DEVELOPMENT OF A VIRTUAL VEHICLE IDENTIFICATION FOR TRACKING HIT-AND-RUN VEHICLE

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DEVELOPMENT OF A VIRTUAL VEHICLE IDENTIFICATION FOR TRACKING HIT-AND-RUN VEHICLE

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed………………………………………………………… (Khoo Boon Sheng)

Date: 24 July 2022

STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated.

Other sources are acknowledged by giving explicit references.

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LIST OF SYMBOL

F	Force (N)
m	Mass (kg)
v	Velocity (m/s)
d	Distance of the car stopped after collision (m)
a	Acceleration (m/s^2)
Δv	Changes in velocity (m/s)
Δt	Changes in time (s)
x	RSSI signal strength (dBm)
a_{res}	Resultant acceleration (m/s^2)
a_x	X-axis acceleration (m/s^2)
a_y	Y-axis acceleration (m/s^2)
a_z	Z-axis acceleration (m/s^2)

LIST OF ABBREVIATIONS

ANRP	Automatic Number-Plate Recognition
DSRC	Dedicated Short-Range Communications
GPS	Global Positioning System
ITS	Intelligent Transportation System
MAC	Media Access Control
RSSI	Received Signal Strength Indication
SSID	Service Set Identifier
RSU	Roadside Unit
RFID	Radio-Frequency Identification
VANET	Vehicular Ad-Hoc Network
V2V	Vehicle-To-Vehicle
V2X	Vehicle-To-Everything
V2I	Vehicle-To-Infrastructure

PEMBANGUNAN PENGENALAN KENDERAAN MAYA UNTUK MENJEJAK KENDERAAN LANGGAR LARI

ABSTRAK

Secara umumnya, nombor plat pendaftaran kenderaan dan saksi adalah petunjuk penting untuk polis menyiasat kemalangan langgar lari. Tanpa petunjuk ini, adalah sukar bagi polis untuk mengesan suspek dan membawa kepada kes tertutup walaupun mangsa maut terlibat. Dalam kerja ini, sistem pengesanan pengenalan kenderaan maya dibangunkan dengan menggunakan antara muka komunikasi tanpa wayar untuk memindahkan data berguna untuk kemalangan jalan raya dan pengawasan lalu lintas. Sistem ini menggunakan pusat akses kenderaan dan menggunakan rangkaian ad hoc kenderaan (VANET) untuk membantu sistem pengesanan identiti kenderaan. Papan pembangunan internet pelbagai benda (IoT) mengimbas semua titik capaian Wi-Fi kenderaan dalam bingkai suar. Dengan ciri-ciri kedudukan kekuatan isyarat yang berbeza dan jarak stesen ke titik akses, adalah sukar untuk menentukan identiti kenderaan pesalah dengan tepat. Oleh itu, kertas kerja ini bertujuan kaedah pengesanan hibrid untuk menggabungkan kaedah pengesanan sebelum kemalangan dan selepas kemalangan untuk mengesan identiti kenderaan. Selain itu, laporan ini menunjukkan identiti titik capaian Wi-Fi yang unik seperti nama jaringan (SSID) dan alamat kawalan akses media (MAC) boleh digunakan sebagai identiti kenderaan maya untuk penjejakan kenderaan dan sistem pengawasan trafik. Secara keseluruhan, keputusan menunjukkan sistem ini boleh mengesan identiti kenderaan suspek dengan pengesanan positif. Apabila kedua-dua pecutan mengesan pecutan hentaman melebihi 4G atau 39.24 m/s^2, papan IoT pemancar diaktifkan dan menukar 32 bait paket dengan pemancar lain. Jarak maksimum untuk sistem mengesan isyarat titik capaian kenderaan adalah sehingga 45 meter dan ia boleh digunakan melebihi 50 km/j kelajuan pemanduan.

DEVELOPMENT OF A VIRTUAL VEHICLE IDENTIFICATION FOR TRACKING HIT-AND-RUN VEHICLE

ABSTRACT

In general, the vehicle registration plate number and the witness are essential clues for police investigating hit-and-run accidents. Without these clues, it will be difficult for police to trace the suspect and lead to a closed case even though a fatal victim is involved. In this work, the virtual vehicle identification tracking system is developed by using wireless communication interfaces to transfer useful data for road accidents and traffic surveillance. This system uses vehicle access points and employs Vehicular Ad Hoc Network (VANET) to assist the vehicle identity tracking system. The Internet of Things (IoT) development board scans all the vehicle Wi-Fi access points within the beacon frames. With the characteristics of different positions of signal strength and the distance of station to access point, it is difficult to accurately determine the offender's vehicle identity. Hence, this paper purposes a hybrid tracking method to combine pre-accident and post-accident tracking methods to track vehicle identity. Moreover, this report shows unique Wi-Fi access point identities such as Service Set Identifier (SSID) and Media Access Control (MAC) addresses can be used as virtual vehicle identities for vehicle tracking and traffic surveillance systems. Overall, the result shows this system can track the suspect vehicle's identity with positive detection. When both accelerometers detect the impact acceleration above 4G or 39.24 m/s^2, the transmitter IoT board is activated and exchanges the 32 bytes of packet with another transmitter. The maximum distance for the system to track vehicle access point signal is up to 45 meters and it is workable above 50 km/h of driving speed.

CHAPTER 1

INTRODUCTION

1.1 Overview of Project

Referring to the Nielsen Global Survey of Automotive Demand in 2013, Malaysia has the third-highest rate of car ownership in the world and almost 93 percent of households owning a car [1]. However, there have been many irresponsible drivers who cause hit-and-run accidents to happen quite frequently in Malaysia. In the worse scenario, hit-and-run accident is a crime that could increase the probability of severe injuries or even death caused by delays in emergency medical services. Inspecting the hit-and-run accident could be challenging for victims to figure out the offending driver's vehicle number plate and find any witnesses to the hit-and-run accidents. The current traffic video surveillance system to track the vehicle may limit by the weather condition and lighting background. With the life of high reliance on internet access and the growth of vehicular communications technology, Wi-Fi interfaces could be the communication protocol used to track the vehicle identity during hit-and-run accidents. Overall, this research study aims to develop a virtual vehicle identification tracking system using wireless communication interfaces to transfer useful data for road accidents and traffic surveillance. For example, the vehicle identity, coordinate location, and estimated distance could be exchanged with another vehicle for forensic investigation purposes.

1.2 Project Background

According to the Malaysian Institute of Road Safety Research (MIROS) report, Malaysia recorded around 4.94 million accident cases in the last decade, with road accidents increasing from 414,421 cases in 2010 to 567,516 nine years later in 2019 [2]. Unfortunately, some of these cases involve hit-and-run accidents, which often happen in Malaysia. In general, hit-and-run accident is a traffic offense where drivers of striking vehicles directly run away from the accident without helping the victims or reporting accidents to relevant authorities. The hit-and-run accidents could even cause the victim to miss the golden period to be rescued, leading to fatalities. Some countries like Australia, Canada, China, and Germany have implemented criminal penalties for hit-and-run accidents. In Malaysia, a hit-and-run accident could be an offence under

Section 52(2) of the Road Transport Act 1987 (Act 333) if a police report is only lodged later than 24 hours from the time of accident without any valid reasons [3].

The location of accident, event time, vehicle registration plate, vehicle colour, and vehicle type are critical clues to investigate hit-and-run cases. Vehicle registration plate is a unique identity for every registered vehicle and this identity is directly linked to the vehicle owner. Most of the time, the victims are also challenging to remember the offending driver's vehicle registration plate and figure out any witnesses in the accidents. Without any offender’s registration plate and the witness, the accident inspection process and the insurance claim could be complicated. Although the current traffic video surveillance system can recognise the vehicle registration plate, the performance may be limited by the non-standard registration plate, extreme weather conditions and lighting background. The current physical vehicle registration plate is only suitable for visual observation to obtain the vehicle identity. However, the visual observation could be constrained by the environment and the damage to physical vehicle registration plate will also cause errors in the system. With the growth of vehicular communications technology, vehicle identification could be integrated with the wireless communication protocol. Hence, this project aims to develop a virtual vehicle number plate by using vehicle access points and employing employs Vehicular Ad Hoc Network (VANET) to assist the system track the hit-and-run vehicle identity.

1.3 Problem Statements

In most hit-and-run accidents, it is challenging for victims to record the offending driver's vehicle registration plate and figure out any witnesses in the accidents. Consequently, the victim may face severe injuries in the accident and the environment also is a factor that leads to the victim failing to record the offender registration plate. Moreover, the late rescue in an accident will also cause the victim fatalities. The performance of current number plate recognition system used in traffic video surveillance is influenced by the non-standard number plate, weather conditions and lighting background. Therefore, this project is expected to present a virtual vehicle identification system for tracking vehicles.

1.4 Objectives

The several objectives of this development project are stated as below based on the problem statement of this study:

i. To develop a virtual vehicle identification tracking system for hit-and-run accident using wireless communication interfaces.
ii. To track and analyse vehicle identification using wireless communication interfaces for road accident and traffic surveillance.

1.5 Scope of Project

The primary purpose of this project is to develop a prototype for virtual vehicle identification tracking system used in hit-and-run accidents. The research study for this project focuses on the wireless vehicle identifier and the ability of tracking detection. The development project fields are toward identifying vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. The communication of VANET is mainly focused on one-to-one node communication. The wireless communication interfaces used to analyse the vehicle identification will use Wi-Fi (IEEE 802.11b/g/n) as the protocol. The prototype testing and data collection are conducted outdoors. The maximum of vehicles involved in on-road testing is fixed within three cars and the testing is based on the assumption of road accidents. Due to the current vehicular communications infrastructure and implementation in Malaysia is still immature, this development project uses future Intelligent Transportation System (ITS) as a part of its ideation.

CHAPTER 2

LITERATURE REVIEW

2.1 Research Background Overview

The research background of this development project is based on the hit-and-run accident background study, previous accident detection work, vehicle identifier method, and vehicular communication and wireless networking protocols. The hit-and-run accident background is used to study the latest road accident cases and their factors. Based on the previous work of accident detection and vehicle identifier method, the strength and limitation of previous work is defined to develop new method for tracking vehicles during accident.

2.2 Hit-and-Run Accident Background Study

Hit-and-run accident can be defined as the offender driver intentionally leaving an accident scene without helping victims or reporting accidents to relevant authorities. In the worse scenario, the hit-and-run accidents could cause the victim to miss the golden period to be rescued. Usually, it could be challenging for victims to figure out the offending driver's vehicle number plate and find any witnesses to the hit-and-run accidents. According to the latest traffic news, a hit-and-run crash happened along the Damansara-Puchong Highway on 25 July 2021. The police are seeking eyewitnesses to assist in the investigation. This accident caused a food delivery rider to suffer severe injury and coma in hospital [4]. The coverage of traffic cameras in Malaysia is still low in the urban area and it causes some road accidents that lack clues and evidence. On 23 December 2021, a freak accident occurred on the Grand Saga Highway at 10:45 pm in a hit and run accident, resulting in one death and five injured victims. Unfortunately, the highway there does not have a traffic camera. The police urge anyone who may have witnessed the accident or passed by the area to reach out with car cam footage or additional information [5].

Based on a study of the factors associated with the prospect of hit-and-run accidents, the logistic regression model shows the drivers were more likely to run when crashes happened at night, on a bridge and flyover, bend, straight road and near shop houses [6]. The main influence of this incident is the drivers always believe they could run away from detection. This hypothesis can be proved that hit-and-run crashes often happen at night when the visibility and vehicle traffic is lower. It occurred at locations easier for the drivers to leave the crash sites to avoid detection, such as bridges and flyovers, bends, straight roads and shop houses. The authors suggested that increasing the surveillance cameras on hit-and-run crash prone areas could address hit-and-run accidents. The enforcement of criminal penalties for hit-and-run accidents is important to restrict hit-and-run accidents. Although this enforcement was implemented several years ago, the hit-and-run case in Malaysia is still often happening.

Regarding a study for predicting the contributing factors of hit-and-run accidents, vehicle insurance could also increase the probability of hit-and-run accidents [7]. This is because the drivers may believe that if they are caught, their insurance rate will increase and this might be a leading motivation for offenders to trust in their speeding vehicles to flee the scene on a freeway. The motor vehicle registration number and the witness are essential clues for police investigating hit-and-run accidents. Without these clues, it will be difficult for police to trace down the suspect and lead to a closed case even though a fatal victim is involved. Usually, the paint traces or topcoat colour of motor vehicles are the only vital information that can be collected to investigate hit-and-run accidents [8]. The vehicle paint trace found in the accident can be compared with the paint sample taken from the suspected car for investigation. However, the limited sample size collected and lack of database sources are still difficult for police to track the offender's vehicle identity.

2.3 Previous Work of Accident Detection

Generally, the collision responses in an accident could be detected by measuring the vibration, acceleration, velocity, impact force, pressure and sound. Based on these responses, several accident detection methods and devices were developed. The vehicle collision detection and remote alarm device developed by Apurva ManeA uses ATMEGA 16 microcontroller, Micro-Electro-Mechanical System (MEMS) accelerometer and vibration sensor to detect accidents [9]. When the accident happens, the vibration sensor senses the vibrations, and these signals are given to the controller through the amplifying circuit. If there is a roll over of the vehicle, the angle of the rolls over will be detected by the MEMS accelerometer and given as the input to the controller. Smart Accident Notification and Tracker (SANAT) are similar to previous vehicle collision detection systems [10]. The difference between these two applications is that SANAT uses a shock sensor as the input that would detect an impact whenever an accident occurs. The actual force ratio determined the shock sensor's sensitivity to experimental force by using shock generator. The average actual impact force was determined by using equation (1).

$$F = \frac{1}{2}mv^2/d \qquad (1)$$

The ratio of actual car mass to the mass of experimental weight is 200:1. Based on this ratio, the shock sensor will sense 0 voltage and detect the collision when the impact force with 588.40 N and 117.68 m/s^2 of acceleration was generated to the prototype. Different types of sensors were integrated to combine with accelerometer to improve the accuracy of accident detection. Another IoT based car accident detection was developed by using the algorithm that operates on the data gathered by accelerometer ADXL345, vibration sensor, heart rate sensor, GPS and GSM module [11]. This detection system uses a heart rate sensor to track the person's heartbeat to know whether the driver is injured or safe to detect the accident. The peak value for heart rate sensor is above 170 bpm and the peak value of accelerometer is between $-150m/s^2$ to $-200m/s^2$ for retardation to detect accidents. However, the heart rate sensor attached to the driver's seat belt may cause the driver to feel uncomfortable and the measurement reading may be inaccurate if the seat belt is not close to the driver.

Among all the sensors used for detecting accidents, accelerometer is the most widely used sensor to measure acceleration and detect accidents. The current airbag control unit uses accelerometers to detect the vehicle's rapid deceleration during a crash. Usually, the accelerometer will sense the change of g-forces on the vehicle to identify the collision or crash magnitude. G-force is the force of gravity or acceleration on a body. An experiment of scarp car colliding with a concrete wall was conducted with varying speeds up to 40km/h [12]. The crash test results show that the mild accident was detected when the g-forces were between 5G and 20G, but the emergency message was not activated. The medium accident was detected between 20G to 40G and the serve accident could be considered when the g-forces were above 4G. The emergency message only will be activated when the medium accident and serve accident are detected. Another crash test using low g-forces accelerometer and high g-forces accelerometer was conducted to measure the time variation of acceleration, force and other parameters [13]. The impact speeds were between 35 and 40km/h in a different direction. The crash result for vehicle-vehicle collision shows the impact of a stationary vehicle with another vehicle could produce around -14G to the x-axis acceleration and 4G to the y-axis acceleration. The crash pulse of vehicle-vehicle collision to stationary vehicle can refer into Figure 2.1.

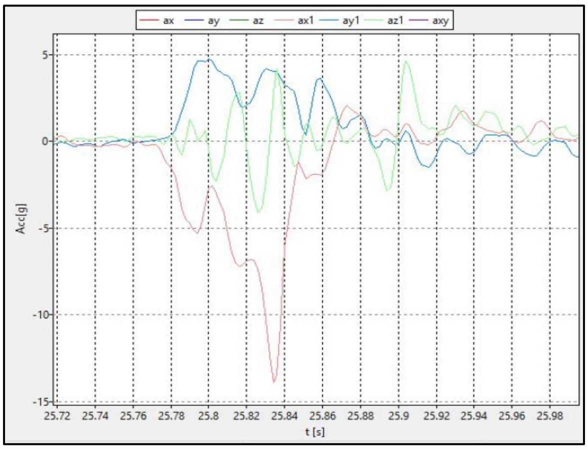

Figure 2.1 Crash pulse from a vehicle-vehicle collision [13]

Generally, the vehicle acceleration is the changes in moving velocity at a particular time and it can be determined by using equation (2). Based on this equation and the measurement of ADXL345 accelerometer, the velocity and acceleration of vehicle being stationary, moving slowly, and being stopped are provided in Figure 2.2. It shows the resultant vehicle acceleration is within the range of 0.4G to -0.3G for normal driving conditions [14].

$$a = \frac{\Delta V}{\Delta t} = \frac{F}{m} \qquad (2)$$

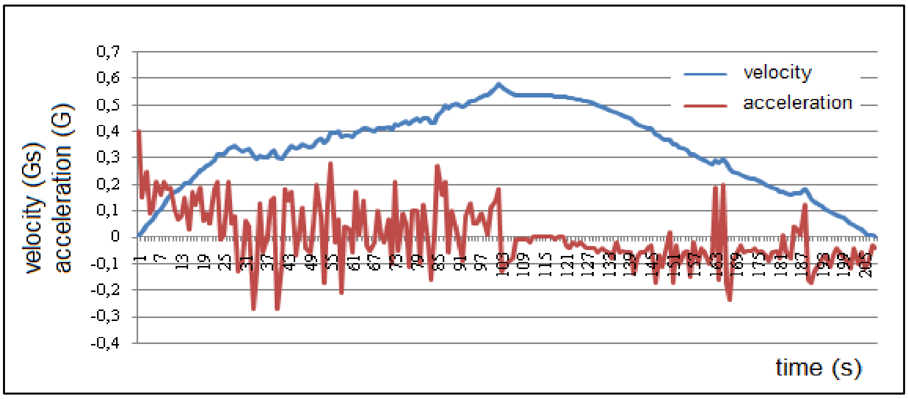

Figure 2.2 Vehicle velocity and acceleration with normal driving [14]

According to a novel of IoT-enabled accident detection, the Accident Detection and Reporting System (ADRS) was developed using a modern Android smartphone [15]. This system assumes that each car is connected to a smartphone. The smartphone is equipped with pressure sensor, microphone, accelerometer and speed sensor to determine the occurrence of an accident. They set the threshold for smartphone would experience a G-force of more than 4G in the case of an accident. This is because the smartphone's dropping in the vehicle, the maximum force experienced is not more than 3.3G and even the vehicle stops suddenly but is not under emergency braking. An experiment of evaluating false positives and negatives with crash data for automatic traffic accident detection (WreckWatch) was conducted by using smartphone. The results show the acceleration to real crash should be set as 30G for the minimum threshold value to prevent false-negative results [16]. However, using smartphones to detect the accident could be challenging since the detection is based on the phone's sensor, not the vehicle, and smartphones may have different specifications.

2.4 Previous Work of Vehicle Identifier Method

Currently, some traffic surveillance systems are equipped with automatic vehicle plate recognition technology to track the vehicle identity. An automatic vehicle plate detection system was developed using image processing techniques to monitor road traffic, such as vehicle speed and vehicle owner identification [17]. The image processing and Optical Character Recognition (OCR) techniques were used to obtain accurate vehicle plate recognition for stationary vehicles in Malaysia. The vehicle plate detecting method using OCR is highly sensitive to misalignment and number size. For Probabilistic Neural Network (PNN) and Fuzzy system are sensitive to brightness of lights and fail to detect the boundary of the plate. After the author applies cropping, filtering, and morphology techniques, the characters and numbers in the vehicle plate image are correctly identified.

However, a survey of automatic number plate recognition algorithms was conducted. The result showed the performance of Automatic Number Plate Recognition (ANPR) system could be reduced by the number plate condition, non-standardized formats, complex scenes, camera quality, camera mount position, tolerance to distortion, motion-blur, image contrast, reflections, processing and memory limitations, environmental conditions, indoor/outdoor or day/night shots [18]. The current physical vehicle registration plate with slight tilt, fonts change, broken, snow or dirt on characters will deceive the optical character recognition mechanism, since the image recognition depends on vision. Hence, the authors proposed Radio-Frequency Identification (RFID) based vehicle verification systems could be integrated with the current ANPR system. This is because the vehicle can be tracked with RFID technology irrespective of its location, whether within or without the sight of the camera view. The hybrid system of RFID and ANPR may improve the system efficiency without the influence of environment.

Based on the latest planning from Royal Malaysia Police (PDRM), the police put forward a proposal to the Road Transport Department (JPJ) and Transport Ministry for standardizing the number plates of all Malaysian vehicles under an e-plate system [19]. This e-plate uses a security microchip embedded in the number plate to verify vehicle details without setting up roadblocks. A design of RFID e-plate antenna based was developed and used to study the optimum performance by utilizing the plate number size for the RFID chip to be attached [20]. In general, the RFID tags can separate into active and passive tags. The active tag does not require line of sight as it has inbuilt power sources that enable it to send and receive signals up to a distance of 100 meters. However, the cost of active RFID is higher than standard passive tag and the passive tag does not utilize power and it only can be recognized when the tag is placed near the reader. The antenna used by authors for e-plate design is a low-cost FR4 material and it worked for Ultra-High Frequency (UHF) passive RFID application. The testing results showed that their RFID reader could obtain the signal up to 12 meters between antennas and plate number. Another testing design uses a small long-range UHF RFID passive tag attached to the license plate holder [21]. The result showed the reading range of the tag attached to the vehicle's front bumper was 9.4 m.

Several RFID-based vehicle identification systems were proposed to track the hit-and-run vehicle. This RFID-based vehicle identification system is installing active RFID tag and GSM module in each vehicle to track hit-and-run vehicle identity [22]. When two vehicles get collided, the reader from the victim’s car scans the tag placed on another car and sends the information to the registered location by GSM module. However, the RFID-based vehicle identification systems have limitations in tracking the vehicle identity during accidents. The UHF passive RFID requires specific direction or scanning distance based on these two identification systems, and it cannot fulfill the accident from different directions and impact distances. Although the active RFID tag can scan without line of sight and wide distance range, the cost for active RFID tag and reader are expensive and lack flexibility.

According to a review of RFID challenge, the RF signal is attenuated by the surrounding materials such as metal could affect the read or write range of the RFID sensor [23]. The current RFID module lacks flexibility since the tags cannot be replaced or reconfigured without a costly redesign and reproduction. The RFID module's primary purpose is only for object identification and tracking, unlike wireless sensor networks. It provides identification function and users also can use communication protocol for mobile devices to exchange data. The multiple transmissions among RFID readers and tags can cause collision problems since the tags and readers use the same wireless frequency channel [24]. The signal interference issue might happen between RFID and WLAN or WPAN, such as Bluetooth was used in vehicle head units under standard frequency bands with RFID. Moreover, the cost of commercial RFID readers is higher than the cost of sensors and tags. Installing the RFID reader and tags for each vehicle to track hit-and-run vehicles could lead to poor cost-effectiveness on the system.

2.5 Vehicular Communication and Wireless Networking Protocols

Wireless communication protocol can be defined as a protocol for various electronic devices to exchange data with each other wirelessly. Vehicular communications use wireless communication protocol to communicate with other vehicles and include roadside communication infrastructure. Usually, the telematics device consists of a GPS module, onboard vehicle diagnostics, wireless telematics devices, and accelerometer to record and transmit vehicle data, such as driving speed, position, travel distance, and other data to the cloud. With the advance in Inter-Vehicle Communications (IVC) system, the V2V and V2I communication can promote driving more safely and reduce traffic deaths.

Referring to the latest comprehensive review of Vehicle to Everything (V2X) communication technology, Malaysia is following the direction of the mobility revolution and marketing strategies for connected vehicles under National Automotive Strategy 2020, which it involving V2X, autonomous vehicles and safety systems [25].

The review paper purpose the solution of hybrid dedicated short-range communications (DSRC) and cellular network (4G/5G) as the support for V2X communication in the future. V2V could play an important role in tracking the hit-and-run vehicle, enabling nearby vehicles to form a mesh network and exchange data such as vehicle identity. On the other hand, V2I can track the information provided from vehicle to infrastructure through a roadside unit (RSU).

DSRC is similar to Wi-Fi under the same 802.11 protocols and uses medium-range RF communication technology to exchange data. The difference between Wi-Fi and DSRC is that DSRC is explicitly designed for in-vehicle environments that provide high-speed, real-time, accurate, and reliable connectivity between vehicles and roadside infrastructure [26]. DSRC consists of a series of protocols and standards that work similarly to RFID technology. VANET is a subcategory of Mobile ad-hoc networks (MANET) that is specific to vehicles and it usually works together with DSRC or Cellular V2X. In the VANET principle, each vehicle represents a node and can move around independently in the network [27]. The network configures itself based on the nodes connected and reconfigures when a node leaves or enters the network beacon frame. Figure 5 depicts the general concept of VANET [28]. Usually, the Wi-Fi use IEEE 802.11 a/b/g/n standard for point-to-point communication. It also can perform the function of DSRC for devices to interact at full speed via a wireless message within the range of 200 meters Wi-Fi network [29]. Thus, Wi-Fi can be selected to represent DSRC in the vehicular development project since the equipment and device to support DSRC are still rare in Malaysia's current market.

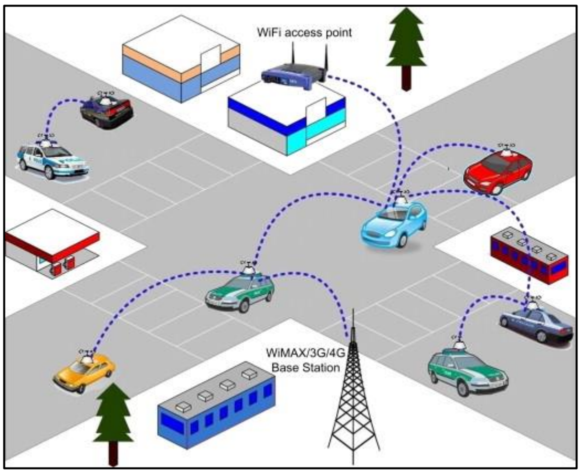

Figure 2.3 The concept of VANET [28]

According to the performance evaluation of IEEE802.11-based for VANET, the WLAN wireless router with IEEE802.11a, b and g standard was used to study the response of vehicle velocity, obstacle and distance to goodput [30]. The result show the distance increased, the throughput decreased significantly, and IEEE802.11b, g can access longer distance for vehicles exchange data. Both of them reached a distance of more than 700m. It also shows the velocity change within 60km/h has no significant influence on the goodput of WLAN channels based on IEEE802.11a, b and g. This evaluation study mainly focuses on the data transfer when both devices are paired.

This system's methodology uses Wi-Fi Received Signal Strength Indicator (RSSI) Trilateration to find vehicle location. When two wireless devices are getting further apart, the signal strength within the radius will weaken. On the contrary, the higher positive RSSI value indicates stronger signal strength when both vehicles are approach. Hence, it shows that the Wi-Fi router's signal strength and transfer rate is reduced if the distance between vehicles increases. The relationship between Wi-Fi transfer rate and vehicle distance is provided in Figure 2.4.

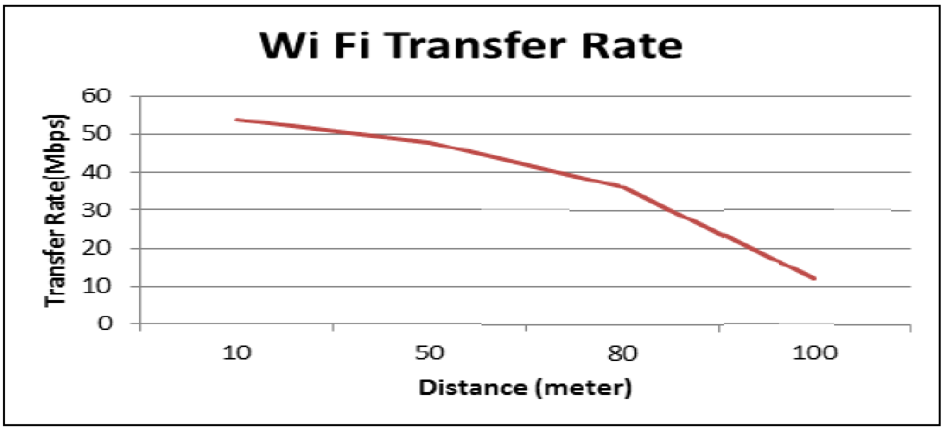

Figure 2.4 Wi-Fi distance (meter) against transfer rate (Mbps) [31]

Based on the relationship between Wi-Fi distance and signal strength, a secondary vehicle identifier was proposed using Wi-Fi interfaces and Bluetooth [32]. These two wireless protocols were proposed because the latest vehicle head-units could establish a Wi-Fi hot spot to support internet access for vehicle passengers or drivers. For example, BMW ConnectedDrive uses the iDrive system to reduce distracted driving and allow quick and easy access to navigation and entertainment services [25]. At the same time, the V2V also be deployed based on IEEE 802.11p technology to form ITS. Since the head-units configured as access points require a unique Service Set Identifier

(SSID) and Media Access Control (MAC) address, this information could be formed as a secondary vehicle identifier. The information in Wi-Fi beacon frames could be used for V2V identification. Based on the measurement results of the secondary vehicle identifier, the Wi-Fi based vehicle identifier can be detected up to 424 m with a TP-Link device and high vehicle speed of up to 100 km/h. The result also shows that the detection range for Wi-Fi is larger than Bluetooth, which can detect more vehicle identities. Hence, this Wi-Fi based secondary vehicle identifier can be used to track misuse vehicles. Figure 2.5 shows the 8 points radiation characteristics of the vehicle access point and this characteristic could be used to analyse the nearby vehicle position region. However, this radiation characteristic does not involve the vehicle's distance to vehicle. Hence, the vehicle's radiation characteristic should be investigated, since the glass material has medium obstacle severity, which could cause 3 to 13 dB penetration loss [33].

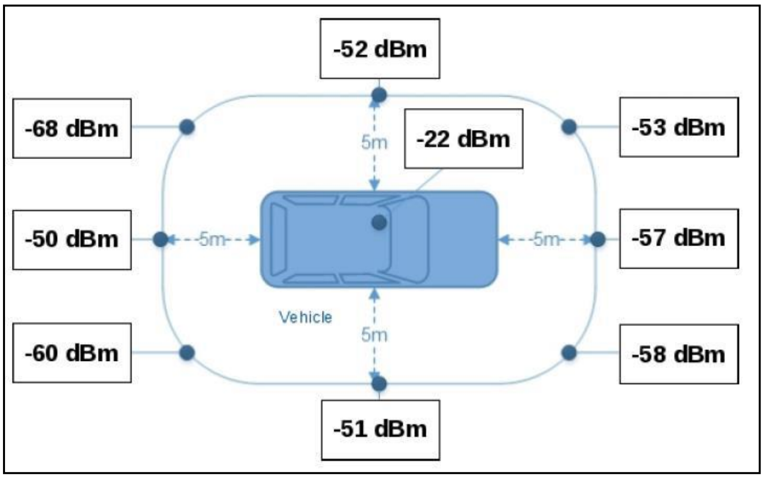

Figure 2.5 Radiation characteristic of the vehicle access point [32]

Another digital vehicle identity with Wi-Fi technology was developed using a chip ESP8266 to store the identity of a motor vehicle [34]. This digital identification system is used to identify the vehicles in case of crucial problems. The chip of unique SSID was set in the form of motor vehicle license plate number. When all the data entered ESP8266 paired subsequent chip in vehicle, it serves as a client to transmit data. The chip will connect and provide access point SSID to the vehicle identification database if the access point is found. Then, the router with chip ESP8266 filled program at the parking area will detect the presence of a motor vehicle by capturing SSID motor vehicle through the Wi-Fi signal.

The Pedestrian Collision Avoidance System (WiSafe) proved that Wi-Fi could be used for high-speed vehicles and long-range transmission [35]. This system also shows the advantages of implementing Wi-Fi technology, such as high detection range, low latency and low cost. But this result could be different with the type of router device and the type of vehicle. Therefore, measuring and clarifying the availability range for Wi-Fi RSSI to scan the vehicle access points is important. The distance measurement could be calculated by using RSSI technique. This research was conducted by using NodeMCU acts as Access Point (AP) and another as a Station (STA) to measure the RSSI signal and distance physically [36]. In fact, the RSSI should be a negative dBm value and values closer to 0 dBm are strong signals. Based on comparing actual and estimated distance for function, a formula with an average error of 8.3173% was formed to calculate the distance based on RSSI signal strength. The distance could be calculated by using equation (3). The relationship between distance and RSSI shows an exponential curve in Figure 2.6.

$$Distance = \frac{(-0.043x^5 - 4.92x^4 - 171.5x^3 - 600.8x^2 + 41.41x - 0.84)}{(x^4 + 250.4\,x^3 + 14780x^2 - 455.9x + 12.24)} \qquad (3)$$

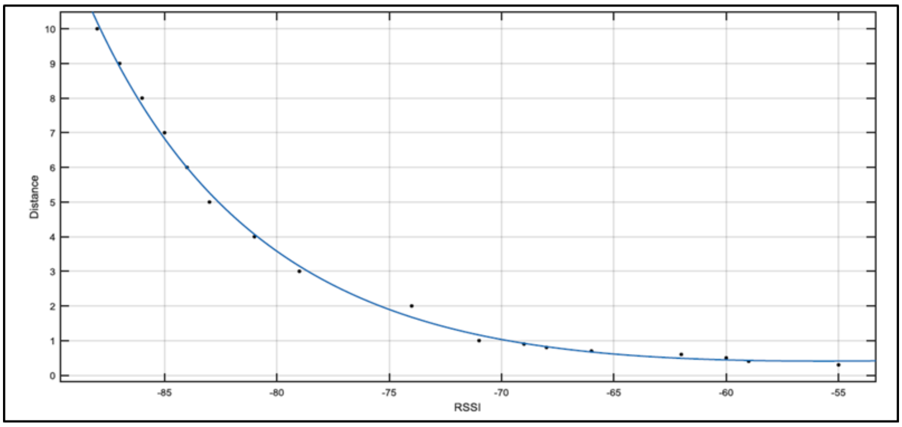

Figure 2.6 Relationship between Wi-Fi RSSI and access point distance [36]

The relationship between Wi-Fi RSSI and the distance also can refer to a feasibility study of a Wi-Fi-based vehicular ad hoc network. This measurements study was conducted on level 1 in the West City Auckland shopping mall parking lot with two cars and two laptops [37]. Figure 2.7 shows the RSSI versus distance coverage. The measurements were completed by slowly increasing the distance between the transmitter and receiver until getting the ad-hoc signal. This feasibility study shows that the Wi-Fi signal could be detected within 1m to 57m including the wall barrier, car moving, and human moving. It also shows the RSSI could give good performance and reliability when its value was -45 dBm in about 1m to 2m distance. Therefore, the tracking of the hit-and-run vehicle could use the same concept. Those access points with strong RSSI signal strength have a high possibility of approaching the victim vehicle before accident happen.

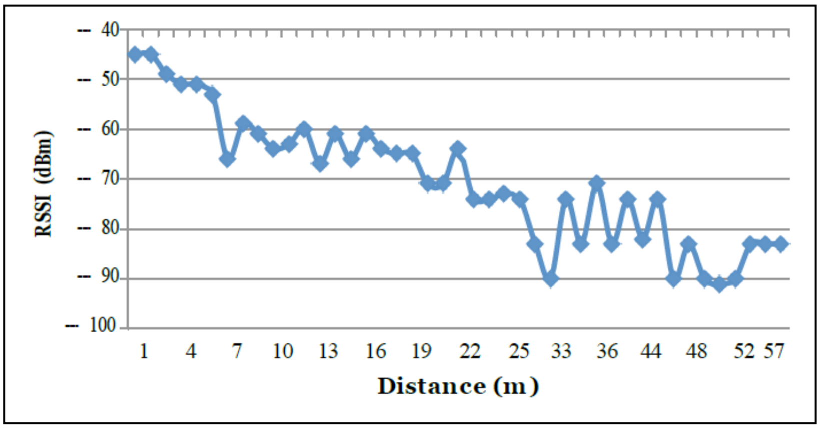

Figure 2.7 RSSI versus distance coverage [37]

2.6 Summary of Literature Review

Based on the review of previous accident detection work and vehicle identifier methods, most of the research is conducted independently without integrating the tracking vehicle identification used for road accident conditions. ANRP and RFID are the main solutions for tracking vehicle identity. However, these two methods usually are limited by environmental factors, direction and distance. Although the review from vehicular communication and wireless networking protocols could be used to track the vehicle, but their introduced systems are not purposed for hit-and-run accidents. In the review of vehicular communication and wireless networking protocols, the integration of using RSSI signal strength and VANET has the potential to design as the tracking system. Hence, this research study is to develop virtual vehicle identification tracking system by using wireless communication interfaces to track and analyse vehicle identification.

CHAPTER 3

METHODOLOGY

3.1 Methodologies Overview

There are four categories of methodology for this development project which are system integration for virtual vehicle identification system, methodology of tracking, accident detection, and signal strength measurement. The system integration introduces the working flow of virtual vehicle identification system. The methodology of tracking describes the algorithm of hybrid tracking method. Accident detection and signal strength measurement are used to test the performance and false positive analysis.

3.2 System Integration

With the advance in communication technologies used in modern vehicles, the head units of cars are increasingly establishing a Wi-Fi hot spot to support internet access for vehicle drivers and passengers. Moreover, V2V communication technology and intelligent transportation system will be deployed based on IEEE 802.11 technology in the future since the head units configured as access points need a unique SSID to connect their devices. Then every vehicle with Wi-Fi SSID can be permanently registered as the physical vehicle number plate characters to make the Wi-Fi SSID a virtual vehicle number plate. The MAC address can be used as device identity and this information should be collected with SSID as verification for SSID identification. The relationship between Wi-Fi RSSI and physical distance shows that access points with strong RSSI signal strength are close to the victim's vehicle. Then, it could also represent the strongest signal strength of the vehicle access point with a high possibility of the offender vehicle during the impact. At the same time, the following strong signal strength on a nearby vehicle access point could also become a witness in that accident.

This system is generally separated into virtual vehicle identification transmission and traffic surveillance systems. The overall high-level system diagram of virtual vehicle identification system is shown in Figure 3.1. The virtual vehicle identification transmission system is built with two ESP 32 devkit development boards. ESP 32 devkit development board is dual-core and runs with 32 bits. It has 2.4 GHz Wi-Fi-and-Bluetooth built-in feature [38]. Figure 3.2 depicts the pinout diagram of the ESP 32 devkit board. ESP32 is integrated with in-built antenna switches, RF balun and power amplifier which can work as a completely independent system or as a slave device to communicate with another ESP32 board. This feature is useful for developing ad-hoc network devices.

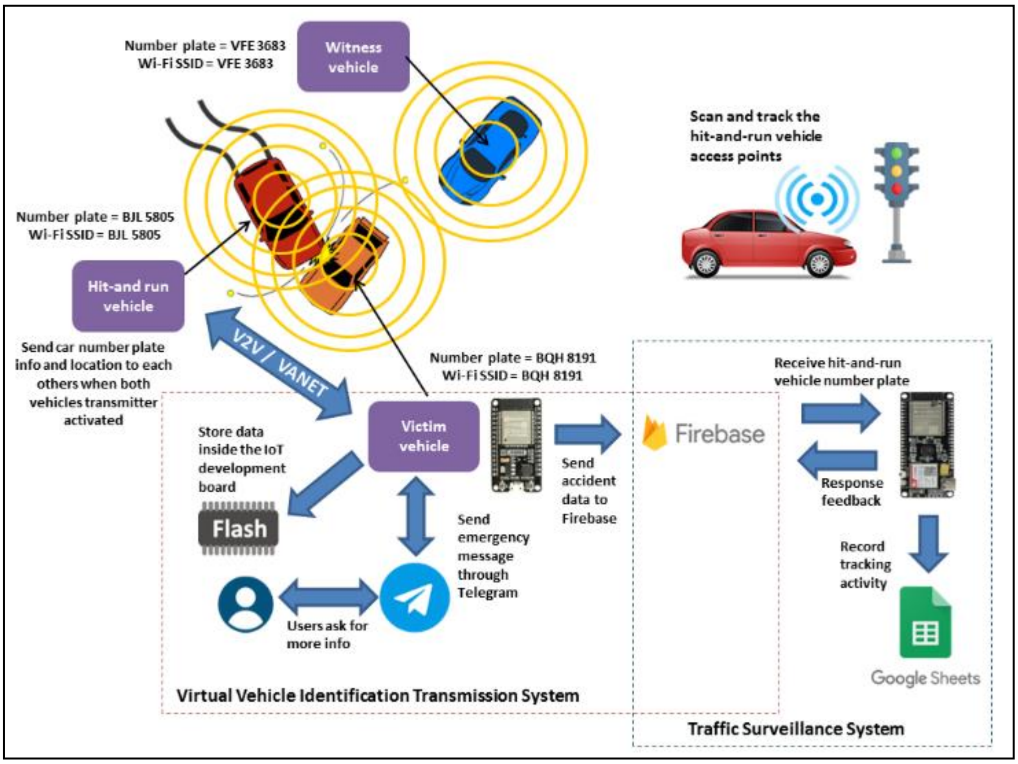

Figure 3.1 High-level system diagram of virtual vehicle identification system

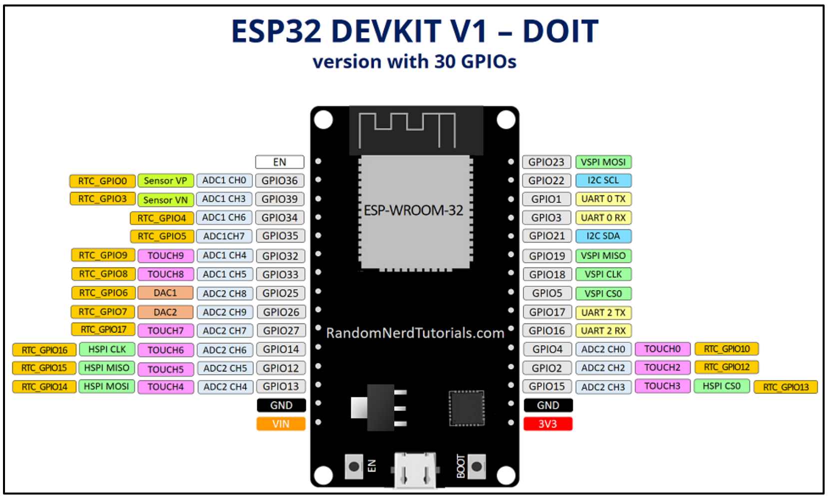

Figure 3.2 Pinout diagram of ESP 32 devkit board [38]

The role of main IoT board is to upload the data to Firebase and Telegram. The transmitter IoT board communicates and exchanges messages with other vehicle transmitters. Due to the transmitter board need to use Wi-Fi as protocol to form ad hoc network and ESP 32 board only consists single antenna, hence the NRF24L01 transceiver module is used for transmitter IoT board to send data to main IoT board. NRF24L01 is using SPI protocol to exchange data with an operating radio frequency of 2.4 to 2.5 GHz ISM band. The message packets are converted into JavaScript object notation (JSON) format to serialize and exchange information between boards. The role of Wi-Fi modem is to provide internet access to main IoT board. It also worked as the virtual vehicle identity for other vehicles or traffic surveillance system to track the identity. The hardware prototype setup for virtual vehicle identification system is shown in Figure 3.3 and the circuit diagram for vehicle identification transmission system is shown in Figure 3.4.

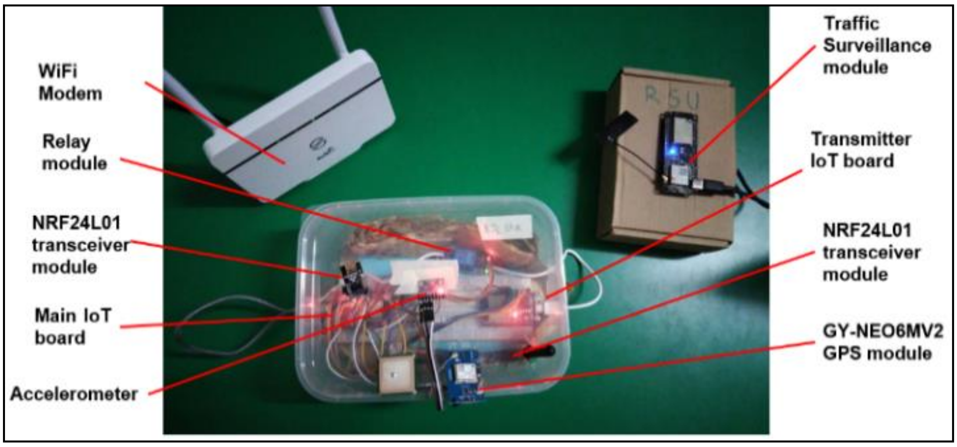

Figure 3.3 Hardware prototype setup for virtual vehicle identification system

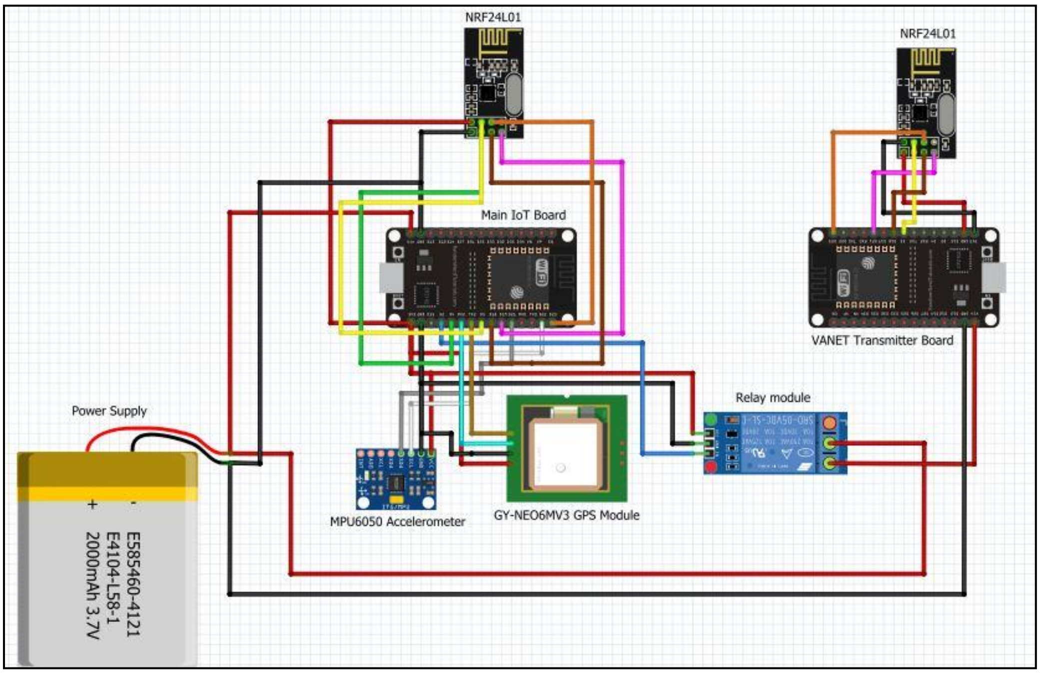

Figure 3.4 Circuit diagram for vehicle identification transmission system

During the prototype on-road testing, all the vehicles have their Wi-Fi modem and vehicle identification transmission system. Firstly, the main IoT board is automatically connected with an in-car Wi-Fi modem and starts to scan the available signal strength of the access point within the Wi-Fi beacon frame. This board is connected with an accelerometer, relay module and GY-NEO6MV2 GPS module. The accelerometer used in this system is MPU 6050 triaxial accelerometer and the resultant acceleration from all 3-axis accelerations helps detect fall and impact event [39]. Hence, the resultant acceleration is measured and calculated using equation (4). An experiment on scarp car colliding with a concrete wall was conducted with speeds up to 40km/h [12]. The crash test results show the serve accident could be considered when the G-forces were above 4G. In the prototype testing, the resultant acceleration threshold for detecting accident is fixed at 4G or 39.24m/s^2. In the actual case scenario, the airbag accelerometer could be used to detect crash and the threshold can depend on the airbag activation.

$$a_{res} = \sqrt{a_x^2 + a_y^2 + a_z^2} \quad (4)$$

When the accident happened, the high vibration caused the transmitter IoT board to activate through relay module and the GPS module to track vehicle accident location. It uses painlessmesh ad hoc networks to communicate and exchange messages. The messages such as car plate number and GPS coordinate are exchanged by the transmitter IoT board to another vehicle transmitter board. The GPS real-time location coordinates and the nearby virtual vehicle number plate information are transmitted through the Telegram and Firebase IoT platform through internet access. Firebase is Google’s mobile application development platform and its real-time database is a cloud-hosted database in which data is stored as JSON. In fact, this system can act as a black box by using EEPROM library to keep this information in the flash memory of the development board without internet access support for further inspection, especially in rural areas. The flow chart for virtual vehicle identification transmission system is shown in Figure 3.5.

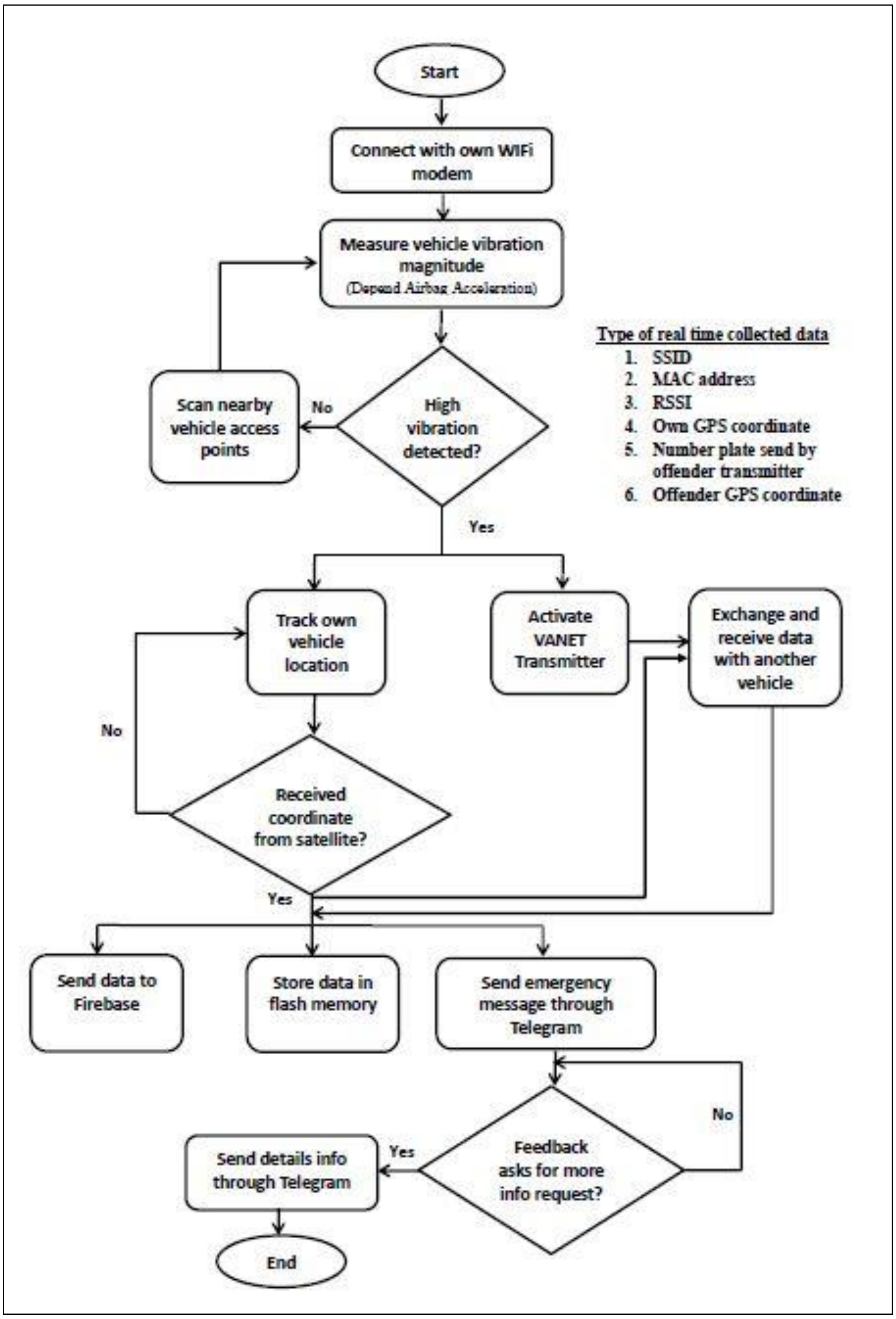

Figure 3.5 Process flow of virtual vehicle identification transmission system

On the other hand, the traffic surveillance system can be placed at any road junctions for roadside unit to scan and track the offender's vehicle access points in that area. Usually, the vehicle needs to slow down at road junctions and this factor can provide sufficient time for traffic surveillance system to scan all nearby vehicle access points. Figure 3.6 shows the traffic surveillance module placed at road junction. The IoT board used in this system is TTGO T-Call, including a SIM800L GSM/GPRS module. This board is operated by using single or dual-core 32-bit LX6 microprocessor and it has 520 kB of static random-access memory [40]. The pinout diagram of TTGO T-Call is shown in Figure 3.7. It can connect to any global GSM network with any 2G SIM and access internet service. The suspect vehicle plate number from the Firebase IoT platform can be received and read by traffic surveillance system to track the suspect or offender's vehicle and record the tracking activity to Google Sheet when the offender's vehicle is detected.

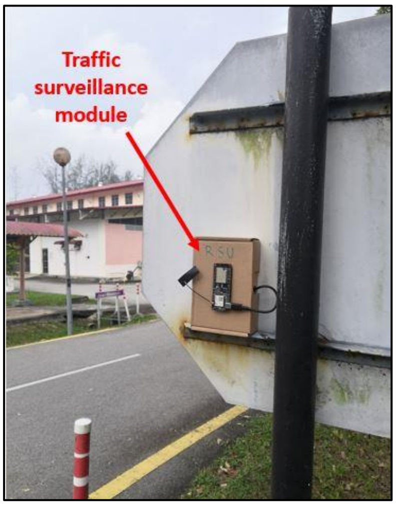

Figure 3.6 Traffic surveillance module placed at road junction

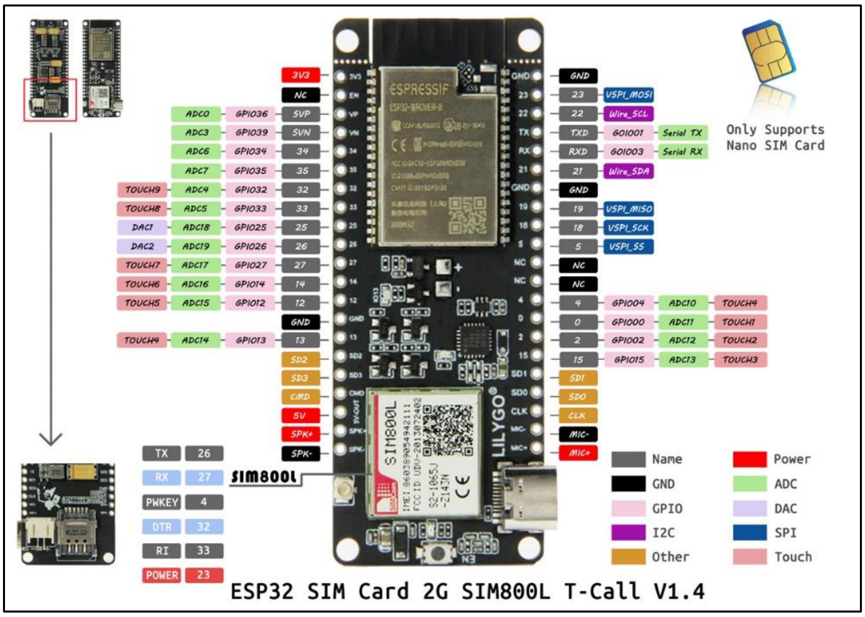

Figure 3.7 Pinout diagram of TTGO T-Call [40]

3.3 Methodology of Tracking

The virtual vehicle identification system tracking method used in road accidents is the hybrid tracking method by combining the pre-accident and post-accident tracking methods. The pre-accident tracking method was operated before the accident happened. It worked as a radar to scan all nearby vehicle access points' identities with SSID and MAC addresses. This tracking concept uses Wi-Fi received signal strength to estimate the distance since the signal strength is high when the cars approach a short distance. The vehicle's distance is calculated by using Equation (3).

However, this method cannot accurately determine the offender's vehicle since the performance could differ with the router device and vehicle type. The post-accident tracking method is operated after the accident happens. The relay module activates the transmitter IoT board when the main IoT board detects high-impact vibration. This board can search another transmitter at other vehicles under the same network and exchange car plate numbers and GPS coordinates to another car through painlessMesh ad hoc networks when both transmitters activate by accelerometers.

Wireless Mesh Networks (WMN) are dynamically self-organized and self-configured. According to an introduction of Wireless Mesh Sensor Network (WMSN), wireless cellular mesh sensor network can be used to control the traffic for self-driving vehicles in VANET [41]. The vehicle node is mobility and random organization of communication with other nodes. The road side unit node is stationary connection and fixed with the number of nodes. Based on the concept of VANET, the vehicle node and road side unit node can work as network to communicate between nodes. By using the painlessMesh library, it creates a simple WMN through ESP 32 controller and automatically connects the nodes with the same mesh prefix, mesh password and mesh port [42]. In the painlessMesh network, each node can act as both an access point and station for node to transfer data and received data from another node. Based on the Figure 3.8, every node is aware of the whole network topology to follow the scheduler to send data periodically [43]. Every ESP32 boards have its own unique board chip ID. The messages such as car number plate, GPS coordinate, and board chip ID are sent to all available nodes within the network beacon frame. At the same time, the board also received messages from other nodes. Using mesh callback function, the system is always updated to receive messages from different nodes whenever a connection changes on the network to join or leave from the network.

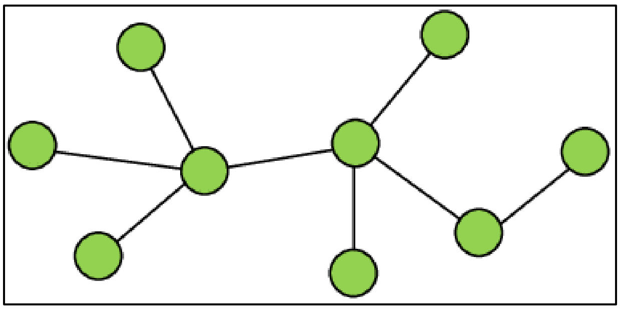

Figure 3.8 Topology of painlessMesh network [43]

However, the scope of this study focuses on one-to-one node communication. The result of the post-accident tracking method can be used to verify the pre-method because it uses the same event activity as the tracking strategy. However, this method required both vehicle accelerometers to meet the vibration impact requirement and required a longer processing time to setup and scanning. Different types of vehicles may have different mass and the impact vibration would be different for other vehicles. As a result, the hybrid tracking method is introduced to reduce the weakness and strengthen the strength of each method to collect all available information and identify the offender. Figure 3.9 depicts the timeline of hybrid tracking method.

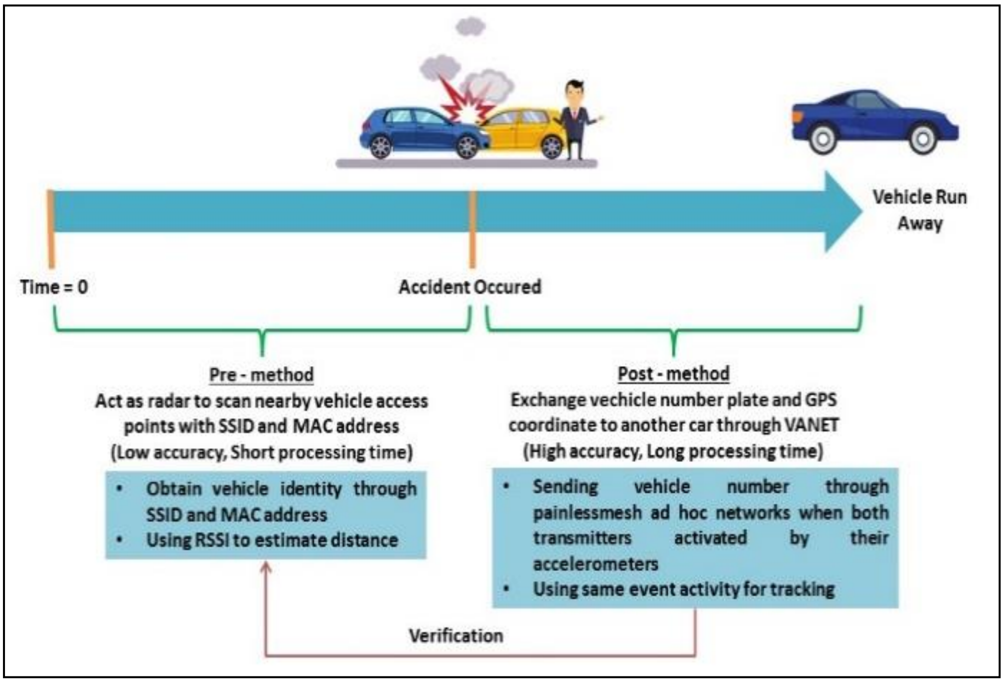

Figure 3.9 Timeline of hybrid tracking method

3.4 Accident Detection

According to the literature review of accident detection, the minimum impact acceleration above 4G or 39.24 m/s^2 can be determined as a threshold to raise an accident event [13]. The prototype with an accelerometer sensor is tested in different scenarios to avoid false-positive detection in the vehicle identification tracking system. The resultant acceleration for every scenario is measured and recorded to the system. The test case scenarios are listed as below:

i. Stationary
ii. Move on a straight road with around 40km/h
iii. Move on a road corner with around 40km/h
iv. Crossing speed bump
v. Sudden break
vi. Accident activation with above 4G magnitude

3.5 Signal Strength Measurement

Referring to the radiation characteristic measurements in Figure 2.5, the signal strength measurements in this project involve the different distances between vehicle-to-vehicle with the medium obstacle severity. This measurement is taken from one vehicle to the next in one central position and eight surrounded positions. The vehicle identification transmission system is placed at the top of head-unit and the Wi-Fi modem is placed at below of head-unit inside the car. This setup can be referred to Figure 3.10. The vehicle distances are divided into 1m, 2m, 3m, 4m, and 5m. Figure 3.11 depicts the positions and top view layout of the vehicles and Figure 3.12 shows the positions and measurement of the vehicles distance. It is used to measure the effect of signal strength based on vehicle approach distances. After 5m, the vehicle Wi-Fi beacon frame or the maximum distance for detecting the WiFi signal from the access point is determined.