD. First, we consider the number of moderate and aggressive events per kilometre. Moderate (GA_M) linear acceleration events are those with values greater than 1 m/s^2 and aggressive (GA_A) events are those with values greater than 2 m/s^2. Secondly, we consider the maximum linear acceleration (GA_P).

3) Braking

In some studies (Castignani, Frank, and Engel, 2013), braking is considered together with acceleration. We decide to consider and analyse them separately since the controls of accelerator and brake are independent. Braking reactively or too late for a situation increases the likelihood that the vehicle behind will run into the back of the front car.

Similar to acceleration, we define the braking as deceleration during a certain time period, normally 1 second. Braking is calculated by the acceleration equation and only negative acceleration results are selected. We also consider three input variables. Moderate braking (BR_M) events are those with negative acceleration less than -1 m/s^2, aggressive braking (BR_A) events are those with negative acceleration less than -2 m/s^2 and the maximum braking (BR_N) is the maximum deceleration.

4) Steering Rate

Excessive speed through corner or bend is a dangerous and aggressive manner that seems to upset the balance of the car. To measure the steering behaviour of drivers, we consider the bearing angle per second. Since the smartphone-collected sensing data has a high level of noise, we decide to compute the steering angle changed in one second from two consecutive GPS coordinates collected by GPS tracker.

We consider three input variables for the steering rate. First, the number of moderate and aggressive events per kilometre, BE_M and BE_A, respectively imply those where the bearing rate is greater than 10° /s and greater than 40° /s based on our empirical findings and previous studies (Castignani, Frank, and Engel, 2013). Moreover, we also consider the maximum observed steering rate, BR_P, as the other input variable.

3.2 Fuzzy Algorithm for Driver Profiles

After collecting and computing all the input variables, a driver is characterized by a set of variables describing over-speed (OS_T, OS_A, OS_P), acceleration (GA_M, GA_A, GA_P), braking (BR_M, BR_A, BR_N) and steering rate (BE_M, BE_A, BE_P) in the proposed scoring instrument. According to the step shown in Figure 3.1, first, we assign all input variables with a non-numeric linguistic value qualitatively to facilitate rules evaluation. All sets are labelled with three linguistic values: LOW, MEDIUM and HIGH. The limits of each set have been cautiously defined based on empirical data and previous studies (Dingus, Klauer, Neale, Petersen, Lee, Sudweeks, and Bucher, 2006).

Figure 3.2.1 and 3.2.2 show the two speed graphs of driving on local road and highway. We consider that average over-speed (OS_A) excesses more than 15 percent of the limit speed as MEDIUM, more than 30 percent of the limit as HIGH, and otherwise as LOW. Also, excessing more than 20 percent of the limit speed and 40 percent of the limit speed are the limit values for maximum over-speed (OS_P).

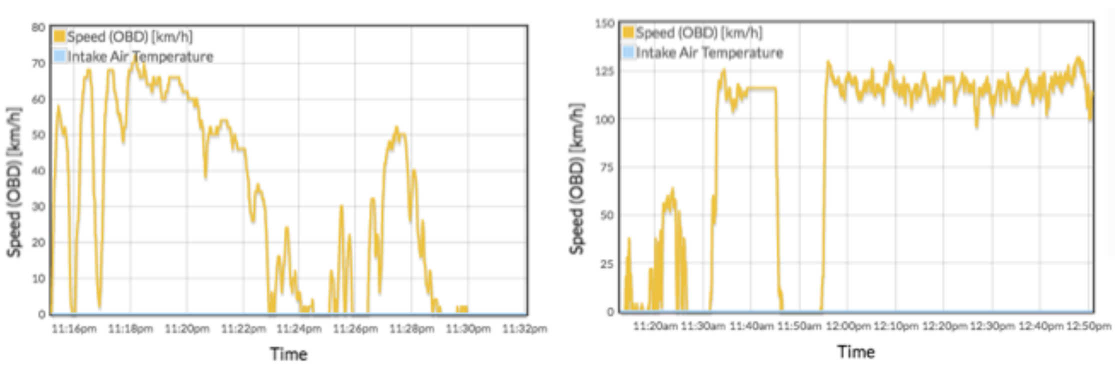


Figure 3.2.1 and 3.2.2: Speed Graph- Data are collected on local roads and highway individually

Figure 3.3.1 and Figure 3.3.2 show an acceleration plot of a set of our testing data and a graph of moderate and aggressive events computed by testing data collect in several trips. The maximum acceleration (GA_P) exceeding 2 m/s^2 indicates HIGH, exceeding 1 m/s^2 indicates Medium, and otherwise indicates LOW. We consider that the number of moderate events per kilometre exceeding 12 as MEDIUM, exceeding 16 as HIGH, and otherwise as LOW. Also, the number of events exceeding 1 and 2 are considered as the limit values for the aggressive events (GA_A).

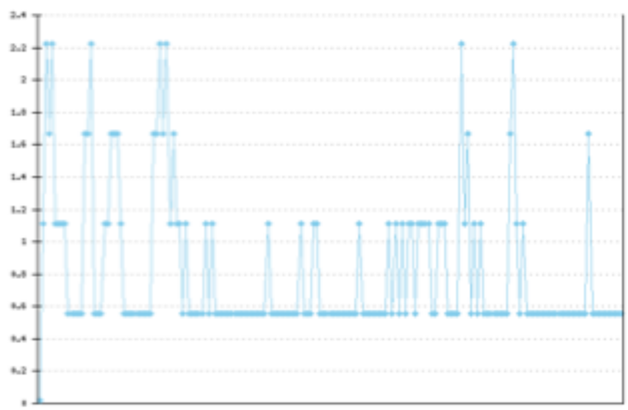


Figure 3.3.1: Acceleration plotting

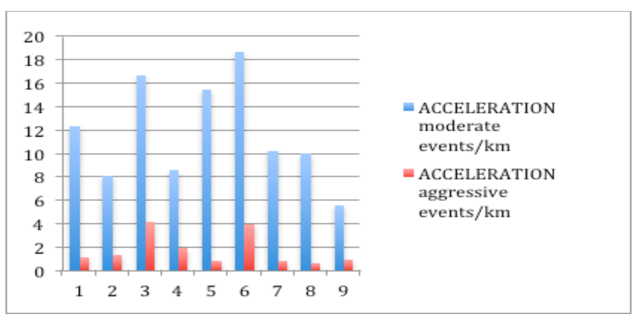


Figure 3.3.2: Moderate and Aggressive Events of Acceleration

Figure 3.4.1 and Figure 3.4.2 show a braking plotting of a set of our testing data and a graph of moderate and aggressive events computed by testing data collected in several trips. The maximum braking (BR_N) exceeding -2 m/s^2 indicates HIGH, exceeding 1 m/s^2 indicates

Medium, otherwise indicates LOW. We consider that the number of moderate events per kilometre exceeding 10 as MEDIUM, excessing 13 as HIGH, and otherwise as LOW. Also, the number of events exceeding 3 and 5 are considered as the limit values for the aggressive events (GA_A).

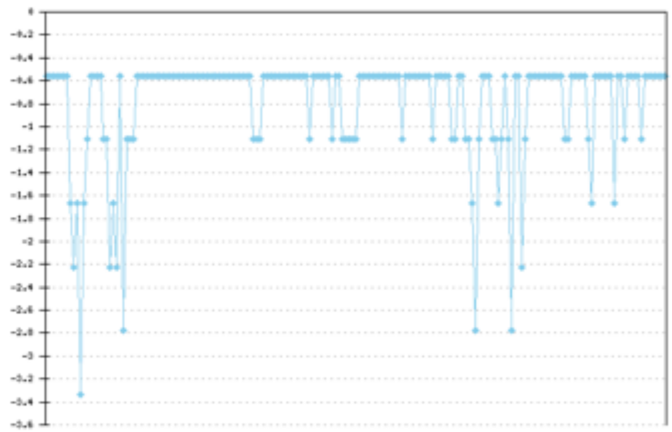


Figure 3.4.1: Braking Plotting

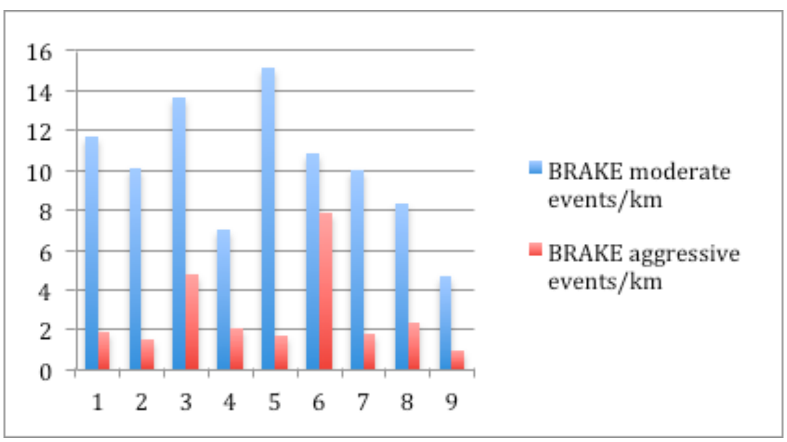


Figure 3.4.2: Moderate and Aggressive Events of Acceleration

Figure 3.5.1 and Figure 3.5.2 show a steering wheel position plot of a set of our testing data and a graph of moderate and aggressive events collected in several trips. The maximum bearing angle (GA_P) exceeding 40 °/s indicates HIGH, exceeding 10 °/s indicates Medium, and otherwise indicates LOW. If there are more than 3 moderate events per kilometre, the situation will be considered as MEDIUM. The situations with more than 5 moderate events per kilometre are considered as HIGH, and other situations are considered as LOW. Also, the number of events exceeding 2 and 4 are considered as the limit values for the aggressive events (GA_A).

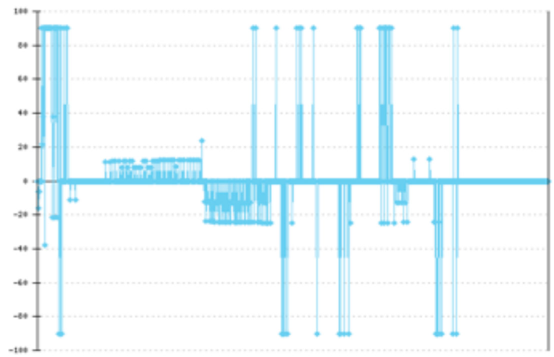


Figure 3.5.1: Steering Wheel Position Plotting

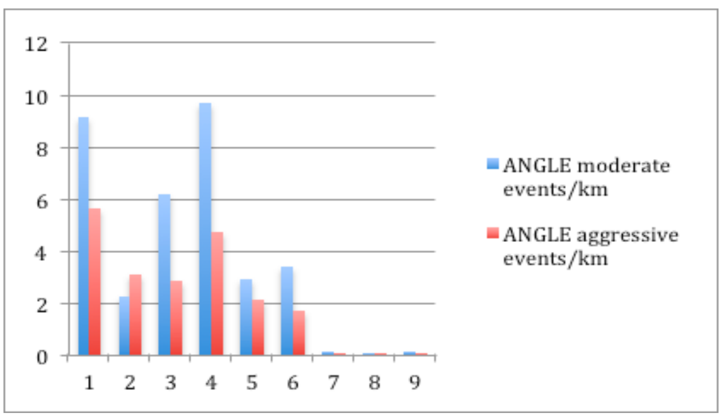


Figure 3.5.2: Moderate and Aggressive Events of Steering Wheel Position

Regarding the output variable, we also consider three categories for the score: LOW, MEDIUM, and HIGH, same as the input values. Figure 3.6 illustrated the fuzzy set for the output variables.

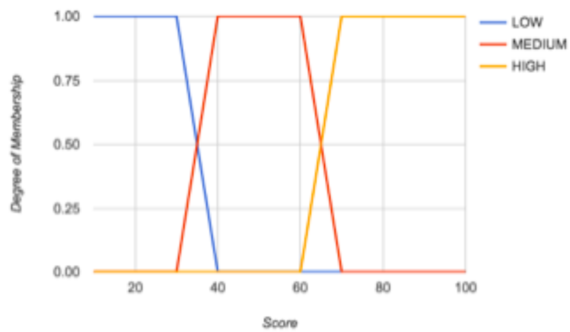


Figure 3.6: Output Fuzzy Set

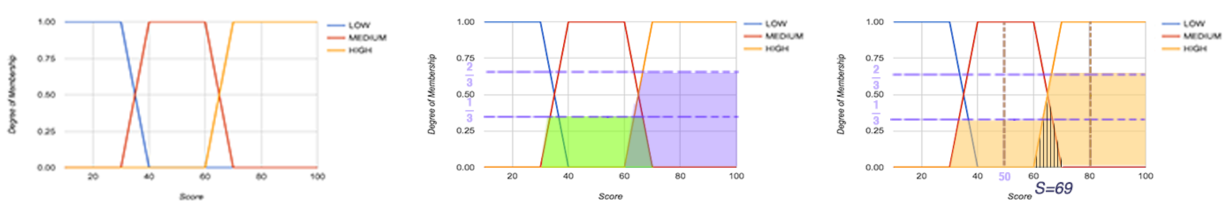
Then, we define Fuzzy rules for all possible combinations of the different input variables to classify the driver's hazard level of the four measurements. There are 27 combinations of each measurement. Ignoring the order of the combinations, there are 10 different combinations with 3 input variables. We develop a set of rules that have the form of if-then statements. Figure 3.7 describes all the rules in detail. The number in the table reflects the count of the variables in a fuzzy set. For example, in the first row, if the number of 'LOW' inputs is 3 in a certain fuzzy set, then the output of that measurement is 'LOW'.

LOW	MEDIUM	HIGH	OUTPUT
3	0	0	LOW
2	1	0	LOW
2	0	1	MEDIUM
1	2	0	LOW
1	0	2	HIGH
1	1	1	MEDIUM
0	3	0	MEDIUM
0	2	1	HIGH
0	0	3	HIGH
0	1	2	HIGH

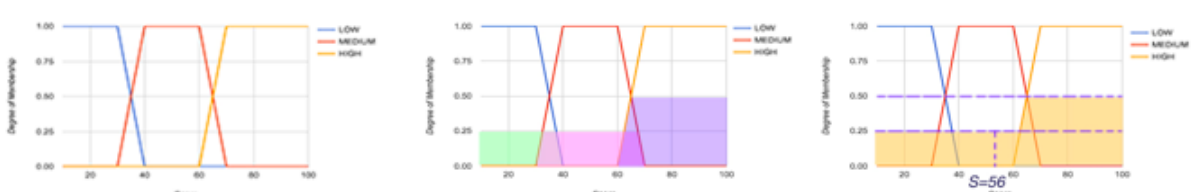
Rule Evaluation

Figure 3.7: Evaluation of Rules

Even though the rule-evaluation process assigns strengths to each measurement, a numerical score is still necessary to decipher the meaning of vague linguistic variables using membership function. Through a defuzzification process, we apply the centre of gravity (COG) method to generate the score. Figure 3.8 (a) illustrates the process of COG to generate the score of one of the measurement with one MEDIUM input and two HIGH inputs. Each of them weights 1/3 equally. The graph shows 2 variables, MEDIUM with membership 1/3 and HIGH with membership 2/3. A centroid point on the X-axis is determined for each output membership function (Klir, Yuan, 1995). Then, the defuzzified output is derived by a weighted average of the centroid points and the computed areas, with the areas serving as the weights. The score after defuzzification is 69, which indicates the driver should pay attention to this measurement. Moreover, Figure 3.8 (b) illustrates the way to generate the overall score of the driver profiling. Each of the four measurements has a membership degree of 0.25. And, the input variables are two HIGH, one LOW and one MEDIUM. Thorough the same process of defuzzification, the driver gets an overall score of 56, which indicates that she is a moderate driver.



(a)



(b)

Figure 3.8: Defuzzification Process

4. ROAD CONDITION EVALUATION

The detection of vehicle's driving environment is necessary to secure transport facilities safe from accidents and to keep the performance smooth. Road condition is one of the most important factors toward detection of vehicle driving environments, since poor road condition such as missing guardrails, potholes, and faulty design can be the cause of serious car damage or even injuries for the unwary driver (Horiba et. al, 2002). If the driver is familiar with the potential road, traffic, visibility or weather conditions which in fact arose, the driver has a duty to exercise caution by driving at a speed that was not excessive relative to those conditions which may reduce the rate of accident happen.

The traffic and road condition may be assimilated from smartphone, OBD sensors and human reporting. Due to limited time and resources, the road condition in our application could only be detected and stored in the database by human self reporting using the DriveSafe Android application. According to the study by Aleyadh in 2014, if the system is well developed by getting information from different sources would better assists viewers in understanding the road condition on the route they are travelling on.

In our application, the road condition is continuously evaluated in terms of driver reporting the potholes and icy road condition through Drive Safe Android application. After the report of potholes and slippery condition, the results will be transmitted back to server with the corresponding GPS coordinates. For surface coarseness analysis, the number of reported poor road condition, as an numeric values, would be categorized into three linguistic set: LOW, MEDIUM, and HIGH. The risk level would be reported as HIGH when the pothole and icy condition are reported more than three times in the range of 10-metre radius wide from current GPS coordinates. The number of reported condition in the range of one to three would be indicated as MEDIUM, and the number below would be considered as LOW in the risky score level. Furthermore, the score would be displayed on DriveSafe application in order to alert the driver that is going to travel through the same location. The experimental results demonstrate the feasibility of our road condition monitoring system for detecting the condition of road surfaces in close to real-time.

5. SURROUNDING DRIVERS EVALUATION

Recent studies of driver distraction have reported a number of detrimental effects of in-vehicle interaction on driver performance. Specifically, by the results of simulating two distinct car-following scenarios illustrate that in-vehicle interaction by one driver can have significant downstream effects on other drivers (Salvucci, 2013). In this situation, to sense whether the driver is surrounded by aggressive driver has become important since such behaviour has been shown to be a major cause of traffic accidents and quantifying it and its determinants can help design programs that aim at reducing aggressive driving behaviour.

This system of detecting surrounding drivers is aim to provide forecast of current circumstances to the driver, in addition for driver to make the best routes to their destination. In our application, all drivers are assumed to have OBD and Torque Android application installed on their vehicles and also have mobile network to upload the data simultaneously to the web server for analysis. All the driver profile score would be stored in database. Every time the driver has made a new trip; in addition, the total aggressiveness score of the particular driver would be updated. Similar algorithm as detecting the risky level of road condition, the total score of each driver's behaviour would be categorized into three linguistic sets: LOW, MEDIUM, and HIGH. If there are more than three aggressive drivers around the user within 10 metres of the current GPS coordinates, the score of surrounding driver profile would be displayed as HIGH on DriveSafe mobile application. The number of aggressive drivers in range of 1 and 3 would be considered as MEDIUM, and the number that below would be indicated as LOW. It would also send a warning message, if the score of surrounding driver profile becomes HIGH, for driver to remain a safety distance from the other aggressive drivers.

6. USER INTERFACE AND WORKFLOW

DriveSafe employs a simplistic style of design in order to minimise the learning cycle of users. Since DriveSafe is designed to be used whilst driving, the user experience flow is designed to be as readable as possible, and the interface is straightforward in conveying warning messages and suggestions.

When opening the application, the users are presented with a welcome screen containing three choices: User Profile, New Drive and Intersection. The user can choose to view her profile, start a new drive, or view the surrounding drivers' risk level in the current intersection accordingly.

Figure 6.1 Select Screen

The users are able to view their numeric driving scores derived from the driver behaviour models in the user profile screen. A refresh button is provided to update the scores in case the current data is still being transmitted and calculated when this screen in present.

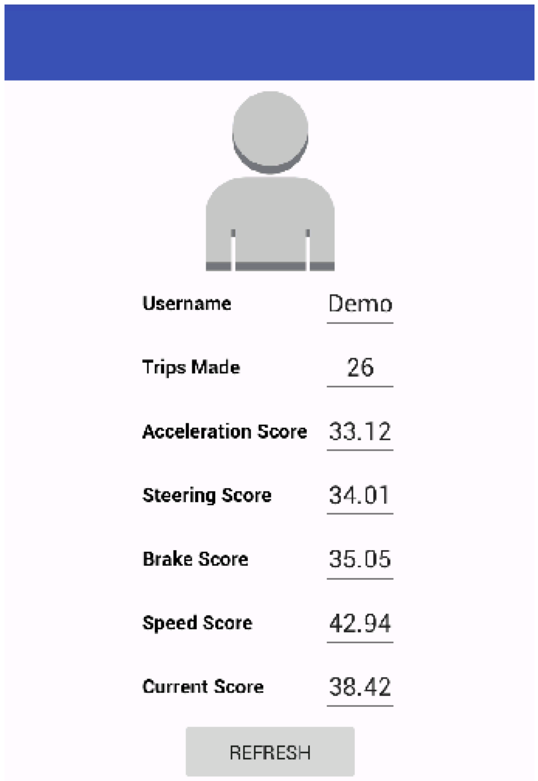


Figure 6.2 User Profile

When the users start driving, they press the 'New Drive' button and navigate to the main screen of DriveSafe that contains the risk level and its detailed breakdown. The screen is divided into three parts. In the top of the screen, a coloured banner represents the overall risk level the user is facing. Below the banner lies the driver profile section, which contains the user's level of over-speed, hard braking, aggressive steering and sudden acceleration. Road condition and the number of surrounding aggressive drivers are also included in the major part of the screen. Near the bottom of the screen, there are buttons for starting and stopping updating the score, and reporting different road conditions in the current location. In this version of DriveSafe, users are able to report potholes and icy road conditions in the main screen. The reported data is shared among all DriveSafe users, and their corresponding ‘road conditions’ section will be updated once they drive near the reported locations. In the very bottom of the screen, a banner of warning message is displayed once the user becomes aggressive in any driver profile field, or she is about to face any reported road anomaly.

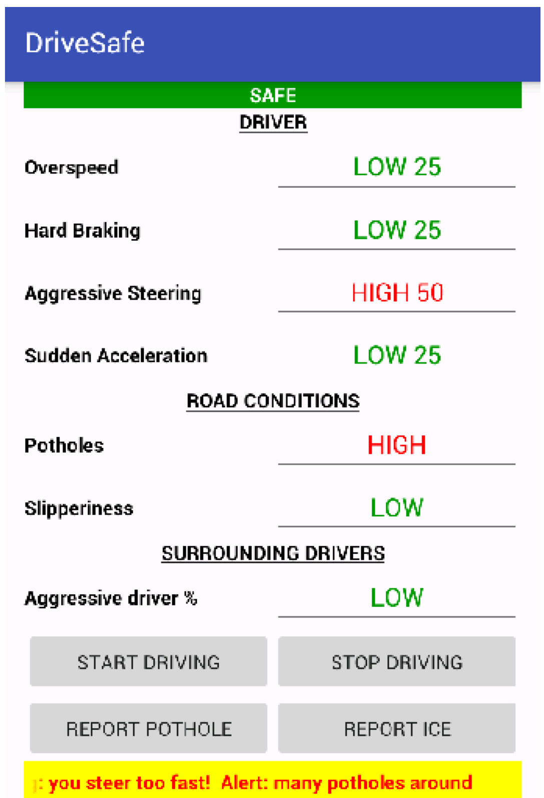


Figure 6.3 Main Screen (New Drive)

In order to raise the user’s awareness if she becomes more aggressive or any road anomaly occurs, DriveSafe creates a dialog every time it updates if there is any pending warning message. The user is blocked from accessing other functionalities of DriveSafe until she acknowledges the message by pressing ‘OK’. If she chooses to ignore the message, the dialog will update itself along with the warning message banner in every update cycle.

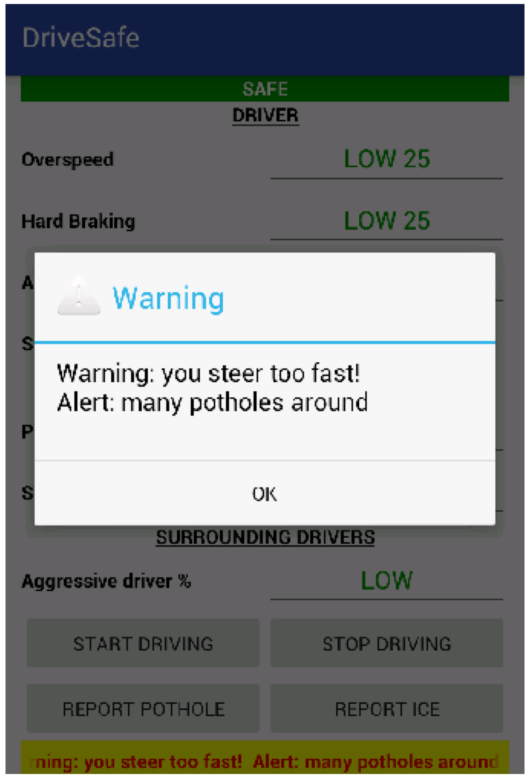


Figure 6.4 Main Screen (Dialog)

When the user drives into an intersection, DriveSafe displays the ‘Intersection’ screen and provides information about the percentage of aggressive drivers from different directions. Since intersections are one of the most common accidents spots, the user could pay higher attention at a certain direction with more aggressive drivers. Alternatively, the user can enter here from the selection screen directly if they do not wish to update the current risk levels in the ‘New Drive’ screen.

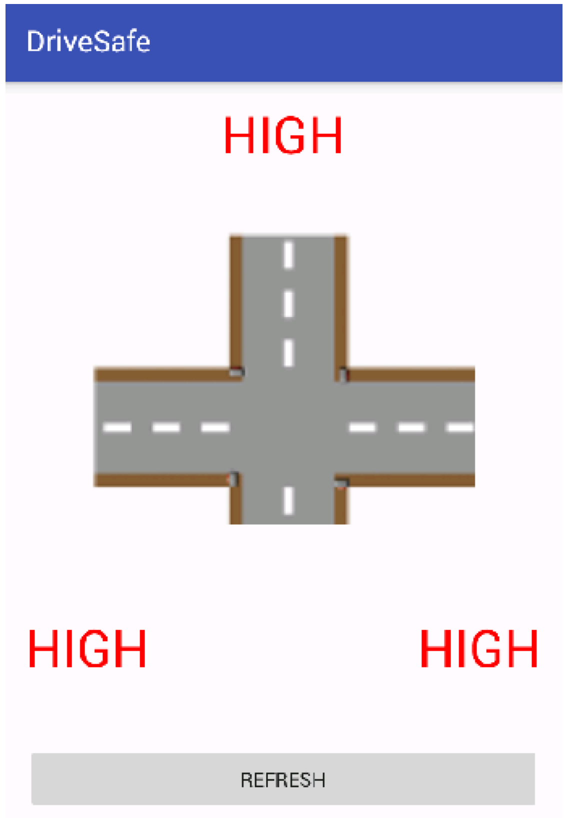


Figure 6.5 Intersection Screen

After a trip is done, the user or any party in interest can use the web portal to evaluate the user's driving performance. The web portal first prompts the user to select one of her trips to show the corresponding data. Once the trip session to display is selected, the user can choose to merge the session with others or delete it. The user can choose to plot one of the input variables against time, and the change of variable values over time is shown when the mouse moves on the chart. A map view is implemented to display the trip route and the change of selected variable values over the geographic movement. A brief summary of the selected variable is provided, as well as the overall driver profile score. The user is provided with functionality to download the raw data is .csv or .json format in the bottom of the web portal.

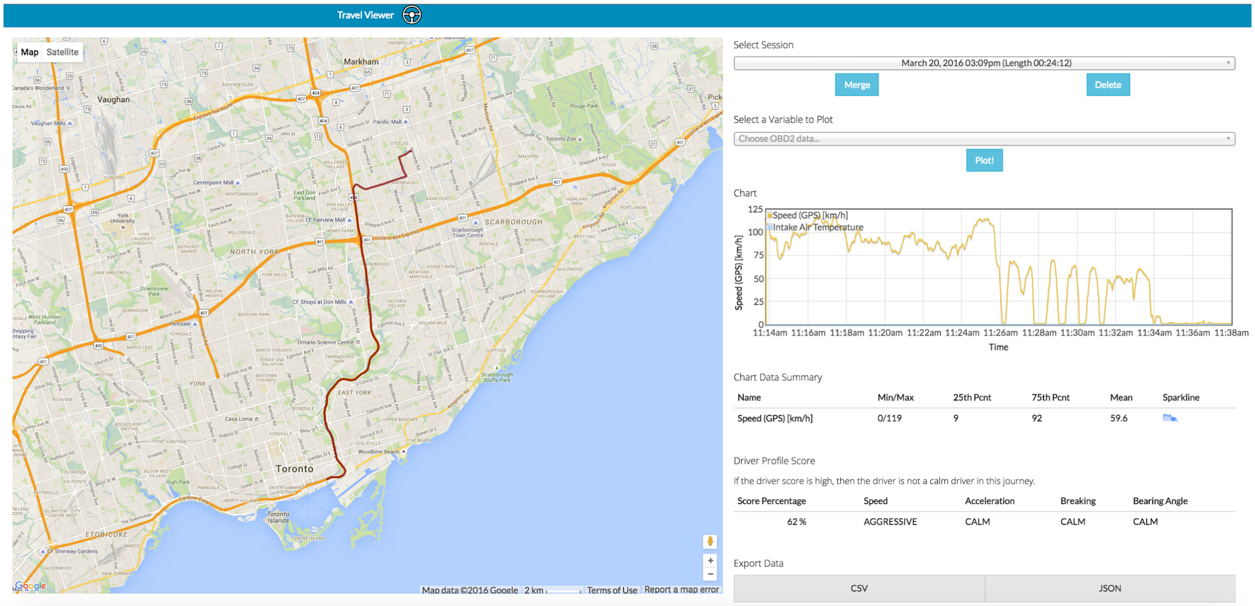


Figure 6.6 Web Portal

7. FUTURE WORK

DriveSafe could be improved in the future by using Google Map's API to retrieve any given geographic location's speed limit (Google, 2016). Currently, the in-app speed limit is set manually according to the road conditions. The accuracy of over-speed measurement for drivers will be increased significantly if the in-app speed limit changes according to the real-world regulation on every road.

The notification system of DriveSafe could be improved by replacing pop up dialogs with warning message voice clips. The current implementation of warning messages may be distracting for users to notice when they are driving. Other means of warning, including integration with the car audio system or dashboard system, may be feasible and should be investigated.

Until recently, Google Map has yet to develop tools that are able to detect intersections given the GPS coordinates. Detection of intersections is crucial to fully utilise the 'intersection' functionality of DriveSafe. By doing so, the users are shown with the 'intersection' screen once they drive near the area. This gives the drivers more time to respond to the messages, hence promotes the overall safety at intersections. Further development may include automatic route suggestion according to the number of aggressive drivers on different routes.

APPENDIX: Installation Guide

In order to deploy our software system, it is recommended to follow these instructions:

1. Set up a web server that holds the data retrieved from Torque and runs fuzzy algorithm mentioned in this report. We used an Amazon Web Service (AWS) EC2 instance to perform such tasks. Instructions can be found on https://aws.amazon.com/ and https://github.com/econpy/torque.
2. Attach the Bluetooth OBD device to your car. Download Torque application from Google Play Store. Connect Torque with the OBD device and the server mentioned in step 1.
3. Once you start logging data to the server, run DriveSafe. You will be able to view the current driving score once you start driving. Warning: it is against the law to operate your phone while you are driving.
4. Once you stop logging the data to the server, your driving session is ended. You will be able to see the detailed analytics of your driving session on https://your-web-server-ip-address/session.php.

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