A REAL TIME AUTOMATED VEHICLE INCIDENT DETECTION USING HIGH ACCURACY GLOBAL POSITIONING SYSTEM

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FACULTY OF ENGINEERING AND BUILT ENVIRONMENT
UNIVERSITI KEBANGSAAN MALAYSIA
BANGI

2013
PENGESANAN INSIDEN KENDERAA SECARA AUTOMATIK MASA NYATA MENGGUNAKAN SISTEM PENENTUUDUKAN GLOBAL BERKETEPATAN TINGGI

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TESIS YANG DIKEMUKAKAN UNTUK MEMPEROLEH IJAZAH DOKTOR FALSAFAH

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UNIVERSITI KEBANGSAAN MALAYSIA
BANGI

2013
DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

31 July 2013                               ISHAK BIN MOHAMAD

P 42465
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ABSTRACT

The Malaysian Institute of Road Safety Research (MIROS) reported that in 2009, there were 397,330 road accidents in Malaysia and half of them were occurred on municipal roads. In order to avoid major traffic congestion and other consequent incidents, an efficient incident detection system is therefore essential. Although various incident detection systems have been deployed such as laser, multi-sensors, closed-loop detector and Global Positioning System (GPS), the systems are still not fully automated, require longer delay for detection, have high operational cost and high detection error. Moreover, GPS is only used for navigation or positioning and not fully utilized for incident detection. The objective of this research is to develop a new and efficient real time automated incident detection (AID) system with short time to detect, no false alarm and higher detection rate. The research involved three phases; data collection, AID algorithm development and verifications through simulation and drive testing. During static data collection, GPS signal availability and reliability at four locations in the study area were checked. In the mobile data collection, the GPS probe vehicle gathered various information such as vehicle position, direction, and speed while driving along municipal trunk roads in Bandar Baru Bangi, Selangor. The data were transmitted via ultra high frequency (UHF) radio band to a monitoring station (MS). The AID algorithm detected abnormal measures based on user input threshold of the vehicle’s maximum speed, maximum acceleration and maximum deceleration from mobile data collection. The algorithm was also verified through simulation and the result could be viewed from the AID Interface (AIDEG) using random data for the normal and abnormal condition extracted from recorded mobile data. The system performance indicator includes time to detect (TTD), false alarm rate (FAR) and detection rate (DR). Finally, real time data from five GPS equipped vehicles along the pilot route were sent to the MS to test the performance of the AID system. The static test shows GPS availability and reliability rate of 99.9% and up to 99.7% respectively, thus the study area is appropriate for AID application. Algorithm parameters obtained from mobile data are 33.33 m/s for the maximum speed, 3.24 m/s² for the maximum acceleration and 4.63 m/s² for the maximum deceleration. The result for real time monitoring shows excellent value of performance indicators; 3.3 µs to 3000099 µs TTD, zero FAR and 81% and above DR. However, the performance of the system depends on the availability of GPS signal and data transmission from the vehicles to the MS.
ABSTRAK

Institut Kajian Keselamatan Jalanraya Malaysia (MIROS) melaporkan pada tahun 2009 terdapat sejumlah 397,330 kemalangan jalanraya di Malaysia dan setengah daripadanya berlaku di jalan-jalan bandaran. Untuk mengelakkan kesesakan trafik yang teruk dan kemalangan baru berlaku, sistem pengesanan kemalangan yang efisien adalah diperlukan. Walaupun pelbagai sistem pengesanan kemalangan telah digunapakai seperti laser, pelbagai penderia, pengesan gelang-tertutup dan Sistem Penentududukan Global (GPS), sistem ini masih lagi tidak sepenuhnya automatik dengan masa mengesan yang panjang, kos operasi yang tinggi dan kadar kesilapan pengesanan yang besar. Tambahan pula GPS hanya digunakan untuk navigasi dan penentududukan dan tidak sepenuhnya digunakan untuk pengesanan kemalangan. Objektif kajian ini adalah untuk membangunkan sistem pengesanan kemalangan (AID) baru dan efisien masa nyata yang boleh menghasilkan masa mengesan yang pendek, tiada amaran palsu dan kadar pengesanan yang tinggi. Penyelidikan ini melibatkan tiga fasa kajian; pengumpulan data, pembangunan algoritma AID dan verifikasi algoritma melalui simulasi dan uji pandu. Dalam pengumpulan data statik, kebolehsediaan dan kebolehpercayaan isyarat GPS di empat lokasi di dalam kawasan kajian telah diuji. Dalam pengumpulan data bergerak, kenderaan yang dipasang GPS mengumpulkan maklumat seperti kedudukan kenderaan, arah dan kelajuan semasa memandu sepanjang jalan utama bandaran di Bandar Baru Bangi, Selangor. Data kemudiannya dihantar melalui jalur radio frequensi lampau tinggi (UHF) ke stesen pemantau (MS). Algoritma AID mengesankan keadaan yang tidak normal berdasarkan nilai ambang kelajuan maksimum kenderaan, nyahpecutan maksimum dan pecutan maksimum masukan pengguna yang diperoleh dari pengumpulan data bergerak. Algoritma juga diverifikasi melalui simulasi dan keputusannya boleh dilihat dari antaramuka AID (AID EG) menggunakan data rawak dari keadaan normal dan tidak normal yang diambil dari rakaman data bergerak. Petunjuk prestasi sistem terdiri dari masa untuk mengesan (TTD), kadar amaran palsu (FAR) dan kadar pengesanan (DR). Akhir sekali, data masa nyata dari lima kenderaan terpasang GPS sepanjang laluan utama dihantar ke MS untuk ujian prestasi sistem AID. Ujian statik menunjukkan kadar kebolehsediaan dan kebolehpercayaan isyarat GPS masing-masing 99.9% dan 99.7%, justeru itu kawasan kajian adalah sesuai untuk aplikasi AID. Parameter algoritma yang diperoleh dari ujian bergerak ialah 33.33 m/s (halaju maksimum), 3.24 m/s² (pecutan maksimum) dan 4.63 m/s² (nyahpecutan maksimum). Keputusan untuk pemantauan masa nyata menunjukkan nilai petunjuk prestasi yang cemerlang; TTD di antara 3.3 µs hingga 3000099 µs, FAR sifar dan DR melebihi 81%. Walau bagaimanapun prestasi sistem bergantung kepada kebolehsediaan isyarat GPS dan penghantaran data dari kenderaan ke MS.
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LIST OF SYMBOLS

$l_1$  Latitude of position 1
$l_2$  Latitude of position 2
$l_1$  Longitude of position 1
$l_2$  Longitude of position 2
$V_n$  Current speed
$V_{max}$  Maximum speed
$V_{n-1}$  Previous speed
$V_{n+1}$  Next speed
$\sigma_{lat}$  Standard deviation of latitude
$\sigma_{lon}$  Standard deviation of longitude
$T_t$  Total measurement time
$T_n$  Measurement time without coordinates or no GPS signal.
d  Direction
$A$  Availability
$R$  Realibility
$t_1$  Time wait for the time slot
$t_2$  Time taken to send the modulated data to the Monitoring Station
$t_{i\_detection}$  Time where incident is detected
$t_{i\_occurance}$  Time where incident is occurred
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<td>Anti Break Locking System</td>
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<tr>
<td>AGPS</td>
<td>Assisted GPS</td>
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<td>AID</td>
<td>Automated Incident Detection</td>
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<td>AIDEG</td>
<td>Automated Incident Detection based on GPS</td>
</tr>
<tr>
<td>AOA</td>
<td>Angle of Arrival</td>
</tr>
<tr>
<td>APCO</td>
<td>Association of Public-safety Systems</td>
</tr>
<tr>
<td>AVI</td>
<td>Automatic Vehicle Identification</td>
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<td>CCTV</td>
<td>Closed Circuit Television</td>
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<td>CDMA</td>
<td>Code Division Multiplexing Access</td>
</tr>
<tr>
<td>DOP</td>
<td>Dilution of Precision</td>
</tr>
<tr>
<td>DR</td>
<td>Detection Rate</td>
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<tr>
<td>dGPS</td>
<td>differential GPS</td>
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<td>ECP</td>
<td>Electronic Congestion Pricing</td>
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<tr>
<td>ETC</td>
<td>Electronic Toll Collection</td>
</tr>
<tr>
<td>FAR</td>
<td>False Alarm Rate</td>
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<tr>
<td>FCC</td>
<td>Federal Communication Commission</td>
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<tr>
<td>FDMA</td>
<td>Frequency Division Multiplexing Access</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<td>GPRS</td>
<td>General Packet Radio System</td>
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<tr>
<td>GNSS</td>
<td>Global Satellite Navigation Systems</td>
</tr>
<tr>
<td>GSM</td>
<td>Global System for Mobile Communication</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphic User Interface</td>
</tr>
<tr>
<td>HDOP</td>
<td>Horizontal Dilution of Precision</td>
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<tr>
<td>HSGPS</td>
<td>High sensitivity GPS</td>
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<tr>
<td>IDA</td>
<td>Information Details and Adequacy</td>
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<td>IDS</td>
<td>Incident Detection System</td>
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<td>ILD</td>
<td>Inductive Loop Detector</td>
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<td>ITS</td>
<td>Intelligent Transport System</td>
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<tr>
<td>LOS</td>
<td>Line of Sight</td>
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<td>MCCS</td>
<td>Motorway Control and Signaling System</td>
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<td>MIROS</td>
<td>Malaysia Institute of Road Safety</td>
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<td>MPPS</td>
<td>Mobile Phone Positioning System</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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<td>---------------------------------------------</td>
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<td>MS</td>
<td>Monitoring Station</td>
</tr>
<tr>
<td>MTS</td>
<td>Mean Travel Speed</td>
</tr>
<tr>
<td>NOSV</td>
<td>Number of Satellites in View</td>
</tr>
<tr>
<td>PDA</td>
<td>Personal Digital Assistant</td>
</tr>
<tr>
<td>RO</td>
<td>Radio Occultation</td>
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<tr>
<td>RF</td>
<td>Radio Frequency</td>
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<tr>
<td>RTK</td>
<td>Real-Time-Kinematik</td>
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<td>SoG</td>
<td>Speed of Vehicle over Ground</td>
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<td>SVRA</td>
<td>Sleep Related Vehicle Accident</td>
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<tr>
<td>SWM</td>
<td>Steering Wheel Movement</td>
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<tr>
<td>TDMA</td>
<td>Time Division Multiplexing Access</td>
</tr>
<tr>
<td>TDOA</td>
<td>Time Different of Arrival</td>
</tr>
<tr>
<td>TMC</td>
<td>Transport Management Center</td>
</tr>
<tr>
<td>TTD</td>
<td>Time to Detect</td>
</tr>
<tr>
<td>UMTS</td>
<td>Universal Traffic Management System</td>
</tr>
<tr>
<td>UHF</td>
<td>Ultra High Frequency</td>
</tr>
<tr>
<td>UTC</td>
<td>Coordinated Universal Time</td>
</tr>
<tr>
<td>VIP</td>
<td>Video Image Processor</td>
</tr>
<tr>
<td>VRC</td>
<td>Vehicle to Roadside Communication</td>
</tr>
<tr>
<td>WLAN</td>
<td>Wireless Local Area Network</td>
</tr>
<tr>
<td>3G</td>
<td>Third Generation</td>
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<td>Fourth Generation</td>
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CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

Traffic incidents have become major contributors to fatality statistics. Besides causing congestion on major roads, traffic incidents also involve losses amounting to millions of American Dollars. An incident is defined as any non-recurring event that causes a reduction of roadway capacity or an abnormal increase in demand (Farradyne 2000), such as traffic crashes (accidents), disabled vehicles, spilled cargo, temporary maintenance and construction activities, signal and detector malfunctions, and other special and unusual events that disrupt the normal flow of traffic and cause motorist delay (Yuan & Cheu 2003). Incident is an event which has the potential to result in unintended harm or damage while accident is an event that results in unintended harm or damage (Birds & Germain 1996). Traffic accident refers to any traffic crashes and is a part of traffic incident.

Although there is no statistics of traffic incident, the number is definitely larger than the number of accidents. The Malaysian Institute of Road Safety Research (MIROS) reported that Malaysia lost RM 7.8 billion due to road accidents in 2008 (MIROS 2009). MIROS also reported that there is an increase in the number of deaths due to road accidents from 5,849 in the year 2001 to 6,745 in the year 2009. A total of 397,330 road accidents were reported in 2009 and half of them were on municipal roads. Table 1.1 shows the accident statistics by type of road in Malaysia from 2002 to 2008. The government is concerned over the high rate of accidents which occur on the municipal roads.
Table 1.1 Accident statistics by type of road

<table>
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<th>Type of road</th>
<th>‘02</th>
<th>‘03</th>
<th>‘04</th>
<th>‘05</th>
<th>‘06</th>
<th>‘07</th>
<th>‘08</th>
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<td>Highway</td>
<td>21,549</td>
<td>24,953</td>
<td>27,257</td>
<td>27,511</td>
<td>30,107</td>
<td>33,613</td>
<td>35,261</td>
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<tr>
<td>Federal</td>
<td>70,400</td>
<td>72,988</td>
<td>78,550</td>
<td>84,965</td>
<td>81,923</td>
<td>90,476</td>
<td>93,550</td>
</tr>
<tr>
<td>State</td>
<td>45,826</td>
<td>47,641</td>
<td>56,066</td>
<td>56,153</td>
<td>57,214</td>
<td>60,202</td>
<td>61,994</td>
</tr>
<tr>
<td>Municipal</td>
<td>114,801</td>
<td>124,986</td>
<td>136,953</td>
<td>134,571</td>
<td>155,355</td>
<td>163,104</td>
<td>165,617</td>
</tr>
<tr>
<td>Others</td>
<td>27,315</td>
<td>28,085</td>
<td>27,989</td>
<td>25,064</td>
<td>16,653</td>
<td>15,924</td>
<td>16,649</td>
</tr>
<tr>
<td>Total</td>
<td>279,711</td>
<td>298,653</td>
<td>326,815</td>
<td>328,264</td>
<td>341,252</td>
<td>363,319</td>
<td>373,071</td>
</tr>
</tbody>
</table>

Source: MIROS 2009

Previous investigations indicate that incidents are one of the major causes of loss of time and increase in avoidable costs in transportation networks in the United State of America. According to a Federal Highway Administration (FHWA) research report (Cambridge Systematics, Inc., 2005), approximately 50 percent of congestion on freeways is non-recurrent congestion caused by incidents (25 percent), work zones (10 percent), and bad weather (15 percent). The situation is even more severe in urban areas. Approximately one-half to two-thirds of the total travel delay in large metropolitan areas is incident-related (Center for Urban Transportation Research, 2005). Traffic incidents are not only major contributors to traffic delay and congestion, but are also a significant threat to traffic safety and a caused of environmental pollution.

Driver inattention and vehicle condition are the major contributors to incidents. Driver behavior and human errors are the cause in the overwhelming majority of car crashes (Evans 2004). Driving above the speed limit, changing the vehicle’s lateral position unpredictably and driving in the middle of the road are caused by psychological and physical factors. For example, sleep related vehicle accidents (SRVAs), whether these involved cars, lorries, or other vehicle, are simply attributed to driver inattention (Horne & Reyner 1999). Based on researches done by the Real Automóvil Club de España (RACE), a high percentage (30%) of traffic
incidents involves driver drowsiness (Rogado et al. 2009). Speed not only affects the severity of a crash, but is also related to the risk of being involved in a crash (Elvik et al. 2004). It is easy to comprehend that at high speeds the time to react to changes in the environment is shorter, the stopping distance is larger, and maneuverability is reduced. However, it is difficult to quantify this relationship unequivocally since there are many factors that would determine the extent to which the consequences of a higher speed affect the crash rate.

In order to provide the fastest and appropriate emergency response to people and vehicle to reduce high number of deaths, property losses and traffic congestions, incident detection is an important subject of both the government and commercial organizations. Engineers and transportation officials have dedicated substantial resources in the past years to find better ways in preventing incidents from occurring and managing them when they do. When there is an incident, minimizing the response time (i.e. the time from when an incident occurs to the time that the emergency crew arrives at the scene) is crucial in terms of several aspects. The most important is the treatment of injuries. The faster the treatment is given, the greater the survival rate of persons with serious injuries during an incident. Second, a quick clearing of the incident minimizes traffic flow disruption and the potential for secondary incidents.

In traffic incident management, if the abnormal condition cannot be detected and resolved, it will increase traffic delay and reduces road capacity, and will often causes new traffic accidents (Wang et al. 2008). Highly efficient and reliable traffic incident detection is of high importance in establishing appropriate incident response strategies, in providing drivers with real-time traffic information, in reducing traffic congestion, and in minimizing traffic delay (Wen & Yang 2005). Prompt and reliable incident detection is vital in reducing incident congestion, post-incident delay and the potential for additional incidents. Automatic incident detection (AID) has been considered as a method for quickly detecting potential incidents. The technology has been in the research, development, and testing stages since the 1970s. During that time, many incident detection methods and algorithms were developed. Past experience has shown that when a traditional AID system is installed, the number of false alarms have become such a problem that traffic operation centers stopped using
them altogether. Other systems have a poor enough detection rate that operators are unable to rely on the system as their primary method of incident detection (Martin et al. 2000). The issues of incident detection systems are:

i. Incident detection performance such as detection rate, false alarm rate and time to detect.

ii. Cost of installation, operation and maintenance.

iii. Detection methods; automatic detection or non-automatic.

iv. Coverage area.

The current incident detection uses several types of sensors together with vehicle Global Positioning System (GPS). GPS probe vehicle has a low installation and maintenance cost, wide data area that covers the whole city and also meets the real-time requirement of the universal traffic management system (UMTS) (Liu et al. 2007). Nevertheless, GPS is not fully deployed as incident detection system due to the low accuracy of the conventional receiver which would result in poor performance, for instance low detection rate. The issue of installing high accuracy GPS in vehicles is the high cost and its bulkiness. However, with the new GPS technology, a small sized high accuracy GPS can be bought for only a few hundred American Dollars. Due to its high accuracy and easy availability, the GPS is now becoming one of the traffic research data sources (Byon et al. 2006; Shi & Liu 2009). By providing information such as vehicle location, direction, speed, time, and others, the GPS is apposite equipment for this research. Moreover, the GPS has already been used and installed in vehicles as a positioning technique in navigation systems. GPS has been shown to be an accurate method to determine the position of a subject during biological and biomechanical studies (Terrier et al. 2000; Terrier et al. 2001).

Since the 1960s, many kinds of incident detection methods have appeared which can generally be categorized as manual detection methods and automatic detection methods (Wen 2008). Many efforts have been taken to improve the Incident Detection System (IDS) in past decades, including the deployment of many new detection technologies and the development of a variety of processing algorithms. A
variety of automatic incident detection algorithms have been developed since the 1960s, but most of these algorithms have used roadway-based detector data (Wen & Yang 2005). Many AID systems have generally not performed well when actually implemented, in terms of the standard performance measures of detection rates (DR), false alarm rates (FAR) and time to detect (TTD). Figure 1.1 shows the dependency of the AID parameters. The reaction time, the false alarm probability and the detection probability are mutually dependent. Improvement of one parameter usually results in worse values for the other parameters. An optimum has to be found, depending on the requirements.

![Figure 1.1 Dependency of AID parameters](source: Reijmers 2006)

In Malaysia itself, no AID system has been introduced to reduce fatality statistics. To date, no such research has been carried out by any traffic research party including MIROS and the Ministry of Transportation. Although the number of traffic incident is on the rise, the research emphasis to date has only been on vehicle and road condition, not incident detection.

Therefore, the goal of this work is to develop an IDS which only utilizes high accuracy GPS as a tool and radio band as a data transmission media. In this study, real time means that the real time GPS data is sent in real time using radio band to the monitoring station (MS). Real time data will result in an efficient and reliable system that can provide the fastest time for detection with a lower error rate. Vehicles are
equipped with the GPS receiver and all data are sent via Ultra High Frequency (UHF) radio band to MS as shown in Figure 1.2. A detection algorithm will recognize any incident automatically for further action. Furthermore, the recommended system is less complex and lower in cost (USD 383 per vehicle) in comparison to the current Automated Incident Detection System (AID) as shown in Table 1.2 and Table 1.3.

![Incident detection system based on real time GPS signal](image)

**Figure 1.2 Incident detection system based on real time GPS signal**

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Unit Cost (USD)</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic</td>
<td>875</td>
<td>Single Lane</td>
</tr>
<tr>
<td>Microwave Radar</td>
<td>3,500</td>
<td>Multiple Lanes</td>
</tr>
<tr>
<td>Microwave Doppler</td>
<td>1,000</td>
<td>Multiple Lanes</td>
</tr>
<tr>
<td>Infrared</td>
<td>4,500</td>
<td>Multiple Lanes</td>
</tr>
<tr>
<td>Infrared</td>
<td>1,500</td>
<td>Multiple Lanes</td>
</tr>
<tr>
<td>Ultrasonic</td>
<td>560</td>
<td>Single Lane</td>
</tr>
<tr>
<td>Acoustic</td>
<td>485</td>
<td>Single Lane</td>
</tr>
<tr>
<td>Laser</td>
<td>Not available</td>
<td>Double Lanes</td>
</tr>
<tr>
<td>Video Image Processor</td>
<td>3480</td>
<td>Multiple Lanes</td>
</tr>
</tbody>
</table>

Source: Middleton & Parker 2000; Berka & Lall 1998
Table 1.3 Comparative costs AID per detection site

<table>
<thead>
<tr>
<th>Cost Item</th>
<th>ILD (USD)</th>
<th>VIP (USD)</th>
<th>MRD (USD)</th>
<th>AVI (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware</td>
<td>4,100</td>
<td>24,500</td>
<td>26,500</td>
<td>14,700</td>
</tr>
<tr>
<td>Capital Cost</td>
<td>50,560</td>
<td>45,100</td>
<td>25,200</td>
<td>21,700</td>
</tr>
<tr>
<td>Total</td>
<td>54,660</td>
<td>69,600</td>
<td>51,700</td>
<td>36,400</td>
</tr>
<tr>
<td>Maintenance</td>
<td>7,950</td>
<td>3,300</td>
<td>2,900</td>
<td>2,900</td>
</tr>
<tr>
<td>Annual Cost</td>
<td>2,040</td>
<td>2,040</td>
<td>2,040</td>
<td>2,040</td>
</tr>
<tr>
<td>Total</td>
<td>9,990</td>
<td>5,340</td>
<td>4,940</td>
<td>4,940</td>
</tr>
<tr>
<td>Year-One</td>
<td>Total Cost</td>
<td>64,650</td>
<td>74,940</td>
<td>56,640</td>
</tr>
</tbody>
</table>

Source: Mouskos et al. 1998

1.2 PROBLEM STATEMENT

The GPS is not fully utilized as incident detection system due to the poor accuracy of the vehicle’s navigation GPS receiver. The availability of the GPS signal is even worse in certain areas especially in urban areas with tall buildings blocking the signal path. Many incident detection and vehicle tracking systems use General Packet Radio System (GPRS), Third Generation (3G) modems, Fourth Generation (4G) modems or Personal Digital Assistance (PDA) devices for data transmission. These will increase the operational cost as the users have to subscribe to the provider of the wireless telecommunication service and users have to pay for every bit of data sent and received. Furthermore, delay and data loss could occur while using GPRS, 3G/4G modem or internet for data transmission.

Although various incident detection systems have been deployed such as radar, multi-sensors and closed-loop detector, the systems are still not fully automated, have longer delays in detection and high detection error. AID algorithm relies on data collection technology; for example, comparative algorithm uses roadway-based sensor while advanced algorithm uses probe-based sensor.
A variety of sensors is used in detecting and providing real time traffic information for incident detection. However, such systems and approaches have not completely resolved or dramatically improved the real time traffic incident detection process (Kamran & Hass 2007). There are various reasons for this, including the really high cost of implementation, technical complexities including in-vehicle installation and the disproportionate rise in vehicle numbers as compared to infrastructural changes.

Recently, GPS has been used together with traffic detection/sensor technologies as automatic vehicle locator only. GPS data such as speed and direction has not been used as detection parameter. This is due to the inaccurate information as compared to other detection devices. High accuracy GPS possibly has a potential to be used as detector parameter if it could provide accurate and reliable information in real time via Radio Frequency (RF) transmission. In order to achieve short TTD, the GPS information must reach the MS or the processing center in real time with no delay. Zero FAR could be achieved with minimum data error and efficient filtering mechanism. DR is related to GPS signal availability and could reach 100% if no data is lost. Data collection technologies, data processing algorithms and algorithm training will improve the reliability and effectiveness of the incident detection systems. Furthermore, algorithm verification will be done through the drive testing and simulated data.

1.3 RESEARCH OBJECTIVES

The current state of technology in GPS which is more accurate and the economic feasibility of mass usage of in-vehicle positioning systems (Witte & Wilson 2004) have resulted in this study being conducted. In this research, the capabilities of high accuracy GPS technologies that have significant potential to improve the performance of incident detection are investigated and developed.
Hence, the objectives of this research work can be stated as follows:

a) To fully utilize GPS as vehicle incident detection system data source and RF for real time data transmission.

b) To develop a new real time automatic response and alert in the incident detection system prototype using high accuracy GPS data.

c) To develop a new efficient automated incident detection system conformance to the AID standard performance, namely short TTD, zero FAR and higher DR as compared to the current systems.

1.4 RESEARCH SCOPE

The research work was carried out in Bandar Baru Bangi, Selangor, Malaysia within 2.916° N, 101.740° E to 2.988° N, 101.797° E GPS coordinates. This area was selected as the area for study as more than 10 municipal trunk roads are located here and the area is also in close proximity to the Universiti Kebangsaan Malaysia (UKM) where the MS will be located. The allocation of MS in UKM because no such traffic monitoring station with higher altitude is available at other places.

The first stage of the study was to assess the availability, reliability and accuracy of the GPS signal in this studied area. Four stations were selected for static positioning and signal triangulation test from June 4, 2009 to June 5, 2009, over a period of 24-hours. Preliminary drive tests were conducted along the 10 roads from February 3, 2009 to May 6, 2009. The aims were to obtain vehicle speed parameters such as maximum speed, maximum acceleration and deceleration for a new imminent AID algorithm and to assess the GPS signal quality. A new GPS data logger algorithm was designed to collect and monitor the data collection in real time.

The threshold parameter determined from the preliminary field tests were used as user input threshold during the development process. At the beginning, the AID algorithm was tested using random data, followed by simulated data and finally by real time signal from the modem receiver.
The final experiment or drive testing was conducted in two conditions; the first was conducted in heavy rain on May 20, 2009 where the aim was to evaluate the driving style and at the same time the GPS signal reception and RF signal transmission in bad weather condition. The second was in normal traffic and sunny condition on May 21, 2009. Every drive testing involved 5 drivers with 5 GPS-equipped vehicles in which data were sent to MS for processing.

The aim of this AID system is to detect any ground vehicle incident based on abnormal driving speed and abnormal vehicle movements. Simulated data created from the modified test drive signal were used to verify the effectiveness of the detection system because it is risky to create real incidents without the involvement of professional driver. Up to the time this research was written, the AID algorithm only detected abnormal driving (almost certainly sleepiness) and not real accidents which involved car crashes, injuries or fatalities. This is because only five test vehicles were equipped with the system and the system was limited to only a 20 kilometer radius from the MS.

1.5 THESIS CONTRIBUTION

The main contributions of this thesis are as follows:

1. The development of a new GPS data logger suitable for vehicle GPS modem used for this research and any GPS receiver that are connected to the computer via serial or universal serial port.

2. Integrating a high accuracy GPS receiver as a detector or data source for incident detection application apart from localization and navigation tools.

3. Mapping of GPS signal quality including the availability and reliability for major roads in Bandar Baru Bangi for incident detection application, hearability test and others.

4. A prototype of a new developed AID system that can be used to predict and detect abnormal driving and incidents. The system has a better incident
detection performance indicator; short time to detect, zero false error and high detection rate.

5. AID system MS deployed in UKM that can be used by UKM and Bandar Baru Bangi community.

1.6 THESIS ORGANIZATION

Chapter I begins by defining traffic incident introduces vehicle incident detection system and incident detection development issues. Additionally, the chapter presents a concise description of the research problem statement, followed by the research objectives and finally the contributions introduced by the thesis which are summarized toward the end of the chapter. Chapter II covers the research work done by others in incident detection system, detection/sensor technology, standard incident detection performance and technology for incident detection. Meanwhile, Chapter III presents the methodology used in developing the automated incident detection system.

Chapter IV focuses on the development of the incident detection system including the system configuration and detection algorithm. Then, one efficient incident detection algorithm is proposed. Chapter V presents the experiment and result of the study. The new proposed detection algorithm is verified through simulation and real field tests. Finally, VI describes and concludes the main contributions of this research study. This chapter also highlights several suggestions or recommendations for future work.
CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents a review of the literature on vehicle incident detection systems and their technologies. Various techniques that are used to develop incident detection systems based on sensor/detector to improve detection performance are discussed. Automated incident detection and application of wireless communications have been introduced to overcome the weaknesses of human-based detection system and to upgrade the system performance including the time to detect and false error rate. A comprehensive review of the current detection systems and their performance indicators are also discussed in this chapter. The ability of GPS as IDS data source and the advantage of multiple access system are highlighted.

2.2 OVERVIEW OF VEHICLE INCIDENT DETECTION SYSTEM

Many promising applications for traffic dynamics, including the study of route selection, vehicle emissions and traffic safety were proposed in the 1950s and 1960s. Some of these applications and the basic ideas of traffic dynamics have been investigated using vehicles equipped with recording accelerometers, speedometers and other cumbersome equipment. After these early efforts, traffic dynamic study was all but abandoned when the high cost of data collection and impracticality of the application implementation with the existing measurement technology discouraged further research (Sermons & Koppelman 1996). In 1994, Robertson et al. developed and measured the acceleration signature parameter to investigate the link between traffic dynamic parameters and driver safety. Lu (1992) applied spectral analysis
techniques used in other engineering fields to the vehicle movement characterization task. His discussion suggests the use of traffic dynamics for the detection of roadway incidents.

Incident detection is a crucial step in incident management; it affects consequent actions and determines the reliability and efficiency of the whole system. The procurement of real-time incident detection information is an integral element that supports the realization of many other functions in traffic management. Nevertheless, incident detection is one of the weakest links in the implementation of advanced traffic control and management concepts that have surfaced over the last decade (Michalopoulos et al. 1993; Mahmassani & Hass 1998).

IDS basically consists of detector or information source that supply abnormal vehicle movement or abnormal traffic condition data to the determination device such as a computer or human that is used to verify whether an incident has occurred. For instance, service patrol vehicles, police in highway cruisers and Closed Circuit Television (CCTV) monitoring by the operators serve as the main sources of information for incident detection. Figure 2.1 illustrates the block diagram of conventional incident detection; it consists of the data collection device, transmission medium and data processing.

![Diagram](https://via.placeholder.com/150)

**Figure 2.1 Block diagram of conventional incident detection systems**
2.3 INCIDENT DETECTION TECHNOLOGIES

The performance of an incident detection system is determined on two levels; data collection and data processing. Data collection refers to the detection/sense/surveillance technologies that are used to obtain data. Data processing refers to the algorithms used for detecting and classifying incidents through analyzing the traffic parameters from detectors or sensors for the purpose of alerting observers of the occurrence, severity, and location of an incident. The two levels provide a technical platform on which a variety of algorithms can be designed and applied. The combination of data collection technologies and data processing methodologies results in a variety of solutions for incident detection. Basically, IDS technology is firstly dependent on the information source or data collection technique including data transmission and secondly by the data processing technique.

2.3.1 Inductive Loop Detector Detection System

The origins of IDS lie in freeway incident detection that mostly uses fixed detector such as inductive loop detectors (Peeta & Das 1998). The system is believed to have a high false alarm rate, especially when there are two lanes and vehicles can change lanes. The standard Inductive Loop Detector Detection System (ILD) is a length of insulated wire bent into a closed shape, traditionally a square or a rectangle, and connected to a power source/sensor on both sides of the wire. New versions of ILDs use higher frequencies to identify specific metal components of vehicles, which can be used to classify vehicles (Nelson 2000).

The sensitivity of an ILD is adjustable and can be tuned for a variety of different locations and environments. However, ILDs have a tendency to double-count trucks (Labell & May 1990). Due to the vehicle's structure, trucks as well as other long vehicles are often regarded as two passenger cars by an ILD. Tractor-trailer units often have concentrations of metal far enough above the loop so that the detector electronics cannot detect them, resulting in detection gaps. ILD systems still suffer from poor reliability, related to causes such as inclement weather, improper connections made in pull boxes, and in the application of sealants over the cutout.
These problems are accentuated when ILDs are installed in poor pavements or in areas where utilities frequently disturb the roadbed. Most cities with mature systems report that 25 to 30 percent of their detectors are not operating properly at any given time (Underwood 1990). Moreover, the installation and maintenance of ILDs require lane closures to dig grooves in the road, causing traffic disturbances. In addition, the precise nature of an incident detected by ILDs cannot be ascertained, and ILDs perform less effectively for incident detection in low volume conditions.

Figure 2.2 shows an example of IDS using ILD. Initially, fixed detector and probe vehicle models were separately estimated with the pooled data (all incidents) and with the three groups of incidents distinguished by location. Comparisons among these models using each type of data showed that very different parameter estimates were obtained for incidents at different locations on the link. Both the fixed detector and probe vehicles models estimated with downstream incident data performed substantially better than the corresponding pooled, midblock, or upstream incident models, i.e. downstream incidents could be detected at a much greater rate than incidents at other locations, and the impact of an incident was found to be a function of its location on the link. Midblock incidents had little or no effect on the traffic flow variables, upstream incidents had a mild effect, and downstream incidents had the greatest impact.

![Figure 2.2 Incident detection using fixed detector](source: Sethi et al. 1994)
2.3.2 Motorway Control and Signaling System

Figure 2.3 shows the setup of the Motorway Control and Signaling System (MCSS). This system is almost similar to the ILD system except double loop detectors are installed every 500 meters in the road and connected to detector stations (Reijmers 2006). In addition, the system uses matrix panels to show the variable signs. The main reasons for the installation of a motorway signaling system are because the motorways are more and more loaded with traffic. This also increases the probability of accidents and reduces the possibility of doing road works during the day. Adding new roads and enhancements of existing roads are not to be expected to occur too often. Therefore, the existing capacity must be used as efficiently as possible.

![Figure 2.3 MCCS System](image)

Source: Reijmers 2006

2.3.3 Sensor-based Incident Detection System

This system uses either single or multi-sensor as the system input. Thomas (1998) has developed multi state and multi sensor incident detection systems for arterial streets as shown in Figure 2.4. The incompatibility of the spot detector and link wide probe data prevents their fusion into a single measurement vector. The system separately processes measurement vectors from distinct sensors using Bayesian classifier. A Multiple Attribute Decision Making (MADM) fusion classifier processes the categorical vectors resulting from the Bayesian classifiers. Classification by the
Bayesian probe classifier is performed link by link. It is performed station by station by the Bayesian detector classifier. Classification entails the selection of a most representative traffic condition for the link or detector station sampled. Once all links and stations are processed, the fusion commences. Its function is the reconciliation of classifications made for various links and stations by different classifiers. This reconciliation aims to pinpoint incident location; this detection state necessitates the contrasting of traffic states on neighboring links. The reconciliation of classifications achieved over varied times steps leads to the incident duration and time of removal states. The reliability and performance of the system depend on the type of sensor used.

Figure 2.4 Incident detection systems using multi-state and multi-sensor

Source: Thomas 1998
i. Magnetic Sensors

Magnetic sensors are often installed in place of loops on bridge decks, and in heavily reinforced pavement, where steel adversely affects loop performance (Nelson 2000). These magnetic sensors are induction magnetometers. It requires some minimum vehicle speed, usually 4.8 to 8 km/h; hence, they cannot detect stopped vehicles nor provide presence measurements (Klein & Kelley 1996; Klein 2001). The biggest disadvantage of single magnetic detector is that they cannot measure occupancy. Speed may be calculated by installing two magnetic detectors in a close succession, and from speed and flow measurements, occupancy can be calculated. However, if two magnetic detectors are placed too closely together, they may interfere with each other (Labell & May 1990).

ii. Microwave Sensors

Microwave sensors are currently used in traffic surveillance. They are capable of counting vehicles, measuring speeds and detecting vehicle presence. Microwave sensors provide a cost-effective alternative to ILDs for vehicle presence detection and hence for incident detection. They are relatively smaller, lighter in weight and easier to install than ILDs and magnetic sensors, and they can detect multilane traffic and cover a longer range (say 100 meters to 1000 meters). Their small size, low cost and low power consumption makes them suitable for traffic surveillance both at intersections and on highways. However, it needs to be noted that a newly installed microwave sensor may interfere with other similar microwave-based devices in its vicinity (Klein 2001).

iii. Infrared Sensors

A portion of the transmitted energy is reflected back to the sensor by vehicles traveling through the detection zone. An infrared-sensitive element converts the reflected energy into electrical signals that are analyzed in real time.
Infrared sensors can measure presence, speed, volume, occupancy, and vehicle classification. Active infrared detectors are vulnerable to weather conditions such as fog, clouds, shadows, mist, rain, and snow, which scatter and attenuate wave energy. High cost is cited as one of the reasons that they are not more widely used in traffic surveillance. Passive infrared detectors measure the same traffic parameters as active detectors except for speed. On the other hand, multi-zone passive infrared sensors can measure speed and vehicle length as well as the more conventional vehicle count and lane occupancy (Klein 2001). Inclement weather, such as fog, snow, and precipitation that scatter energy, and changes in light, may have adverse effects on performance.

iv. Ultrasonic Sensors

Pulse waveforms are used to measure distances to the road surface and the vehicle surface by detecting the portion of the transmitted energy that is reflected back toward the sensor. When a distance other than that to the background road surface is measured, the sensor interprets that measurement as the presence of a vehicle. The received ultrasonic signal is converted into electrical energy that is analyzed by signal processing techniques. Ultrasonic sensors can measure speed, occupancy, presence, and in some configurations, queue length. Moreover, vehicle profiling can be achieved by installing a pulse ultrasonic detector above the roadway (Black & Loukakos 2000). Ultrasonic sensors have no moving parts so they tend to be reliable, durable and require little maintenance. They are also small and can be sited permanently or used as a portable unit. However, air turbulence and temperature adversely affect operational performance.

v. Acoustic Sensors

The time delay between the arrival of sound at the upper and lower microphones changes with time as the vehicle emitting the sound passes under it. When a vehicle passes through the detection zone, an increase in sound energy is detected by the signal processing algorithm and a vehicle presence
signal is generated. When the vehicle leaves the detection zone, the sound energy level drops below the detection threshold and the vehicle presence signal is terminated. This sensor can count vehicles and measure presence, speed, volume and occupancy. Interference between the noises of multiple vehicles is a limitation to acoustic technology. Its performance is also affected by low temperature and by snow, and dense fog that may muffle sound and lead to undercounting. This sensor can monitor as many as six to seven lanes (Parkany & Bernstein 1995).

vi. Laser Sensors

Laser sensors can offer high-speed measurement accuracy and measure all the vehicle characteristics needed for traffic surveillance and incident detection (Abramson & Chenoweth 2000). Generally, laser sensors are mounted on a gantry over the highway; each unit can provide coverage for two adjacent lanes. A wireless modem connected with the sensor transmits the information between the sensor and a control and processing computer. Almost all traffic parameters, such as presence, classification, speed, volume, occupancy and so on can be measured by laser sensors. Moreover, they provide detailed vehicle shape characteristics needed to uniquely identify vehicles. This capability can be used to measure travel times between two locations on highways, which offers the possibility to develop incident detection schemes based on variations in travel time like the ones that utilize probe-based data.

2.3.4 Video Image Processor Incident Detection System

Video Image Processors (VIP) employ machine vision techniques to automatically analyze traffic data collected with CCTV systems or other video cameras. A VIP system consists of one or more video cameras, a computer for digitizing and processing the video imagery, and software for interpreting the images and converting them into traffic flow data. The image processing algorithms in the computer analyze the variation of groups of pixels contained in the video image frames. By analyzing successive video frames, the VIP is capable of calculating traffic flow information.
One of the primary advantages of using VIP for incident detection is that incidents are not blocked by the resultant traffic queues if the surveillance video camera is installed so as to provide upstream viewing (Nelson 2000). Figure 2.5 illustrates the IDS using video processing. Video of vehicles are sent to central server and the operator will make a decision whether an incident is taking place.

![Figure 2.5 Video incident detection systems](source: Nelson 2000)

Some VIP systems are able to exact a wide range of traffic parameters, including density, queuing length and speed profiles (Parkany & Xie 2005). Other advantages of using VIP for incident detection also include possibly short detection time, quick identification, as well as recognition of the incident type (using human operators), multilane surveillance by one sensor and easy installation. The performance of VIP systems, however, is affected by variations of light and climate, so the installation position and the calibration of image processing algorithms need to be adjusted accurately. In addition, the transmission of video images requires more bandwidth than the transmission of voice and data, which increases the cost of transmission. There appear to be no technological barriers, given the technical maturity of VIPs, to the implementation of incident detection systems; the main challenge lies in refining its corresponding automatic incident detection algorithms (Loukakos, 2000).
2.3.5 GPS-probe Vehicles Incident Detection System

This incident detection system collects real-time data from probe vehicles and archives them to generate historical data for incident detection algorithms (Figure 2.6). Probe vehicles report their position and velocity observations to the information-processing centre at a rate of 1 Hz. These data are then converted into corrected vehicle trajectories and finally to street segment travel time records and acceleration noise. Sermons and Koppelman (1996) applied traffic dynamic measures using GPS positioning data to detect incidents in an arterial environment. Du and Aultman-Hall (2006) describe the difficulties in map matching GPS signals to specific roadways. Other positioning techniques, such as dead reckoning, have been incorporated into GPS systems or combined with GPS receivers in order to improve operating reliability (Sweeney & Loughmiller 1993; Levine & McCasland 1994).

The incidents were detected by analyzing the travel times and the acceleration noise reported by probe vehicles with respect to thresholds established for normal operating conditions. Therefore, successful performance of the algorithm depended on the accuracy of prior information on normal operation characteristics of the street segment, established using archived probe vehicle reports (Basnayake 2004). The system has high Detection Rate (DR) with low False Alarm Rate (FAR). The techniques also yield an average Time to Detect (TTD) of 30 seconds to 3 minutes.
depending on the probe vehicle population size, incident characteristics, and GPS performance. Probe-based monitoring has been identified as a technique with great potential for urban street monitoring. However, the cost of vehicle positioning systems has been one of the limiting factors for the slower adaptation of probe vehicles for IDS.

### 2.3.6 Freeway IDS based on Wireless Positioning

This system was introduced by Rufu et al. (2008). Both GPS and mobile phone positioning system (MPPS) have been combined together to gain double positioning function. MPPS can be used to take control the positioning invalidation and enhance the reliability, and GPS can be used to enhance the accuracy. On the one hand, when running vehicles break down or find other vehicles experiencing traffic accidents, they can observe for a while or immediately press the alarm button on the in-car device, which can give an alarm to the Transport Management Center (TMC) via wireless communication network, such as Global System for Mobile Communications (GSM) and General Packet Radio Service (GPRS).

On the another hand, when the vehicle experiences shaking or encounter a collision, the in-car sensor can detect the situation of the vehicle automatically, compare the detected data with the thresholds (it can receive other in-car equipment’s feedback information, for example, when airbag ejects, the in-car sensor will estimate that the vehicle may be involved in an incident) and estimates if the vehicle has been involved into an incident. If an incident is affirmed, the in-car system will send a default alarm message to the TMC via GSM. Figure 2.7 shows the typical incident detection system based on wireless positioning.
2.3.7 Signpost/Beacon Incident Detection System

Signposts/beacons are infrared, microwave, RF devices mounted on the sides of the roadway or existing cellular base stations (Nelson 2000; Garg & Wilkes 1996). These devices are capable of transmitting and receiving data from vehicles equipped with transceivers when these vehicles pass in close proximity to the signpost/beacon as shown in Figure 2.8. These systems can be either of self-positioning or of remote positioning. In the first case, a tag in the vehicle picks up a signal from the beacon. In the second case, the beacon senses a tag on the vehicle. The basic configuration includes antennas, transmitter electronics, and receiver electronics. Radio frequency beacon systems are becoming more common for applications in traffic surveillance and parking management. This system is similar to vehicle-to-road-side communication (VRS) system, which utilizes radio frequency communication between the transponder installed in vehicles and a roadside reading device (Mussa & Upchurch 2002).
2.3.8 Cellular Geolocation System

Intelligent Transport System (ITS) applications of cellular geolocation technology are currently being explored by researchers and practitioners. The Federal Communications Commission (FCC), as part of its requirements for the E911 system, has directed the cellular telephone industry to implement a system that is able to locate two-thirds of all mobile 911 callers within 125 meters of accuracy. This requirement enhances applications using cellular phone calls from and to motorists as mobile traffic sensors. Several tests of vehicle location and speed-estimation using telemetry data from cellular phone receivers have been conducted (Sakagami et al. 1992; Transportation Studies Center 1997; Lovell 2001; Smith et al. 2001; U.S. Wireless 2001). Figure 2.9 shows the schematic of active positioning system. When requested by the mobile-station, the base-stations "listen" to the signals emanating from the mobile station. For remote-positioning systems, the BSs fuse the measurements to produce a location estimate for the mobile station. For self-positioning systems, the roles are reversed.
The available raw data from the cellular location system include: 1) the mobile identification number; 2) the longitude and latitude of the call location; 3) instantaneous speed; 4) heading—the current compass heading of the call’s mobile device; and 5) time stamp. Other common techniques include signal strength, angle of arrival (AOA), and the difference of arrival (TDOA). This sensor technology used for traffic surveillance has several advantages (Drane & Rizo 1997). It makes use of an existing infrastructure, and requires no alteration to the base station or subscriber handsets and hence significantly reduces the cost of service establishment. Cellular phones have a potential be used as vehicle probes. Wireless technologies offer tremendous possibilities for cost savings with the potential to work with implemented hardwired systems in the ITS domain.

2.3.9 Automatic Vehicle Identification System

Automatic Vehicle Identification (AVI) is designed to identify (typically using short range communications) a vehicle that is situated at a specific location at a specific time. AVI systems as shown in Figure 2.10 have two primary components, the in-vehicle unit (i.e., tag or transponder) and the roadside unit (i.e., reader), and a wireless communications link between them (Parkany & Bernstein 1995). Most AVI systems transmit information through microwave, infrared or radio frequency (RF). Under
good conditions, the reported accuracy of an AVI system is usually in the 99.5% to 99.9% range. However, their accuracy may be reduced by adverse weather conditions and interference from other radiation sources. AVI technology is applied principally for electronic toll collection (ETC), electronic congestion pricing (ECP), and fleet control. The capability of multiple-purpose usage makes AVI a promising sensor technology for incident detection, as long as the percentage of the transponder-equipped vehicles in the market reaches a certain level. Hallenbeck et al. (1992), Parkany & Bernstein (1995), and Hellinga & Knapp (2000) have studied the capabilities and performance of AVI for incident detection in simulation environments.

![Figure 2.10 AVI Vehicle-to-Roadside Communication Process](source)

**Figure 2.10 AVI Vehicle-to-Roadside Communication Process**

*Source: Parkany & Bernstein 1995*

### 2.3.10 Highway Service Patrol

Typically, service patrol vehicles, police in highway cruisers and CCTV monitoring by operators as shown in Figure 2.11 serve as the main sources of information for incident detection. Service patrol vehicles are intended to monitor and assist vehicles
and they generally operate on freeways at a specified frequency. The advantage of this approach is that service patrols can detect and verify incidents at the same time and respond to accidents and other incidents quickly, which greatly reduces verification, response, and clearance time. The cost of service patrols is not inconsequential. With limited patrol vehicles and staff and hence limited dispatch frequency, the time to detect is relatively long; e.g., in the above limited service period it was reported that the average responding time to an incident is approximately 8 to 11 minutes. With the limited daily service duration (e.g., generally 8 hour patrol period per day), the temporal coverage cannot satisfy the demand of monitoring incidents for the whole day (Parkany & Xie 2005).

Figure 2.11 Highway Service Patrol detection system
Source: Parkney & Xie 2005

2.4 AUTOMATED INCIDENT DETECTION ALGORITHMS

There are several traditional families of incident detection algorithms (Singliar & Hauskrecht 2006; Martin et al. 2000). They are grouped into two categories: automatic and non-automatic. Automatic algorithms refer to those algorithms that automatically trigger an incident alarm when traffic condition data are received from field sensors or detectors; on the other hand, non-automatic algorithms or procedures are based on human witness reports. Some automatic algorithms operate imperfectly in a real, in contrast to a simulated, traffic environment. Recently, more attention has been paid to driver-based procedures, e.g. drivers’ wireless phone reports. These are capable of
providing quick detection and identification, rich and interactive descriptions, and
broad spatial and temporal coverage with less initial investment and operation and
maintenance cost (Xie & Parkany 2002). Using another classification system, incident
detection algorithms may be divided into two functional categories: freeway
algorithms and arterial algorithms. Historically, most automatic algorithms were
developed for use in freeway incident detection and few are readily transferable to
arterial roadways. Less effort has been devoted to incident detection on arterials.
Incident detection algorithm is divided into five major groups.

2.4.1 Roadway-Based Algorithms

Most traditional automated incident detection algorithms use roadway-based point
data. Different algorithms have different data requirements, principles, and
complexity. These algorithms are grouped into seven categories in terms of their
principles:

i. Comparative algorithms

Comparative algorithms are designed to compare the value of
measured traffic parameters (i.e., volume, occupancy or speed) to a
pre-established threshold value. An incident alarm is prompted when
the measured traffic parameter exceeds an established threshold.

ii. Statistical algorithms

The statistical algorithms use standard statistical techniques to
determine whether observed detector data differ statistically from
estimated or predicted traffic characteristics.

iii. Time series algorithms

Time series algorithms assume that traffic normally follows a
predictable pattern over time. They employ time series models to
predict normal traffic conditions and detect incidents when detector measurements deviate significantly from model outputs.

iv. Filtering/smoothing algorithms

Smoothing and filtering techniques are designed to remove short-term noises or inhomogeneities from traffic data that cause false alarms and hence permit true traffic patterns to be more visible so as to more readily detect true incidents. Smoothing is a mathematical technique for producing a weighted average of a given traffic variable. Filtering algorithms use a linear filter that allows the low-frequency components of the detector data to pass while removing the undesirable high-frequency portions of the detector data.

v. Traffic modeling algorithms

Traffic modeling approaches for incident detection apply traffic flow theory to describe and predict traffic behavior under incident conditions. Discrimination between incident and incident-free traffic by this type of model is based on the comparison between observed traffic parameters and parameter values estimated by the models.

vi. Artificial intelligence algorithms

Artificial intelligence refers to a set of procedures that apply inexact or "black box" reasoning and uncertainty in complex decision-making and data-analysis processes. The artificial intelligence techniques applied in automatic incident detection include neural networks.

vii. Image processing algorithms

Two types of image processing algorithms have been used for incident detection. In the first instance, the image-processing unit (consisting of a surveillance video camera and an image processing computer program) may be used as a loop detector or another fixed detector to
provide traffic measures, such as volume, occupancy, speed, and/or queue length. The image-processing program extracts traffic variables from video images. In the second method, the image-processing program interprets the entire video image to find stationary or slow-moving vehicles, so as to detect incidents.

All of these algorithms use loop detector or loop-emulating data collected at points along the roadway and are all applied to freeways. There are several disadvantages to using point data for incident detection. The algorithms using loop data suffer from high rates of false alarms (Stephanedes et al. 1992; Petty et al. 1997; Mahmassani et al. 1998). One disadvantage is the tendency of loop detectors to malfunction. Anecdotal evidence indicates that as many as half of the loop detectors in a system may be inoperable at any given time (Ygnace et al. 2000). An inherent disadvantage of point-based sensors (even the new loop-emulators such as video, radar or infrared) is that they collect only spot traffic data. It may be difficult to ascertain true traffic conditions using data at only individual points on a roadway. Besides the difficulties involved with implementing most point-based incident detection algorithms, there are specific problems with road-based systems, namely: 1) the installation and maintenance interrupts traffic, and may even require road closure; and 2) the placement of roadway detectors or the data collection frequency is critical to the accuracy and reliability of point data used for determining an incident; however, these settings are not readily determined.

2.4.2 Probe-Based Algorithms

The primary fixed detector variables are vehicle volume and occupancy (Sethi et al. 1995). Probes, such as toll transponders and GPS receivers mounted on vehicles, are becoming increasingly prevalent for electronic toll collection, congestion pricing and fleet management applications. Using travel times and other spatial traffic measures collected by probes, better information about traffic conditions with wider roadway coverage can be obtained. Given that these probe-based algorithms were designed in accordance with the operation principles and data availability of their corresponding probe sensors, the sensor used will be identified prior to the description of each algorithm. With the exception of the advance algorithms developed in Chicago in the
early ’90s, these probe-based algorithms have been developed for freeway incident detection. These algorithms are grouped into six categories in terms of their principles:

i. MIT algorithms

Parkany and Bernstein (1995) conducted an initial exploration of the use of electronic toll transponders (referred to as vehicle-to-roadside communication, or VRC, in their papers) to detect incidents. They analyzed the capabilities of two types of toll transponders, i.e., “read-only” and “read-write,” for incident detection. “Read-only” means a roadside reader can read information from probe transponders or tags while “read-write” allows both obtaining information from and writing information on transponders.

ii. ADVANCE algorithms

In the ADVANCE operational test, Sethi et al. (1995) and Sermons and Koppelman (1996) developed arterial incident detection algorithms based on probe positioning and timing data, using a discriminant analysis technique. All of the algorithms are designed to eliminate false alarms while keeping detection rates at a high level. In discriminant analysis, analogous to multiple-variable linear regression, a linear relationship of predictor variables describing traffic flow characteristics is developed to distinguish incident and incident-free conditions. The result of discriminant analysis for incident detection is dependent on the measured traffic variables and the prior probability of an incident.

iii. TTI algorithms

The Texas Transportation Institute (TTI), in conjunction with the Texas Department of Transportation, conducted a pilot study to test the feasibility of using probe vehicle travel time to detect incidents on freeways (Balke et al. 1996).
iv. Upper Confident Bound (UCB) algorithms

Petty et al. (1997) proposed a probe-based algorithm using vehicle-equipped radio transponders that communicate with existing cellular phone base stations via the standard cellular digital packet data (CDPD) protocol. This technology is currently used for fleet management, e.g., by taxi or logistics companies to track their individual vehicles' location and to perform scheduling. The CDPD radio is ubiquitous on most freeways and major arterials in the current roadway networks. In this system, probe data transmitted to a base station and then forwarded to a TMC for traffic monitoring and incident detection.

v. TRANSMITT algorithms

Mouskos et al. (1999) and Niver et al. (2000) discuss the performance of a probe-based incident detection algorithm using statistical travel time comparison between probe reports and continuously updated historical archives in TRANSCOM’s (New York and New Jersey) system for managing incidents and traffic (TRANSMIT). In the TRANSMIT operational test, probe vehicles were equipped with E-ZPass electronic toll tags for traffic surveillance and incident detection.

vi. Waterloo algorithms

Three automatic vehicle identification (AVI) or electronic toll transponder-based incident detection algorithms characterizing mean and variance of travel times, named the confidence limit algorithm, speed and confidence limit algorithm, and dual confidence limit algorithm, were proposed and examined by Hellinga and Knapp (2000).
2.4.3 Driver-Based Algorithms

Driver-based algorithms are designed to screen and identify drivers’ phone calls or other witness reports of incidents. Unlike automatic incident detection algorithms (i.e., roadway based and vehicle-based algorithms), driver-based techniques deal with people’s responses to incidents, not to traffic measures converted from sensor signals. Due to the complexity and inconsistency of report contents, the automatic process of witness reports and further incident detection and identification presents a great challenge to information processing technology. Driver-based data sources used for incident detection present inevitable problems, including incorrect or incomplete information from witness reports about an incident location and severity, and false or prank reports (Parkany & Xie 2005).

2.4.4 Sensor Fusion-Based Algorithms

The performance of incident detection algorithms is highly dependent on the quality of collected traffic data. It is reasonable to expect that using multiple data sources, e.g., fixed detectors (collecting point data) and probe vehicles (collecting spatial data), could enhance the input data reliability and completeness and hence improve the performance of an incident detection system. Westerman et al. (1996) attempted to integrate probe vehicle and loop detector data for travel time estimation and incident detection. A parallel structure in the fusion process is employed, in which probe vehicle and loop detector algorithms perform independently but receive support from each other. A two-step structure characterizes this compound algorithm: a trigger mechanism that indicates a suspicion of occurrence of an incident, and a verification mechanism in which this suspicion is automatically verified. The probabilities of an incident occurrence from each algorithm (i.e., hybrid loop detector algorithm, probe vehicle algorithm, and local-related and section-related comparison algorithm) are combined to make a final decision in the verification mechanism, where a weight averaging fusion method is applied. The number of performed verification steps determines the weight factor for each component.
2.4.5 Arterial-Applicable Algorithms

Due to disruptions from signal/sign control and other disturbances (e.g., pedestrian crossings, parking maneuvers, transit stops) on arterial streets, traffic varies more frequently and sharply with much greater complexity on arterials compared to freeways. In addition to commonly defined incidents, there are arterial-specific events that result in non-recurrent congestion on urban arterial streets, e.g., traffic signal malfunction, illegal stopping and parking, blockage of intersection, sports events and concerts, or celebrity visits and parades. Since different traffic phenomena exist in freeway and arterial environments, most incident detection principles and algorithms applicable to freeways are not readily transferred to arterial cases. Incident detection for arterial streets has received significant attention from traffic operations and control personnel only in recent years (Parkany & Xie 2005). A variety of incident detection algorithms has been developed for and is applicable to arterial streets. Each of them is named with its corresponding employed technique/algorithm to signify its underlying principle and operational features. These algorithms are grouped into nine categories in terms of their principles:

i. Pattern Matching Algorithms

Pattern matching/pattern recognition/comparative algorithms for arterial incident detection are designed to track variations of traffic measures and identify corresponding traffic patterns in order to distinguish incident from non-incident traffic conditions.

ii. Kalman Filtering Algorithms

Kalman filtering is a self-learning variable estimation/prediction mechanism that was derived from a solution to the Wiener problems (including prediction of random variables, separation of random signals from random noise, and detection of variables of known form in the presence of random noise), using the state-space model for dynamic and random processes. This technique estimates the state variables iteratively as they vary over time, so that there is a recursive
relationship between the states of the system in consecutive time periods. At each time interval, the projected state of the system is adjusted to account for the observed values of various system parameters.

iii. Discriminant Analysis Algorithms

Linear discriminant analysis is a classification technique in which a linear combination of predictor variables describing traffic flow characteristics on links is used to classify cases into two or more mutually exclusive groups, such as incident and incident-free conditions in the incident detection application. Classification using discriminant analysis depends on a discriminant score, which is a function of the measured variables and the so-called prior probability. The prior probability of incidents is an incident sensitivity indicator that affects the trade-off between detection rate and false alarm rate.

iv. Modular Neural Algorithm

In contrast to the foregoing singular neural network models, Khan and Ritchie (1998) proposed using multiple neural networks in a modular architecture to detect arterial operational problems, including lane-blocking incidents, special on-street events, and detector malfunctioning. A modular neural network architecture allows decomposition and assignment of complex tasks to several modules that are single neural networks, e.g., the commonly used multi-layer feed forward (MLF) neural networks. The multiple modules decompose the problem into two or more subsystems, with each module solving a separate sub-task. Neural networks comprising the modular architecture compete with each other and learn training patterns by partitioning the function into independent tasks and allocating a distinct network to learn each task. Therefore, a modular architecture performs local generalization by learning the patterns of a
particular region. Moreover, the interaction between modules would cause some of the modules to be used for a subtask.

v. Fuzzy Logic Algorithm

Lee et al. (1998) developed a fuzzy logic-based algorithm to detect incidents on a signalized diamond interchange, which was controlled by a real-time traffic adaptive control system. Fuzzy logic is an effective solution technique for models that need to operate in real-time, require approximate reasoning, and exhibit uncertainty.

vi. MSRPT Algorithm

Sheu and Ritchie (1998) applied Modified Sequential Probability Ratio Tests (MSRPT) for arterial incident detection. In their incident detection system, three sequential procedures were developed: 1) symptom identification is a logical knowledge-based rule for identification of incident symptoms; 2) signal processing is used for raw traffic data (i.e., volume and occupancy) pre-processing and real-time prediction of incident-related lane traffic characteristics; and 3) pattern recognition conducts a decision-making process for incident recognition.

vii. CUSUM Algorithm

The cumulative sum (CUSUM) chart is a form of process control that has been developed by industrial engineers to monitor and detect any abrupt change that may contaminate the quality of a product. This chart can detect small to moderate persistent shifts of statistical parameter by memorizing and accumulating past samples to determine the status of the process (Parkany & Xie 2005).
Incident detection can be regarded as a discrete choice problem where incident and incident-free conditions are two definable choices. Lee and Hwang (2001) attempted to apply a multinomial logit (MNL) model, which was originally developed in the econometrics area and widely used for discrete choice modeling and analysis, to model arterial incident detection problems. An incident index, representing the probability of an incident occurrence, was expressed as the utility of the MNL model. They incorporated detector occupancy and volume as the independent variables and assumed the error term followed a Gumbel distribution in the logit-based incident detection algorithm. The proposed algorithm was evaluated by applying simulated data generated from the NETSIM model and compared with a modified California algorithm (applicable to surface streets) and a neural network-based algorithm. The test results indicated this logit-based arterial incident detection algorithm has a high efficiency and accuracy.

2.5 INCIDENT DETECTION PERFORMANCE INDICATOR

The following measures are used as a standard performance indicator for AID systems: detection rate (DR), false alarm rate (FAR) and time to detect (TTD). An ideal algorithm would maximize DR and minimize FAR and TTD. In practice, however, this ideal is never attained due to limitations in incident detection techniques and the complexity of the traffic and roadway environment. Nevertheless, all existing algorithms seek to stake a balance among the several objectives. In the following subsections, the definition of performance is presented and discussed:

2.5.3 Time to Detect (TTD)

Time to detect is defined as the time from when the incident occurs until it is detected. This does not include the time taken to verify the incident. Algorithms will often adjust the persistence of the alarm. This persistence determines the number of time
intervals that incident level flow disruption must exist before an alarm is raised. Most algorithms use 20- or 30-second time intervals. For most research results, the time to detect is assumed to have been calculated based on peak hour volumes. The basis for the calculations, however, generally is not provided with the reported performance results. It is possible that the reported TTD for installed systems is based on peak and off-peak period flows while the TTD for laboratory tests generally is based on peak volumes (Martin et al. 2000).

\[
TTD = \frac{1}{n} \sum_{i=1}^{n} (t_{\text{detection}} - t_{\text{occurrence}})
\]  

(2.1)

where  

\[ t_{\text{detection}} = \text{time where incident is detected} \]

\[ t_{\text{occurrence}} = \text{time where incident is occurred} \]

2.5.4 Detection Rate (DR)

The detection rate is generally considered as the ratio of the number of detected incidents to the total number of incidents. This varies according to the definition of an incident. Some studies count any stalled vehicle to be an incident, regardless of location, while others only count lane-blocking incidents (Martin et al. 2000). Those who belong to the latter group generally have reported higher detection rates because shoulder incidents often do not cause sufficient disruption in traffic flow to trigger an alarm.

DR is defined as the percentage of successfully detected incidents out of all incident cases.

\[
DR = \frac{\text{No. of detected incident}}{\text{Total no. of actual incident}} \times 100\%
\]  

(2.2)
2.5.5 False Alarm Rate (FAR)

The false alarm rate is most often defined as the percentage of incorrect detection signals relative to the total number of algorithm decisions. Most algorithms make one decision per detector stations at each time interval. The reporting of this value is inconsistent in the literature due to the many ways it can be calculated (Martin et al. 2000). Given the above definition, small false alarm rates are reported. The number of decisions and the total number of detector pairs in a network can cause many false alarms in a short time. Others make relatively few decisions over a period of time creating a high percentage of reported false alarms. Another definition used is the number of false alarms per time frame, per station.

FAR is also defined as the percentage of times where incidents were indicated by the algorithm when there was no actual incident. False alarm rate (FAR) has different definitions for different applications. The commonly used FAR is defined as the ratio of the number of false alarms to the total number of algorithm applications, as shown by equation 2.3. Alternatively, FAR may be defined as a fraction of the number of false alarms to the total number of declared incident alarms, including all correct and false alarms, as shown by equation 2.4. A third FAR, FAR3 may be defined as the number of false alarms per day or per hour as shown in equation 2.5. This measure is used to reflect traffic operators' workload. In this chapter, the first definition is applied.

\[
\text{FAR1} = \frac{\text{No. of false alarms}}{\text{Total no. of algorithm applications}} \times 100\% \quad (2.3)
\]

\[
\text{FAR2} = \frac{\text{No. of false alarms}}{\text{Total no. of declared incident alarms}} \times 100\% \quad (2.4)
\]

\[
\text{FAR3} = \frac{\text{No. of false alarms}}{\text{Time period}} \quad (2.5)
\]
An incident detection algorithm with a higher DR, lower FAR, and a faster TTD is capable of functioning as a powerful tool for automated traffic monitoring. Detection rate and false alarm rate are considered to be measures of the effectiveness of an algorithm, while the mean time to detect reflects the algorithm efficiency (Yu et al. 2008). The values of these measures are interdependent. Generally, increasing the performance of detection rates will result in the false alarm rate to also rise. Similarly, if false alarms are decreased, then the sensitivity of the algorithm is reduced as a whole and the detection rate falls. In general, the longer an algorithm is given to analyze data, the better results it will give. These mean that by increasing TTD, both the DR and FAR improve. Because of this dependency, most reports give a range of DR, FAR, and TTD to describe the performance of an algorithm. These values must be calibrated for each specific installation to balance the tolerable number of false alarms with an acceptable time to detect and detection rate.

The original intent was to compare the performance reports for each of the algorithms according to the three parameters. It quickly became evident, however, that most of the studies (Martin et al. 2000) use different combinations of the definitions and do not always explicitly state what definitions they use. This makes a direct comparison of each algorithm rarely possible and likely to be inaccurate because each site has its own number of detectors, detector spacing, time intervals, geometry, and recurrent congestion characteristics. To compare 100 percent detection rate for an algorithm tested on only eight detectors to an algorithm tested on 500 detectors, with a rate of 68 percent is not reasonable because of the different characteristics. Instead of attempting a direct comparison of performance measures, each set of performance measures is given as reported. Additionally, the definitions of the measurement methods are given where they are reported.

Another indicator to evaluate incident detection is Information Details and Adequacy (IDA). IDA is not a numeric performance measure, but an indicator reflecting the reporting capability of an algorithm when it reports an unusual congestion problem. It incorporates incident-related information, such as incident location, type, severity, number of vehicles involved, etc. High IDA reporting capability can greatly facilitate incident confirmation and response. The IDA, as a
qualitative measure, is increasingly being paid attention to and becoming an important consideration when transportation professionals assess the effectiveness of an incident detection and management system. Table 2.1 shows the performance indicator for incident detection using GPS data and sending via PDA device to gateway server, studied by Kamran and Hass (2007). This multilevel traffic incident detection system has a very good TTD but poor DR.

Table 2.1 Detection Rate (DR), False Error Rate (FAR) and Time to Detect (TTD) for Incident Detection Using GPS Data and sending via PDA device to gateway server.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Vehicles Per Seg.</th>
<th>Seg.</th>
<th>Road Type</th>
<th>DR %</th>
<th>FAR %</th>
<th>TTD mm:ss:ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10 - 20</td>
<td>10</td>
<td>Motorway</td>
<td>78.70</td>
<td>1.18</td>
<td>00:2:20</td>
</tr>
<tr>
<td>1</td>
<td>20 - 80</td>
<td>10</td>
<td>Motorway</td>
<td>75.30</td>
<td>1.23</td>
<td>00:2:20</td>
</tr>
<tr>
<td>1</td>
<td>100 - 200</td>
<td>10</td>
<td>Motorway</td>
<td>71.00</td>
<td>1.37</td>
<td>00:2:20</td>
</tr>
<tr>
<td>1</td>
<td>100 - 200</td>
<td>20</td>
<td>Motorway</td>
<td>71.60</td>
<td>1.38</td>
<td>00:2:30</td>
</tr>
<tr>
<td>2</td>
<td>10 - 20</td>
<td>10</td>
<td>Motorway</td>
<td>62.70</td>
<td>2.16</td>
<td>00:3:40</td>
</tr>
<tr>
<td>2</td>
<td>20 - 80</td>
<td>10</td>
<td>Motorway</td>
<td>59.30</td>
<td>2.28</td>
<td>00:3:40</td>
</tr>
<tr>
<td>2</td>
<td>100 - 200</td>
<td>10</td>
<td>Motorway</td>
<td>53.60</td>
<td>2.31</td>
<td>00:3:40</td>
</tr>
<tr>
<td>2</td>
<td>100 - 200</td>
<td>20</td>
<td>Motorway</td>
<td>52.20</td>
<td>2.32</td>
<td>00:3:50</td>
</tr>
</tbody>
</table>

Result for driver based and highway based VRC incident detection by Mussa and Upchurch (2002) is shown in Table 2.2. Both systems have 2 minutes and more TTD and whereas highway based has DR of less than 50%.

Table 2.2 Driver based and Highway based VRC

<table>
<thead>
<tr>
<th>Detection method</th>
<th>Detection Rate (DR) (# of incidents detected per true incidents)</th>
<th>Time to Detect (TTD) (minutes from simulated occurrence to detection)</th>
<th>False Alarm Rate (FAR) (# of false alarms per algorithm repetitions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headway algorithm</td>
<td>75%</td>
<td>2.0</td>
<td>1.95%</td>
</tr>
<tr>
<td>Speed and confidence limit algorithm</td>
<td>48%</td>
<td>4.1</td>
<td>0.20%</td>
</tr>
<tr>
<td>Driver-based detection</td>
<td>100%</td>
<td>2.0</td>
<td>–</td>
</tr>
</tbody>
</table>
2.6 ALGORITHM VERIFICATION

There are two types of algorithms for incident detection (Thomas & Berkum 2008). The first group of algorithms is based on ‘positive identification’ or recognition, i.e. an incident is identified when the data is similar to those during an incident from the past. Algorithms based on recognition may be sophisticated, but their performance is only superior when all of the incidents provide rather similar data. The second group contains algorithms that identify outliers. These algorithms are based on ‘negative identification’, i.e. an incident is identified when the measurements deviate significantly from the ‘normal’ situation. In time-series algorithms, for example, an incident is detected when the measurements differ significantly from the predictions (Stephanedes et al. 1992; Dudek et al. 1974), and in decision structure algorithms incidents are detected when measurements exceed thresholds (Knibbe et al. 2005; Ash 1997; Payne & Tignor, 1978). Algorithms based on ‘negative identification’ are less sophisticated, but they may be more suitable for an urban network.

Incident algorithm verification is to verify if an incident has happened, where it has happened, how severe it is and other incident information. From the study, there is no precedent of traffic incident detection method based on wireless positioning technology that has been used on a large scale in the world. Consequently, in the absence of field data, a simulation test model was developed to measure the effectiveness of this incident detection method theoretically. Generally, operational measures of interest to a highway agency are the amount of time it takes to detect an incident from the time of incident occurrence and the percentage of actual incidents that can be detected by the system. These two measures, together with the false alarm rate, have traditionally been used in the literature to assess highway-based incident detection systems and other forms of driver-based incident detection systems (Mussa et al. 1998; Dudek & Messer 1974; Payne et al. 1975; Persaud & Hall 1989; Stephanedes & Chassiakos 1993; Tsai & Case 1979). False alarms are difficult to model and only a field study can quantify the extent of the false alarm problem for AID system.
2.7 GPS RECEIVER ACCURACY

Vehicle positioning is a key requirement for many intelligent transport systems (ITS) (Piao et al. 2010). It is estimated that accurate location information can greatly saving about 2000 lives per year across Europe (Bell 2006). These days, numerous services, equipment and hi-tech gadgets are fully utilizing the Global Positioning System’s (GPS) special features which rendered information such as locations, positions, coordinates, directions and speed. More and more companies will begin to embrace this technology in the future as have been predicted by experts. The GPS is enhanced for diverse applications such as aeronautic technology, communication, surveillance, logistics, traffic management, security, commercial, agriculture, deep-sea fishing, incident detection and in other fields (Theiss et al. 2005).

GPS is one of three global satellite navigation systems (GNSS) in operation that allow the determining of geographic location anywhere around the Earth at anytime. GPS includes a constellation of 24 NAVSTAR (NAVigation System with Timing and Ranging) satellites orbiting our planet 20,200 km above ground. These satellites have been placed in 6 different orbital planes at an inclination of 55°. They circle the Earth every 12 hours and use two L band (L1 and L2) frequencies to broadcast pseudo-random radio signal. As any other radio signal, messages broadcast by GPS satellites travel at the speed of light. These messages contain names of the satellites that sent them, time when the messages were sent and other technical information. The exact location in the space of every satellite at every moment of time is known. A GPS receiver listens to several satellites simultaneously and measures the time it takes for the signal to reach the receiver. Then, distance from the receiver to each satellite can be found as follows: Distance = Speed of light x Signal travel time.

The GPS receiver uses the method of triangulation to determine its location. Therefore, it needs to calculate distances to a minimum of three visible satellites if the receiver is located on the surface of the Earth. The fourth satellite is needed to calculate the height of the receiver (position in 3D). Although clocks installed on the satellites are very accurate, the clock inside a GPS receiver may provide significant errors. To adjust time measurements, additional satellites are desirable. Therefore,
more visible satellites usually result in more accurate distance measurements. By its nature, GPS signal is very weak and it cannot travel through a wall of a building or even through a canopy of trees.

Most modern receivers can “listen” to up to 12 satellites at the same time. However, only 8 to 9 satellites are normally visible in an open field. Therefore, when the receiver closes to a building or a tall tree, it may not be able to receive signal from more than four satellites. Clear sky is a “must have” condition for proper operation of a GPS receiver. It does not work inside. In addition to the number of satellites, it is important that all of them are spread around the sky instead of clustering on one side. The “receiver” could easily move around without getting any of the strings loose. In GPS terms, Dilution of Precision (DOP) is used to describe how well the visible satellites are spread around the sky (Adamchuk & Thomas 2008). It is typically represented by a value from 1 to 6. A good DOP suggests a sufficient number of satellites are evenly spread around the sky and is typically low. A poor DOP means that the quality of position estimate is low. Good DOP is obtained when satellites in view angle (θ) is wider as compared to poor DOP which has small view angles (see Figure 2.12).

Conventional GPS receiver has accuracy up to 100 meters: however, with the use of differential GPS (dGPS) this offset can be narrowed down to less than 10 meters. Thus hi-tech GPS receivers are incisively accurate and precise. Researchers are continually conceptualizing new ways and creative means to improve the GPS
receivers from massive contraptions to handheld gadgets, creating real-time-kinematic technology which allows for the GPS receivers to be updated more rapidly. A new cellular networked assisted-GPS (AGPS) performs significantly better than the GPS in stand-alone mode due to the faster satellites equalization time, improves service availability in the rural, suburban and urban areas and reduces terminal complexity. The accuracy range of conventional GPS makes it difficult to distinguish between vehicle collision and vehicles that stopped close to each other due to congestion, traffic light, junction and many others (Kamran & Hass 2007). The advancement of GPS technology facilitates in-vehicle data collection (Taylor et al. 2000), providing an opportunity to thoroughly examine vehicle activities under various conditions at reasonable cost and accuracy (Ko et al. 2010). The comparison of accuracy and cost between GPS type is shown in Table 2.3.

The availability, reliability and accuracy of the GPS are influenced by several variables. The number of satellites available to the receiver is distinctively vital and theoretically, a minimum of four satellites are required to obtain a 3D position fix. In addition, the geometrical arrangement of the satellites relative to each other and the receiver affects the quality of the triangulation for position (Witte & Wilson 2004). The probability of receiving four or more GPS satellites with good geometry, quantified by a Position Dilution of Precision (PDOP) of less than six and an elevation higher than 5° is about 99%. This is, however, 24 hours global average, and not a guarantee for the availability at a special place and time on Earth (Lechner & Baumann 2000). GPS is a line of sight (LOS) signal service and it can be blocked, impeded or degraded by local topography, man-made structures and vegetation canopy (Stopher et al. 2007). It will affect the efficiency and accuracy of any GPS equipment or gadgets.

Innovative utilizations of Global Navigation Satellite System (GNSS) signals in precise navigation, geodesy, atmospheric physics, meteorology, seismology and other scientific fields frequently rely on highly accurate data (Beyerle et al. 2009). Simple, cheap and lightweight non-differential GPS units have been used for applications in animal tracking (Hunerbein et al. 2000) and the accuracy of these systems for the determination of speed has recently been tested (Witte & Wilson
Although some overshoot does occur during transitions, the GPS is accurate for determination of speed over ground (about 10 times more accurate than a car speedometer) when moving at relatively constant speed on curved paths (Witte & Wilson 2004). Therefore, GPS has great potential for a wide range of applications including vehicle incident detection.

GPS, with its high accuracy and easy availability, is now becoming one of the major data sources for traffic research including incident detection and traffic monitoring (Shi & Liu 2009; Byon et al. 2006; Wardrop 1952). In the millennium decade, many researchers have endeavored to estimate traffic conditions using GPS-equipped vehicles. Although mean travel speed (MTS) can hardly be treated as a critical traffic flow characteristic, Poomrittigul et al. (2008) has described a MTS estimation method using non-ID GPS-equipped vehicles (Ni 2007). Chen et al. (2007) proposed a traffic condition estimation method which tracked GPS-equipped vehicles according to their GPS traces and estimated traffic conditions based on MTS, yet the relationship between MTS and traffic conditions is not clear. Shi et al. (2008) described a GPS/GIS integrated system, in which an adaptive traffic flow model is proposed to estimate traffic conditions, but the lack of consideration of traffic signal’s influences deteriorated the method’s accuracy. Moreover, similar researches have been conducted by Tantiyanugulchai et al. (2003), Quiroga & Bullock (1998) and Fu et al. (2006). It shows that GSP is suited to be used as localization and speed determination device.

### 2.8 DATA TRANSMISSION IN INCIDENT DETECTION SYSTEM

Data transmission in incident detection is the transfer of information from the detector or data source to the processing center. Two types of communication were used; wired and wireless. Wired communication utilizes copper and optical fiber telephone line as a medium for data transfer. Wireless communications applied in IDS are GPRS, PDA, 3G, 4G and wireless local area network (WLAN). Internet service is also used for data transmission. The reliability and performance of IDS is depends on these data transmission technique. Table 2.4 summarizes the data transmission used for incident detection, as well as their advantages and disadvantages.
<table>
<thead>
<tr>
<th>GPS Type</th>
<th>Accuracy</th>
<th>Cost</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Stand alone GPS</td>
<td>15 meters</td>
<td>- GPS receiver – RM1500 ~ RM 2000</td>
<td>Outdoors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Subscription fee - free</td>
<td></td>
</tr>
<tr>
<td>WAAS GPS</td>
<td>7 meter</td>
<td>GPS receiver – RM3000 above Subscription fee - free</td>
<td>Outdoors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- DGPS/GPS receiver RM5000 ~ 10000 Subscription fee - free</td>
<td>Outdoors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Other cost : Radio signal and data</td>
<td></td>
</tr>
<tr>
<td>DGPS</td>
<td>1 to 5 meters</td>
<td>- GPS access point a) GPS receiver b) Low power computer</td>
<td>Outdoors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>c) Wireless router d) Antenna e) Power supply</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Rover GPS receiver Subscription fee - free</td>
<td></td>
</tr>
<tr>
<td>RTK-DGPS</td>
<td>centimeter to decimeter</td>
<td>- AGPS receiver – RM1000 ~ 2000</td>
<td>Outdoors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Subscription fee – GSM/GPRS data, depend on GSM provider</td>
<td></td>
</tr>
<tr>
<td>High sensitivity GPS (HSGPS)</td>
<td>&lt; 5 meter</td>
<td>- HSGPS</td>
<td>Outdoors</td>
</tr>
<tr>
<td></td>
<td>&lt; 50 meter</td>
<td></td>
<td>Indoors</td>
</tr>
<tr>
<td></td>
<td>typically outdoors in suburban and rural environments) within 10-50 meters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AGPS</td>
<td>Hybrid / Network Triangulation (typically indoors and in high density urban environments) – &gt; 50 meters</td>
<td>Outdoors</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 500 meters</td>
<td>Indoors</td>
</tr>
</tbody>
</table>
Table 2.4 Summary of the data transmission in IDS

<table>
<thead>
<tr>
<th>Transmission Technique</th>
<th>Incident Detection Technology</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Dedicated telephone line | – Inductive Loop Detector (ILD)  
– Motorway Control and Signaling System  
– Sensor-based  
– Video Image Processors | – use existing infrastructure  
– small delay and less congestion | – Higher operational cost (line rental) |
| Wireless broadband (GPRS/PDA/3G/4G) | – Motorway Control and Signaling System  
– Sensor-based  
– Video Image Processors  
– Freeway incident detection system based on wireless positioning  
– Automatic Vehicle Identification System | – use existing infrastructure | – Higher operational cost  
– delay and congestion  
– Data loss  
– Increase TTD  
– Decrease DR  
– Increase FAR |
| Wired Internet | – Inductive Loop Detector (ILD)  
– Motorway Control and Signaling System  
– Sensor-based  
– GPS-probe Vehicles  
– Video Image Processors | – use existing infrastructure | – Higher operational cost  
– delay and congestion  
– Data loss  
– Increase TTD  
– Decrease DR  
– Increase FAR |
| WLAN | – Video Image Processors  
– Cellular Geolocation System | – small delay and less congestion  
– less operational cost | – new infrastructure |

Since all vehicular data should transmit their signals at the same time to a processing centre, multiple access schemes have probably affected the speed of data transmission. In addition, the scheme has higher data rate between 2 Mbit/s (TDMA and frequency hopping CDMA) to 248 Mbit/s (OFDM-TDMA). Frequency Division Multiplexing Access (FDMA) technology is widely used in cable, satellite and terrestrial radio networks. The major benefits of FDMA are in its channel equalization and low required transmit power that is either much simpler than with other multiple access techniques or not needed at all.
Time Division Multiplexing Access (TDMA) is a popular multiple access technique which has been relied on in different international standards. In the TDMA technique, all users make use of the same band and are separated by allocating distinct and short Time Slots. Therefore, the co-channel interference in a cellular system is only found because of the frequency re-use. On the other hand, in Code Division Multiplexing Access (CDMA) all the users can transmit their signals at the same time using the same carrier via wider bandwidth than in a TDMA system. The signals of users are distinguished by assigning different spreading codes with low cross correlation properties. The advantages of the spread spectrum technique are robust against multi-path fading channel distortion, high flexibility, simple frequency planning, resistance to interference and variable rate transmission. The main advantages and disadvantage of FDMA, TDMA and CDMA are discussed briefly in Table 2.5.

Table 2.5 Advantages and drawbacks of multiple access system

<table>
<thead>
<tr>
<th>Multiple Access Scheme</th>
<th>Advantages</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDMA</td>
<td>– Low transmitting power</td>
<td>– Low peak data rate</td>
</tr>
<tr>
<td></td>
<td>– Robust to multi-path</td>
<td>– Loss due to guard bands</td>
</tr>
<tr>
<td></td>
<td>– Easy frequency planning</td>
<td>– Sensitive to narrowband interference</td>
</tr>
<tr>
<td></td>
<td>– Low delay</td>
<td></td>
</tr>
<tr>
<td>TDMA</td>
<td>– High peak data rate</td>
<td>– High transmit power</td>
</tr>
<tr>
<td></td>
<td>– High multiplexing gain in the case of busy traffic</td>
<td>– Sensitive to multi-path</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– Difficult frequency planning</td>
</tr>
<tr>
<td>CDMA</td>
<td>– Low transmitting power</td>
<td>– Low peak data rate</td>
</tr>
<tr>
<td></td>
<td>– Robust to multi-path</td>
<td>– Limited capacity per sector due to multiple access interference</td>
</tr>
<tr>
<td></td>
<td>– Easy frequency planning</td>
<td>– High scalability</td>
</tr>
<tr>
<td></td>
<td>– High scalability</td>
<td>– Low delay</td>
</tr>
<tr>
<td></td>
<td></td>
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</tbody>
</table>

2.9 SUMMARY

This chapter has presented a review of vehicle incident detection and their current technologies. The existing researches in IDS including detectors and algorithms used have also been presented in this chapter. Although various incident detection systems
have been deployed, their performance still suffers from poor reliability. Based on the
detection system used, the communication and processing method that leads to poor
performance, this research focuses on a new system which set up new detection and
communication method. The fully utilization of GPS data could lead to a new system
with excellent performance. Wireless communication that can provide the fastest
information transfer has also been discussed in this chapter. Based on the literature
review, a new method using high accuracy GPS receiver and multiple access system is
introduced. The details of the new method are presented in Chapter three.
CHAPTER III

RESEARCH METHODOLOGY

3.1 INTRODUCTION

Various vehicle IDS have been introduced over the past decade but the efficiency and reliability of the systems are still an issue. This gives the impetus and idea for this study that is to develop a new system with better performance. This chapter describes the equipment used for this study and the methodology adopted for the new AID system. This work begins with selecting the appropriate equipment for the study and the development of the system that can perform short time to detect, no false alarm and higher detection rate with low operational cost and less complexity. The following sections explain the details of the derivation method.

3.2 OVERALL METHODOLOGY

The overall methodology for the research is presented in Figure 3.1, followed by the description of each step. The study starts with the selection of the right equipment for data source, data transmission and data processing. The planning process includes study area selection and Monitoring Station planning. Preliminary study involves static and mobile data collection and data evaluation. Detailed explanations of the system development including system configuration and detection system algorithm can be found in Chapter four. Based on the findings in this chapter and Chapter four, results are then presented in Chapter five.
Figure 3.1 Overall outlook of the methodology
3.3 SYSTEM EQUIPMENT

Several different methods have been used to detect some particular abnormal driving behaviors. Sensing equipment (e.g. electrocardiogram, electromyogram and skin conductance) has been used to detect fatigue and drowsiness (Rogado et al. 2009). Induction loops, infrared detector, radar and camera detector were used to detect unusual vehicle speeds. Near infrared sensor was used to calculate vehicle steering movements (Portouli et al. 2007). Although abnormal driving detection can be based on psychological measures, an alternative source of information is available from vehicle system for example the braking system, speedometer, acceleration pedal and recently, GPS. The current state of technology in GPS and the economic feasibility of mass usage of in-vehicle positioning systems have resulted in the study of automatic vehicle incident detection using high accuracy GPS data (AIDEG) for IDS techniques.

This AIDEG system does not require any sensors and depends exclusively on GPS data. The system instrumentation for this research is shown in Figure 3.2. Real time GPS data from a number of vehicles are transmitted for processing to MS. High speed, reliable, charge free and direct data transmission is required in order to obtain the fastest time to detect. It is not necessary to use an expensive high precision GPS receiver such as RTK-GPS with accuracy of sub centimeters because the important factors are the movements and behaviors of the vehicles. However, to use normal low accuracy GPS receiver with accuracy of more than 10 meters is not appropriate because it is difficult to distinguish between the real movement and the changing of the GPS receiver accuracy, especially at higher speeds.

Raveon RV-M7 modem transceiver with 12-channel internal Trimble Copernicus GPS modules and UHF transmitter is selected for this study. With a reasonable price, at USD383 per set, this GPS modem is used as the vehicular GPS and MS receiver. The position accuracy of the GPS receiver is better than 2.5 meters (50%) and 5 meters (90%). The velocity resolution is 1 kilometer and accuracy is 1 kilometer per hour. Furthermore, the accuracy of the GPS receiver will be assessed during the preliminary static and mobile test. UHF Antenna is a mobile type, operating at 450-470MHz with 5/8 over 1/2 wave and 4.5 dB gain and can
communicate as far as 80 kilometers (depending upon the terrain). The UHF radio band is selected because this bandwidth is available and has no interference with other frequencies. The modem transceiver together with the GPS antenna and UHF antenna are shown in Figure 3.3.

![Figure 3.2 System Instrumentation](image)

The GPS modem will be set as the GPS transmitter in the vehicle and as the transceiver at the MS. The selection of this modem transceiver and GPS receiver was arbitrary due to their reasonably low prize and small size, and thus appropriate to be used in any type of ground vehicles. Their input voltage between 9.5 to 16 VDC is suited to the vehicle’s battery, which is 12 VDC and does not require any voltage regulator. It makes it easier for it to be installed in the vehicle and reduces the installation charge. The user/driver may also simply disassemble this GPS modem and install it in another vehicle. However, the user must firstly inform the operator to update vehicle profile. The modem transmitter/receiver has RS-232 NMEA interface and can be connected to any GPS receiver and any personal computer with serial port or universal serial bus port. The receiver’s antenna at the MS will be located at a higher place such as the telecommunication tower to get a clear Line of Sight (LOS). The MS has an ability to receive and process data up to 9999 vehicles at one time but
the system was limited to only 50 vehicles in order to achieve the best interval for data update. The next 50 vehicles will need another receiver to be located probably at the same MS location or other places.

![Image of a modem transceiver, GPS mounted antenna, and UHF unipole antenna]

**Figure 3.3** Raveon RV-M7 modem transceiver, GPS mounted antenna and UHF unipole antenna

A computer is used to process data from the modem receiver and the system with Intel Core 2 Duo processor and 2 Gigabytes RAM is adequate for the purpose; however, the computer must have large storage space for data storage and backup. A 19-inch LCD monitor is adequate to display all vehicles and other information. Since the computer will be working 24-hours per day, an air-conditioned room with uninterruptable power supply is required. A computer will be utilized to run a noble algorithm for incident detection and display vehicle conditions and status. While traffic engineers are expensive resources (Singliar & Hauskrecht 2006), the AIDEG system equipment is low in maintenance cost.

Before putting into operation the selected GPS receiver for the study, calibration process was carried out in order to obtain an accurate reading. Two types of testing were conducted. Firstly, GPS data was compared to the GPS reference station coordinate located at the Institute of Space Science, UKM (2.923076° N, 101.773051° E). The result as shown in Figure 3.4 is in conformance to the GPS accuracy with maximum error of 0.0005 degree (longitude) and 0.0003 degree (latitude).
Secondly, Google map and online gpsvisualizer software was used to calibrate the GPS receiver. GPS data collected around the university campus was plotted on the Google map. The result as illustrated in Figure 3.5 and Figure 3.6 shows the accurate GPS signal where no coordinates were plotted outside the road boundary.
3.4 SYSTEM PLANNING

The planning stage is an accelerated step that is similar to the project initiation and planning of the standard methodology. The AIDEG system is very feasible in terms of financial resources without the need to consider recurring cost of maintenance. In this planning stage, useful information related to the study such as maps, traffic incident statistic, AIDEG system application, application of Microsoft Visual Basic.net, and literature review was collected. Then, site visit was conducted with the main purpose of becoming familiar with or visualizing the actual layout of the study area, and to obtain useful site information, such as name of the road, length and width of the road and location indicator.

3.4.1 Study Area Selection

Bandar Baru Bangi, Selangor was selected as the study area because there is no traffic monitoring station with higher attitude at other places. Bandar Baru Bangi also has ten major municipal roads, high population and no tall buildings that could block GPS and radio signal reception. Besides, it is close to the UKM. The area of
study is between 2.988° N, 101.740° E to 2.916° N, 101.797° E GPS coordinates. Details of the roads including junctions, roundabouts and location of the area based on Google map are illustrated in Figure 3.7. The lowest altitude is 5 meters and the highest is 95 meters. Figure 3.8 shows the altitude of the study area together with its longitude and latitude.
3.4.2 Monitoring Station Planning

The planning of the MS is quite similar to cellular base station planning. It consists of two distinct stages. The first stage sets out to determine the position of the MS to ensure total coverage. High altitude building and facing the roads are the main intent. The second stage is to ensure the MS is not close to other cellular base stations to avoid any interference. Preliminary test was conducted in Universiti Kebangsaan Malaysia (UKM) campus in January 2009. Figure 3.9 shows one of the work conducted during the MS planning.

Figure 3.10 shows the signal extracted from the GPS modem consisting of required data, location altitude and receiver signal strength and the result of GPS availability in UKM that is illustrated in Figure 3.11. The final finding is the Ibrahim Yaakob Student Hostel that is of 110 meters altitude with no LOS being blocked between this place and the roads as illustrated in Figure 3.12. The location of the MS that faces the major roads is indicated in Figure 3.7.
Figure 3.9 Installing receivers antenna during MS planning

Figure 3.10 GPS modem signal consists of location altitude and signal strength
Figure 3.11 Plotted coordinates observed in UKM campus

Figure 3.12 The Ibrahim Yaakob Student Hostel with an altitude 110 meter
3.5 FIELD DATA COLLECTION

The aims of field data collection are to evaluate availability, reliability and accuracy of GPS signal in the area studied and simultaneously to determine the threshold parameters for algorithm detection such as maximum speed, maximum acceleration, maximum deceleration and maximum direction change. The higher assessment of GPS availability, reliability and accuracy in static and mobile condition is required before implementing such application. Information such as vehicle coordinate, speed, direction, satellites in view and Horizontal Precision of Dilution (HDOP) are the meaningful output of the receiver. The number of satellites in view and the HDOP value are two parameters to be used for performance matrices of the GPS availability and reliability during the field tests. The accurate positioning provided by the GPS is created through triangulation, the process of locating a specific place on Earth by specifying the distances between the GPS handheld receiver and the GPS satellites. In order to triangulate, the receiver calculates the distance between it and at least three satellites. The distance is found by receiving signals that the satellites send down to the handheld units (Theiss et al. 2005). An ideal HDOP is 1.0, the greatest predicted accuracy of triangulation. On the other hand, the maximum value of 50 conveys an unreliable fix (Witte & Wilson 2004). The response of the GPS system to changing satellite availability is of interest for potential application of the system in conditions of less than ideal sky-view.

Profiling of the neutral atmosphere and ionosphere by GPS radio occultation (RO) is ranked among these innovative techniques and is considered a valuable new data source for operational numerical weather prediction and climate change studies (Kursinski et al. 1997; Yunck et al. 2000; Wickert et al. 2008). Furthermore, GPS signal reflections at the Earth’s surface provide information on ocean sea states, altimetric heights or soil humiditiy (Lowe et al. 2002; Treuhaft et al. 2001; Mastrs et al. 2004). GPS is proven a very valuable tool for the purposes of surveying and navigation however, its users must be aware of its characteristics and cautious of its limitations. Common factors affecting the accuracy of GPS are:
i. GPS Technique employed (Autonomous, WADGPS, DGPS, RTK, and others)

ii. Surrounding conditions (satellite visibility and multipath)

iii. Number of satellites in view

iv. Satellite Geometry (HDOP, GDOP, PDOP and others.)

v. Distance from Reference Receiver(s) (non-autonomous GPS: WADGPS, DGPS, RTK)

vi. Ionospheric conditions

vii. Quality of GPS receiver

viii. Signal Delay caused by the Ionosphere

ix. Signal Delay caused by the Troposphere

x. Orbit Errors (GPS satellite position inaccuracy)

xi. Receiver Noise

Since no tall buildings and trees could block the signal, this area is expected to receive very good GPS signal. The quality criteria relevant for geodetic and navigation issues are accuracy, availability, and reliability.

a. Accuracy

Accuracy (closeness to truth) of differential systems is relative to the accuracy of the reference points used. When used in less than ideal conditions, the accuracy and precision of any GPS system can be degraded significantly. Although accuracy and precision are often assumed the same thing, technically they are slightly different. Accuracy refers to the closeness to truth while precision refers to the closeness to the mean of observations (Schwieger 2008). Care must be taken particularly when using differential GPS to the accuracy of the results (closeness to truth) as reference points used can and often are inconsistent with truth. The precision or accuracy quoted by many GPS manufacturers is often done using a statistic known as Circular Error Probable (CEP) and are usually tested under ideal conditions and given by:
CEP = 0.59 \left( \sigma_{\text{lat}} + \sigma_{\text{lon}} \right) \quad (3.1)

where \( \sigma_{\text{lat}} \) = standard deviation of latitude \\
\( \sigma_{\text{lon}} \) = standard deviation of longitude

CEP is the radius of the circle that will contain approximately 50 percent of the horizontal position measurements reported by the GPS receiver. This also means that 50% of the positions reported by your GPS will be outside of this circle. Another common measure of accuracy is 2DRMS (Distance Root Mean Squared) given by:

\[ 2\text{DRMS} = 2 \times \sqrt{\sigma_{\text{lat}} \times \sigma_{\text{lat}} + \sigma_{\text{lon}} \times \sigma_{\text{lon}}} \quad (3.2) \]

where \( \sigma_{\text{lat}} \) = standard deviation of latitude \\
\( \sigma_{\text{lon}} \) = standard deviation of longitude

2DRMS refers to the 95 to 98% probability that the position will be within the stated two-dimensional accuracy. The probability varies between 95 to 98% because the standard deviation of latitude and longitude may not always match. Accuracy describes the random difference between the measured and given value. The accuracy of the GPS receiver depends on hardware and firmware and the manufacturer normally gives this.

b. Availability

Availability is the probability or the measure that a system delivers specified complete information at the precise time. The availability quality parameter is the availability rate in percentage:

\[ A\% = \frac{T_{T} - T_{n}}{T_{T}} \times 100 \quad (3.3) \]

with \( T_{T} \) total measurement time, \\
\( T_{n} \) measurement time without coordinates or no GPS signal.

The other performance criterion analyzed of GPS availability is to obtain an HDOP of less or equal to 5.0.
c. **Reliability**

Reliability may be called correctness, too. Correctness or reliability describes the ability of a system to deliver information corresponding to the reality. Here the deviations between measured and given coordinates should not exceed a limit specified to three times the standard deviation. The reliability quality parameter is the reliability rate in percentage, whereby the percentage value is referred to the number of available measurements \(n_a\) taken within the time \(T_a = T_T - T_n\):

\[
R = \frac{n_{3\sigma}}{n_a} \times 100
\]  

(3.4)

with \(n_{3\sigma}\) number of observations within the 3.\(\sigma\) limit.

and standard deviation,

\[
\sigma = \sqrt{\frac{1}{N} \sum (x_i - \bar{x})^2}
\]  

(3.5)

with \(x_i\) = single coordinate measurement value

\(\bar{x}\) = average

\(N\) = number of measurement

Assessment of GPS accuracy is made by calculating and plotting the coordinates of the GPS signal, and comparing it to a reference point. If the distance between the plotted coordinate and reference point is within the limit, it may confirm the GPS accuracy. HDOP and number of satellite in view are also calculated to justify the GPS availability and reliability of the signal in the study area.

### 3.5.1 Static Position Test

The route of ten trunk roads and location of P1, P2, P3 and P4 for static position test are illustrated in Figure 3.13. First, 24-hour continuous GPS data were collected at four different static position test places (P1, P2, P3 and P4) within the study area to examine triangulation of GPS satellites. The coordinates of P1 to P4 are shown in
Table 3.1 and the location of these four test places is appropriate to cover Bandar Baru Bangi area. The system setup for the study is the same as any normal GPS data collection where the GPS antenna was implanted on an unblocking roof of a building and the receiver together with the data logging computer were placed in an air-conditioned room.

Table 3.1 Static test point coordinates

<table>
<thead>
<tr>
<th>Test point</th>
<th>Longitude (North)</th>
<th>Latitude (East)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>2.921186°</td>
<td>101.777972°</td>
</tr>
<tr>
<td>P2</td>
<td>2.964518°</td>
<td>101.756916°</td>
</tr>
<tr>
<td>P3</td>
<td>2.961343°</td>
<td>101.777341°</td>
</tr>
<tr>
<td>P4</td>
<td>2.941904°</td>
<td>101.767956°</td>
</tr>
</tbody>
</table>

Figure 3.13 Route of field tests and four static location test point

3.5.2 Mobile Position Test

The vehicle was equipped with the setup as shown in Figure 3.14. The GPS receiver in a modem transmitter was mounted on the dashboard of the car and connected to a laptop via a serial port cable. Magnetic mounted antenna was installed at the center of the car’s roof to provide a consistent sky view at all time. At a particular time, only
one car was mobilized to collect data around this area but four models of cars were deployed for all tests. The software tools developed using Microsoft Visual Basic.net and illustrated in Figure 3.15 were used to collect, filter and display data to a monitor in real time. Real time monitoring was required to ensure any problem encountered during the tests would be solved immediately. The display information were the GPS coordinates in longitude, latitude and altitude, Coordinated Universal Time Constant (UTC), speed of the vehicle over ground (SoG), as well as directions and number of satellites in view. Locations of the vehicle were plotted on the digital map to validate the GPS accuracy. If the plotted coordinates were outside the path, they were caused by weak signal. In order to collect valid data, the same type of GPS receiver was used but mounted on vehicles of different models. For each test, different drivers were employed to avoid confusion with driver driving behavior value.

In order to record maximum speed, the test must be carried out on a dry road, with low traffic flow and during the daytime. However, it is difficult to get low traffic flow during the daytime. Low traffic flow at night does not guarantee maximum speed is reached because of the darkness. In order to get maximum acceleration and deceleration, tests must be carried out with all types of traffic flow and weather conditions. All field tests were carried out in the morning, afternoon, evening and at night.

Figure 3.14 In-vehicle instrumentation consisted of a GPS modem, laptop, 12V car adaptor and interfacing equipment. The magnetic mounted antenna was installed at the center of the car’s roof.
The accuracy of the GPS signal during the mobile test can be evaluated by comparing the plotted coordinates with the road’s border. If the coordinates are within the road border, the accuracy is acceptable. Similar to static test, the HDOP and number of satellite in view were also calculated to justify the GPS availability and the reliability of the signal in the study area.

a. Vehicle speeds, acceleration and deceleration

There is a clear dose-response relationship between changes in speed and changes in road safety. The larger the change in speed, the larger the impact on accidents or accident victims. The Power Model describes the relationship between speed and road safety in terms of six equations (Elvik et al. 2004). As an example, the equation referring to fatal accidents is:

\[
\frac{F_a}{F_b} = \left( \frac{S_a}{S_b} \right)^4
\]

(3.6)

where \( F_a \) is fatal incident after, \( F_b \) is fatal incident before, \( S_a \) is speed after and \( S_b \) is speed before.
If speed is reduced from 100 km/h to 90 km/h, the ratio speed after/speed before equals $90/100 = 0.9$. Raising 0.9 to a power of 4 gives 0.656. This means that the number of fatal accidents is estimated to go down to 0.656 times the initial number, corresponding to a reduction of 34.4 percent. This shows that vehicle speed contributes as the major factor to incident and fatalities.

Maximum speed, maximum acceleration and deceleration were observed and determined from the tests and would later be used as the threshold value in the algorithm. It is easy to understand that at high speeds, the time to react to change in the environment is shorter, the stopping distance is larger, and maneuverability is reduced (Liu et al. 2009). Nevertheless, what type of vehicle breaking system (i.e. anti break locking system (ABS) or conventional break) time taken to stop is higher when the speed is high and the impact of the incident is higher too. If the vehicle exceeds the maximum speed, the system’s alarm will be turn on and if the speed is constant or increases followed by a sudden deceleration, an incident is determined to have occurred. On the other hand, if the deceleration exceeds the maximum value and suddenly stops, an incident is happening or taking place. The AIDEG incident definition related to vehicle speed is illustrated in Figure 3.16.
a) If the vehicle exceeds the maximum speed, the system’s alarm will be turn on and if the speed is constant or increases followed by a sudden deceleration, an incident is determined to have occurred.

b) If the deceleration exceeds the maximum value and suddenly stops, an incident is happening or taking place.

c) If the vehicle acceleration is higher than the maximum acceleration threshold value, an incident is happening or taking place.

Figure 3.16 The AIDEG incident definition
b. Vehicle direction and movement

Vehicle movement is one of the measurements that can be used to justify an incident. From the GPS true course, vehicle direction movements such as turning left or right and the degree of turn can be calculated. For example, 180 or -180 degree direction change indicates the possibility of a driver making a u-turn. An abnormal vehicle movement is one of the indications of abnormal driving. The movement of a vehicle is determined by the direction in degree unit with respect to the true north; in other words, how many times and degrees the vehicle changes its direction from left to right and from right to left. Vehicle direction can be calculated from the current and previous GPS coordinates. In this research, steering wheel movement (SWM) is used as a referent for vehicle direction. SWM can be distinguished in terms of small movement (1-5 degree) and large movement (6-10 degree) (Thiffault & Bergeron, 2003). Since 5 degree and below is considered small movement, 6 degree and above will be used as the threshold direction angle. The AIDEG incident definition related to vehicle direction and movement is illustrated in Figure 3.17.

![Figure 3.17 Continuous directions changing with high speed](image)

3.5.3 Speeding-stop Test

The aim of this test is to determine the appropriate time for vehicular GPS to update and transmit their data to MS. The time will then be used to configure the GPS
modem. A 2000 cc car with Anti-Brake Locking (ABS) system is used for the test in order to get a smooth stop without injuring the driver. The test setup is shown in Figure 3.18. The distance between the vehicle and MS is less than 500 meters in order to obtain small time delay. During the test, the GPS transponder was set to update its data for every 1 second to the MS. The vehicle was forced to stop immediately at certain speeds by the driver at the driving field test and the GPS signals were sent to the MS for recording and processing. The vehicle’s speedometer was used by the driver to start braking at certain speeds. From the recorded GPS signal, the vehicle speed and time are calculated.

Figure 3.18 Speeding-stop Test setup
3.6 SUMMARY

This chapter has presented the methodology adopted in the study and the manner in which the data was used for the development of the system. The overall outlook of the workflow and methodology adopted has been shown in a pictorial representation. Techniques adopted to collect static and vehicular GPS data have also been presented in this chapter. Additionally, explanation for the processing techniques for all the data used in this study has been provided. Detailed explanation of the system development and algorithm verification is given in the next chapter.
CHAPTER IV

INCIDENT DETECTION SYSTEM DEVELOPMENT

4.1 INTRODUCTION

System development of incident detection is the major part of this research. It consists of system configuration and IDS algorithm development. Configuration of the MS and in-vehicle equipment together with the system function and setup are discussed in detail in this chapter. The processing part and interface design of the algorithm are also discussed here.

4.2 SYSTEM CONFIGURATION

The proposed AIDEG system configuration is shown in Figure 4.1. The system consists of two parts, the MS and in-vehicle equipment. The MS acts as the information processing centre which consists of data processing, incident detection algorithm and digital database. Vehicle data is modulated before being sent to the MS, simultaneously with numbers of other vehicles on the road. In this system, real-time means the vehicle’s GPS data are sent via radio band signal with lesser time delay is (speed of light), unlike other real-time AID system using 3G/GPRS or internet in which the time delay is higher, unpredictable and costly.

4.2.1 Monitoring Station (MS)

The MS, being the main component of the AIDEG system, is made up of radio band receiver, high gain Omni UHF antenna and a computer as the processing terminal.
The task of the MS is to receive GPS data from all equipped vehicles from the road, processing and making proper response. For one thing, it will trigger the incident alarm to the MS operator and pass them to all other drivers and the emergency response team. A receiver and computer in the MS is only dedicated to 50 vehicles in order to achieve better signal quality and short transmission delay. Another receiver and computer are required for another 50 equipped vehicles on the road, situated at the same MS or at another place. In order to achieve good quality signal, the antenna is located as high as possible above obstructions, vehicles, and buildings. UHF radio channels require a clear LOS between the transmitter in the vehicle and the receiver in the MS. Radio waves will penetrate buildings, and reflect off and around obstacles, but the fewer obstacles between the stations, the better the signal quality will be.

![Figure 4.1 AIDEG System Configurations](image)

**4.2.2 In-vehicle Equipment**

Vehicle equipment installation is shown in Figure 4.2. Vehicles are equipped with GPS modem transmitter and all modulated GPS data are sent from each vehicle in real time via UHF radio band to the MS which is located within 30 kilometer radius. This radius is selected to give adequate time for the emergency response team to clear up the incident and to limit the RF transmission power to 5 watt only. Each vehicle has its own identification and sends information simultaneously along with other vehicles to the MS. The MS also has its own base identification for security purpose.
Transmission is in the TDMA mode and interval can be configured depending on the number of vehicles. TDMA is a very effective way of allowing a lot of radios to share one radio channel. Used extensively in GSM cellular and association of public-safety systems (APCO), TDMA excels at allowing quick and reliable access to radio channels. It allows 2-10 times more radios to share a radio channel than conventional carrier-sense methods. This allows 2-10 times more tracking of radios on one channel, as compared to radios that do not have the TDMA capability (Falconer et al. 1995).

The processing is done individually depending on the signal sent. The current vehicle data is then compared with the previous data. If any abnormal vehicle condition is calculated, the system will automatically detect and trigger an emergency response. In a normal situation, the system is used as a traffic monitoring mechanism which displays vehicle status such as location, direction and speed. Since the detection is done automatically at the MS, there are no tasks for motorists in the vehicles except to make sure that the modem is always switched on and is functioning properly (pilot lamp (LED) is blinking in green and red colour).

Figure 4.2 In-Vehicle equipment consists of the GPS modem in vehicle and two antennas on the roof.

4.2.3 System Function and Setup

The system is divided into two main functions and one minor function as illustrated in Figure 4.3. Main functions are automatic incident detection and traffic monitoring while minor functions are recording and data basing. The AID can detect occurrence of traffic incidents by identifying the abnormal changes of traffic flow parameters.
such as velocity, traffic flow, occupancy and headway, which are received by the traffic monitoring equipment (Rufu et al. 2008). AIDEG detection algorithm only uses GPS data from individual vehicles and it does not require the behaviour of other vehicles, traffic pattern or road conditions. The algorithm is developed to detect any traffic incident in real time, regardless of the causes. The system will trigger an alarm to the monitoring operator and database of the status for further action.

![AIDES System functions](image)

Figure 4.3 AIDEG System functions

Incident duration can be defined as the time difference between accident occurrences and when the response vehicles depart to the accident scene (Garib et al. 1997; Nam & Mannering 2000; Smith & Smith 2001; Chung 2010). In the traditional AID systems, the false alarm rate is defined as the ratio of incident signals in an incident-free condition to the total number of tests for incidents. FAR is also defined as the percentage of times where incidents were indicated by the algorithm when there was no actual incident (Abdulhai & Ritchie 1999; Zhang & Taylor 2002).

An incident detection algorithm with a higher DR, lower FAR, and a faster TTD is capable of functioning as a powerful tool for automated traffic monitoring. In order to obtain faster TTD, the transponders should be configured to update/send real-
time data to the MS at the fastest time as possible. Signal update time will be determined by the speeding-stop test and will be inserted in the algorithm later.

4.3 DETECTION SYSTEM ALGORITHM

Algorithm is the backbone of AID. Developing and improving incident detection algorithms and systems are important to satisfy the demands of traffic and incident management systems under a variety of traffic conditions.

4.3.1 Processing

The proposed flowchart for the system is shown in Figure 4.4. The proposed detection program run on a computer, processed and stored in real time GPS data from all detected vehicles on the road. Each data has seven information items: vehicle identification (ID), location, time, speed, direction, number of satellites in view (NOSV) and received signal strength (RSS). In order to achieve zero FAR, NOSV and signal strength will be used as the filtering mechanisms. GPS data will be filtered out if NOSV is less than 4 or signal strength less than -120 dBm. Data with NOSV less than 4 generally has low accuracy and received signal with strength of less than -120 dBm usually has errors.

The algorithm is designed to be simple because highly specific tests are not easily transferable due to the amount of work that goes into determining thresholds for them. The backbone of the algorithm is a filtering raw data before it is submitted to the algorithm for processing. Example of raw data received by the MS modem is shown in Figure 4.5. Received string starts with $GPRMC and $GPGLL belonging to the MS consist of latitude, longitude, altitude and date whereas string that start with $PRAVE belongs to detected vehicles, consisting of vehicle ID, the MS ID, latitude, longitude, time, NOSV and signal strength. For security reason, the MS receiver can only detect and demodulate vehicles configured to its own ID only. The details of the received string are presented in Appendix B.
START

INITIALIZATION

DATA FROM MS MODEM

MOBILE DATA?

STRING CHECK PASS?

FILTERING VEHICLE SIGNAL (NOSV, RSS)

NOSV >=4 AND RSS> -120

IDENTIFY ID, LOCATION, DISTANCE, SPEED, DIRECTION

SPEED > max.speed or
DECC. > max. dec or
ACC. > max. acc. or
ABN(DIR > 4

REPORTING / AUTOMATIC ALARM

RECORD

END

Figure 4.4 AIDEG Flowchart
The AIDEG algorithm executes the following steps:

Step 0: Initialize the modem port number, identification and baud rate.

Step 1: Extract data from MS modem.

Step 2: Check mobile data. If first string belongs to mobile (vehicle) and ID is correct, go to next step. If not, go to step 11.

Step 3: Check all strings. If word number > 60 and no error (noise), go to next step. If not go to step 1.

Step 4: Filtering vehicle signal (NOSV and signal strength).

Step 5: Check if NOSV >=4 and signal strength > -120 dBm. If not, back to step 1.

Step 6: Identify vehicle ID, location, distance, speed and direction.

Step 7: Check if speed exceed threshold value and deceleration > 50 or if deceleration > threshold value or continuous direction > 4 times. If not, go to step 9.

Step 8: Trigger alarm and reporting incident. Display on screen vehicle status.

Step 9: Record.

Step 10: Go back to step 1.

Step 11: Check all strings. If word number > 40 word and no error (noise), go to next step. If not go to step 1.

Step 12: Extract time, date, coordinate MS status.

Step 13: Display time, date and MS status.

Step 14: Go to step 9.

Step 15: End.
Distance between the vehicle and the MS can be calculated by comparing vehicle coordinate and MS coordinate using the great circle distance formula.

\[
\text{Distance (km)} = 6378.7 \times \arccos \left[ \sin(\varphi_1) \sin(\varphi_2) + \cos(\varphi_1) \cos(\varphi_2) \cos(\lambda_2 - \lambda_1) \right]
\]

where

\( \varphi_1 = \) latitude of position 1; \( \lambda_1 = \) longitude of position 1

\( \varphi_2 = \) latitude of position 2; \( \lambda_2 = \) longitude of position 2

The detection algorithm is based on two parameters which are; position and velocity. Vehicle position or location is determined by latitude and longitude while velocity is in speed and direction degree. Direction of vehicle can be calculated using the GPS true course formula.

\[
\text{True Course (degree) = mod (atan2(sin(\varphi_1-\varphi_2) \times \cos(\lambda_2), cos(\varphi_1) \times \sin(\varphi_2) - \sin(\varphi_1) \times \cos(lat2) \times \cos(\lambda_1-\lambda_2)), 2 \times \pi) }~(4.2)
\]

where

\( \varphi_1 = \) latitude of position 1; \( \lambda_1 = \) longitude of position 1

\( \varphi_2 = \) latitude of position 2; \( \lambda_2 = \) longitude of position 2

Figure 4.5 Snapshot of raw modem data
The algorithm is developed generally by four behaviours which could contribute to abnormal driving and incident.

1. **Speed exceeds maximum threshold value and suddenly stops,**

\[ V_n > V_{\text{max}} \text{ and } |V_{n+1} - V_n| > d \]

where \( V_n \) is the current speed, \( V_{n+1} \) is the next speed, \( V_{\text{max}} \) is the maximum speed threshold value, \( d \) is the deceleration threshold value. The threshold values are determined through the preliminary mobile test.

2. **Speed suddenly drop with high deceleration,**

\[ V_n < V_{n-1} \text{ and } |V_{n-1} - V_n| > d \]

where \( V_n \) is the current speed, \( V_{n-1} \) is the previous speed, \( d \) is the deceleration threshold value. The threshold value is determined through the preliminary mobile test.

3. **Speed increase with high acceleration,**

\[ V_n > V_{n-1} \text{ and } |V_n - V_{n-1}| > a \]

where \( a \) is the acceleration threshold value. The threshold value is determined through the preliminary mobile test.

4. **Unsmooth vehicle direction movements,**

\[ D_1 > 0 \text{ and } D_2 < 0 \text{ and } D_3 > 0 \text{ and } D_4 < 0 \text{ and } s > 30 \]

or

\[ D_1 < 0 \text{ and } D_2 > 0 \text{ and } D_3 < 0 \text{ and } D_4 > 0 \text{ and } s > 30 \]

where \( D_1 \) is \( D_n - D_{n-1} \), \( D_2 \) is \( D_{n-1} - D_{n-2} \), \( D_3 \) is \( D_{n-2} - D_{n-3} \), \( D_4 \) is \( D_{n-3} - D_{n-4} \), are all directions and \( s \) is speed.
All incidents are detected in the algorithm by considering the current, previous and history data. Filtering and error checking are the most important parts of the algorithm in order to achieve high detection performance. Since some data may be lost during transmission and collection, e.g. not every time interval records a valid data; the current and previous data needs to be processed before being used in the abnormal driving detection. The general rule of the data processing is that if the data loss occurs within three consecutive time intervals (9 seconds), the vehicle is considered lost or not detected. The previous information is a new data detected after vehicle lost by base modem. If the incident is detected by algorithm, alarm will be trigged and interface will display emergency warning, incident status and location of incident. The MS operator is then supposed to contact the emergency response team.

4.3.2 Interface

Microsoft visual basic.net is used as the algorithm programming tool as it has the ability to process and data-base, interface with serial port and design of graphic user interface (GUI) (Grundgeiger 2002; Harun & Tasir 2003; Halvorson 2003). Initially, the map of Bandar Baru Bangi is scanned and converted into digital map for the AIDEG environment. Subsequently, the GPS coordinates were entered to test the locations on the map. Figure 4.6 shows the algorithm organization, consisting of the main program file, GUI, port setting file, help information file, vehicle information, database file and all vehicle information files.
Figure 4.7 displays the user-friendly start up interface. After executing a program, the user has to key in the data logging file name, choose start and the program will run. After the MS and vehicle data start logging in less than 5 seconds, all information such as current vehicles detected, location of the vehicles on the map, distance of the vehicles from the MS, original signal from the modem, incident status and many others are displayed in one window.
Figure 4.7 AIDEG start up interface

The user could view details of other information by choosing other sub menus. Figure 4.8 illustrates the full display of the algorithm interface. As an example, data entry for vehicles had been created to store the data (Figure 4.9). For the first time vehicle or driver data or for updating vehicle and driver data, the operator must choose this sub menu. The vehicle profile will then be stored in the database in Microsoft Access via the software interface.
Figure 4.8 AIDEG user interface and real time display

Legend

(a) Detected vehicles on the road
(b) Data logging file name
(c) Running Status
(d) Vehicle position on the map
(e) Universal time (UTC) and date
(f) All vehicle current status
(g) Incident status
(h) Monitoring Station coordinate
(i) Monitoring Station
(j) Original scrolling data from modem

Figure 4.9 Vehicle and driver information data entry
The user could also view the current information of the selected vehicle (Figure 4.10) and the system help menu (Figure 4.11).

![Figure 4.10 Display of a single vehicle’s current information](image1)

![Figure 4.11 Display of system help](image2)

When the vehicle exceeds the maximum threshold value or maximum deceleration or acceleration, the warning alarm will be triggered. If the incident is detected by any of the four behaviors that has been discussed previously, the emergency alarm will be triggered and the display will be shown as in Figure 4.12.
The user could also display and print vehicle speed record, position and direction record, and incident information by selecting the sub menu (Figure 4.13 and Figure 4.14).
4.4 SUMMARY

The development of the AIDEG system went through two phases, data collection devices and data processing (algorithm). The system configuration consists of the MS and in-vehicle equipment. Meanwhile the algorithm development was carried out through numerous playbacks of recording signal and simulation data. In order to test the algorithm’s performance, the test needs to be carried in a real situation or in a driving test. The next chapter presents the discussion of the details and result of the study.
CHAPTER V

RESULTS AND DISCUSSIONS

5.1 INTRODUCTION

The evaluation of the efficiency of the GPS-only-based incident detection was based on the incident detection parameter standard performance. However, driving simulators or simulation data such as traffic flow rate, vehicle speed, incident type and distance from the processing station could also be used. Simulation model is necessary in developing any type of algorithms. However, the best method to assess the AID system is by testing it in a real situation because it is difficult to generate accurate data of weather conditions such as rain, cloudy weather and thunderstorm which may affect road conditions, driving style and signal transmission and reception. The results of the preliminary data collection and AID EG performance are presented and discussed in this chapter.

5.2 EXPERIMENTS - DRIVE TESTING

The main aim of our experiments or drive testing is to evaluate the performance of the developed detection algorithm in real environment while driving, in terms of the driving style and at the same time the GPS signal reception and RF signal transmission in the worst possible condition. The drive testing was conducted in two conditions. The first condition was in heavy rain and the second drive testing was in normal traffic and sunny condition. Every drive testing involved five drivers in GPS-equipped vehicles with unique identification (ID) moving along trunk roads. Each driver took a different route as shown in Figure 5.1 with an average length of 50 kilometers in a period less than 60 minutes. Each route has four roundabouts, twenty traffic lights and more than twenty junctions. Five modulated GPS data were sent
simultaneously at intervals of every 3 seconds. All original signals were recorded and later to be used for data analysis and to be modified as simulation data.

Figure 5.1 All vehicles took a different route during the drive testing

5.3 SIMULATION

Simulated data were used to verify the performance of the detection algorithm because it is risky to drive faster than the speed limit during the field test on the road. Some recorded data from test drive 1 and 2 had been manipulated to provide higher speed, higher acceleration, higher deceleration and abnormal position change. However, bad weather conditions and transmission delay could not be created. The GPS, the geosynchronous satellite nevertheless will not be heavily affected by rain and cloudy day. The modified recorded data (Simulation 1 and 2) from another computer was then fed into the processing computer through the serial port with the same baud rate and interval as the receiver modem. The method manually changes the speed and GPS coordinates from the original raw modem data.
5.4 RESULTS AND DISCUSSIONS

5.4.1 Static Position Tests

In the static field test, a total of 17280 fixed GPS data were collected for each 24-hour test. Table 5.1 shows the value of availability and reliability for all static position tests using Equation 3.1 and Equation 3.2. The value for the standard deviation of each test point (P1 to P4) was calculated using Equation 3.3. All standard deviations are less than 3. The availability rate shows values of more or less 100% for all places. The reliability rate, or in other words the ability to protect against outliers, is excellent. For all scenarios the values are larger than 99.7%, meaning that 99.7% of all measurements are within the sphere around the reference point coordinates.

<table>
<thead>
<tr>
<th>Test point</th>
<th>Standard deviation, $\sigma$</th>
<th>Availability rate (%)</th>
<th>Reliability rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>2.913</td>
<td>99.998</td>
<td>99.87</td>
</tr>
<tr>
<td>P2</td>
<td>2.620</td>
<td>99.998</td>
<td>99.94</td>
</tr>
<tr>
<td>P3</td>
<td>2.752</td>
<td>100</td>
<td>99.97</td>
</tr>
<tr>
<td>P4</td>
<td>2.890</td>
<td>100</td>
<td>99.78</td>
</tr>
</tbody>
</table>

The number of satellites in view and the Horizontal Dilution of Precession (HDOP) value are related to the availability, reliability and accuracy of the position fix. HDOP is an error term determined from the geometry of satellites used for the position fix. This is therefore dependent upon a combination of satellite position and the number of satellites used. To evaluate the triangulation of satellites within this area, the number of satellites in view and HDOP value were plotted together in one graph to show the relationship between them. The number of satellite in view and the HDOP for each data fixed were identified using different algorithm written in MATLAB. Figure 5.2 shows the number of satellites in view and the HDOP value for each GPS fixed data. Note that the lower the Number of Satellite in View (NOSV) number, the higher the value of HDOP. HDOP allows one to more precisely estimate the accuracy of GPS according to the geometry of the satellites used. Geometry of satellite is depends on NOSV. In this study, HDOP values and the higher number of
satellites in view values had been observed. The result for the static position tests at 4 locations within the range of the studied area is presented in Table 5.2.

Figure 5.2 Number of satellites in view and HDOP value for 24-hours static location tests at (a) P1, (b) P2, (c) P3 and (d) P4
As the best result is obtained with 12 satellites in view and 0.1 HDOP, the emphasis of the analysis is to look for the worst condition where the minimum number of satellites in view and maximum HDOP is reached. Maximum number of GPS satellites in a horizon is 12 and if the view angles of all satellites from the GPS receiver are wider, 0.1 HDOP can be obtained. From the table, the minimum number of satellites in view was more than 6 and the HDOP value was constantly displayed; hence, the triangulation of the GPS satellites was very good in this area. It was able to provide reliable GPS signal and higher horizontal accuracy which are needed for identifying vehicle position. Nevertheless, theoretically the horizontal accuracy of the GPS receiver for the static position was better than the mobile position; however, for the mobile position, a similar test had to be carried out. The average number of HDOP value for all tests is 0.8 and the average number of satellites in view was 10.

Table 5.2 NOSV and HDOP Values for Static Position Tests

<table>
<thead>
<tr>
<th>Test Point</th>
<th>Minimum NOSV</th>
<th>Maximum value of HDOP</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>6</td>
<td>1.32</td>
</tr>
<tr>
<td>P2</td>
<td>6</td>
<td>1.48</td>
</tr>
<tr>
<td>P3</td>
<td>7</td>
<td>1.42</td>
</tr>
<tr>
<td>P4</td>
<td>6</td>
<td>2.00</td>
</tr>
</tbody>
</table>

The graph in Figure 5.3 shows the coordinate’s position on June 4, 2009 to June 5, 2009 over a period of 24 hours. The mean value of the latitude is 2.961343° N and the longitude is 101.777341° E. The edge of the diagram is 20 meters and all points are located within a radius of 10 meters. More than 50% of GPS coordinates were within 2.5 meters, 90% within 5 meters, and less than 0.1% was between 5 meters to 10 meter. Hence, the accuracy of the GPS receiver as given by the manufacturer is confirmed. The graphs for another three test points on May 29, June 17 and September 25, 2009 have not been presented here as they rendered similar result.
5.4.2 Mobile Position Tests

More than 720 GPS locations were recorded in every test and a total of 8142 fixed in 8 field tests were made. Raw data were stored in dynamic data storage at each time interval for subsequent analysis. Useful data from raw NMEA-0183 format such as UTC, longitude, latitude, altitude, number of satellites in view, HDOP, vehicle speed and direction in degree with respect to the north were extracted using different algorithm. Data were processed separately according to each test to produce plotted vehicle coordinates and speed and speed change graphs. Combined data from all tests were used to produce information on number of satellites in view, HDOP and Speed Distribution. Plotted vehicle coordinates (latitude and longitude) as shown in Figure 5.4 shows the path of vehicle during field tests. All 8 field tests took the same path and yielded almost the same results. The GPS receiver did not encounter any problem in receiving the signal from the satellites as no massive structure such as tall buildings and foliage in these trunk roads could block signal transmission. The GPS satellites which are geosynchronous were not affected by bad weather condition.

![Plot of the position determination at one static position test point](image)
Number of satellites in view for each data fixed was identified using simple procedure written in MATLAB. Figure 5.5 shows the percentage of the number of satellites in view. The histogram shows that most of the time, the number of satellites in view were 7 to 11. The percentage of NOSV which was 4 or more is 99.87. The value shows that the GPS satellite signals were available almost all the time at the field test area.

Since HDOP is related to accuracy of the position fix in terms of latitude and longitude, its value would be expected to be reflected in the speed accuracy (Witte & Wilson 2004). HDOP values observed during the test are illustrated in Figure 5.6.
From the collected data, only 0.22 percent of the data had HDOP of more than 2.4. The minimum of the HDOP is 0.7 and the mean value is 1.0.

![Histogram of HDOP](image)

**Figure 5.6 Bar chart of Horizontal Dilution of Precision**

### a. Vehicle Speed

The vehicle speed data extracted from the GPS receiver is in knot value and direction in degree. In this study, velocity (combination of speed and direction) is not significant but will be used later to study driver behavior when driving. Knot had to be converted into meter per seconds for standard calculation (1 knot = 1.582 km/h). Figure 5.7 shows the distribution of vehicle speed for all tests. The result shows that none of the speed was above 100 km/h and more than 70 percent were below 50 km/h. Vehicle speed is affected by traffic conditions, for instance heavy and moderate traffic will decrease the vehicle speed and light traffic may increase vehicle speed. For speed assessment in this study, traffic conditions will be divided into two durations. Based on visual observations and data recorded during field tests, the first duration is between 6.00 am to 7.30 pm when the traffic are heavy and moderate (Day Traffic). The second duration is between 7.30 pm to 6.00 am, when the traffic condition is light (Night Traffic).
Figure 5.8 shows how the maximum speed, maximum deceleration and maximum acceleration were determined (positive value is acceleration and negative value is deceleration). Result for all tests can be found in Appendix E. A total of 4 tests were carried out during Day Traffic and 4 tests during Night Traffic at different times of the day. The 8 tests were test 1 (8.44 am to 10.11 am), test 2 (9.02 am to 10.34 am), test 3 (11.04 am to 12.04 pm), test 4 (2.34 pm to 4.02 pm), test 5 (8.09 pm to 9.09 pm), test 6 (10.44 pm to 11.44 pm), test 7 (12.04 am to 1.04 am) and test 8 (2.06 am to 3.06 am).

Figure 5.8 Speed and speed change
Result for the tests processed from 8142 GPS data during two traffic durations is shown in Table 5.3. The value will be used as threshold parameter. The parameters are nearly the same due to the road condition with a lot of traffic lights, junctions and roundabouts. No speed above 100 km/h was recorded although driving in light traffic and early morning between 12.30 am to 6.00 am (Test 7 and Test 8 in Figure 5.8). One of the reason is the darkness as many trees are blocking street lights. Figure 5.9 shows one of the junction with traffic light and one road with tress are blocking street light.

Figure 5.9 Junction with traffic light and road with tress blocking the street light
Table 5.3 Speed Parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Day Traffic</th>
<th>Night Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(km/h) (m/s)</td>
<td>(km/h) (m/s)</td>
</tr>
<tr>
<td>Maximum Speed</td>
<td>96 26.67</td>
<td>120 33.33</td>
</tr>
<tr>
<td>Maximum acceleration</td>
<td>33 3.06</td>
<td>35 3.24</td>
</tr>
<tr>
<td>Maximum deceleration</td>
<td>50 4.63</td>
<td>45 4.16</td>
</tr>
</tbody>
</table>

b. Vehicle direction and movement

The vehicle’s direction and speed in the mobile test is summarized in Table 5.4. The result for all the tests can be found in Appendix F. For normal condition, some right-left-right (RLR) and left-right-left (LRL) movements were detected with a speed between above 0 km/h and above 50 km/h but no left-right-left-right (LRLR) or right-left-right-left (RLRL) movement detected above 30 km/h. Incident will be detected if the driver turns left and right or right and left four times continuously with speed more than 30 km/h.
Table 5.4 Movement of vehicle in 8 mobile tests during normal traffic condition

<table>
<thead>
<tr>
<th>Test</th>
<th>Movement</th>
<th>Number of movement</th>
<th>Speed (&gt; 0 km/h)</th>
<th>Speed (&gt; 10 km/h)</th>
<th>Speed (&gt; 20 km/h)</th>
<th>Speed (&gt; 30 km/h)</th>
<th>Speed (&gt; 40 km/h)</th>
<th>Speed (&gt; 50 km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RLRL</td>
<td>0 0 0 0 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LRLR</td>
<td>0 0 0 0 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LRL</td>
<td>3 1 1 1 1 1 1 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>RLRL</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LRLR</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RLR</td>
<td>7 5 3 2 2 2 2 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LRL</td>
<td>3 2 1 1 1 1 1 1</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LRLR</td>
<td>0 0 0 0 0 0 0 0</td>
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<td></td>
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<tr>
<td></td>
<td>LRL</td>
<td>2 1 1 1 1 0 0 0</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>RLRL</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LRL</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>RLRL</td>
<td>1 0 0 0 0 0 0 0</td>
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<tr>
<td></td>
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</tr>
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<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>LRL</td>
<td>4 2 1 0 0 0 0 0</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>RLRL</td>
<td>0 0 0 0 0 0 0 0</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>LRLR</td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>RLR</td>
<td>3 2 2 2 2 2 1 1</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LRL</td>
<td>0 0 0 0 0 0 0 0</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>7</td>
<td>RLRL</td>
<td>1 0 0 0 0 0 0 0</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LRLR</td>
<td>1 1 0 0 0 0 0 0</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RLR</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>LRL</td>
<td>2 1 0 0 0 0 0 0</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>RLRL</td>
<td>0 0 0 0 0 0 0 0</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LRLR</td>
<td>0 0 0 0 0 0 0 0</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RLR</td>
<td>1 1 1 1 1 1 1 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LRL</td>
<td>0 0 0 0 0 0 0 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
where Right (R) = + Movement (n), Left (L) = - Movement (n),
Movement (n) = Direction (n) – Direction (n-1), and
Direction (n) = Coordinate (n) – Coordinate (n-1),

5.4.3 Speeding-stop Test

After conducting the speeding-stop test, 3 seconds was selected as the interval transmission. This interval is appropriate and was determined from the result of our speeding-stop test as shown in Figure 5.11 and summarized in Table 5.5. The other results for the speeding-stop test can be found in Appendix G.

![Figure 5.10 Plotted graphs for the speeding-stop test to determine the best transmission interval](image)

Table 5.5 Result for the speeding-stop tests

<table>
<thead>
<tr>
<th>Speed before suddenly stopping (km/h)</th>
<th>Time taken to stop, t (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>43</td>
<td>4</td>
</tr>
<tr>
<td>32</td>
<td>3</td>
</tr>
<tr>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>24</td>
<td>2</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>16</td>
<td>2</td>
</tr>
</tbody>
</table>
The fastest response time for the speed of 30 km/h and above is 3 seconds. The other reasons are to allow other vehicles to transmit data simultaneously and faster to the MS and also to minimize vehicle data in the database.

5.5 RESULT OF EXPERIMENTS

Applying the above detection methods, the parameters obtained and the 3 seconds signal update which corresponds to 5 drivers’ driving behaviors, we obtained the results as illustrated in Figure 5.11 and Figure 5.12. Figure 5.11 is for driver 1 in experiment 1 (worst condition – heavy rain and thunderstorm) and Figure 5.13 is for driver 3 in experiment 2 (normal condition – sunny day). All results for both experiments can be referred to in Appendix H and summarized in Table 5.6. The experiment results show 7 times of driving above the speed limit (90 km/h) was detected among the 5 vehicles/drivers in both worst conditions and 8 times in normal conditions. No acceleration above 35 km/h or deceleration above 50 km/h was observed in both experiments. Only one LRL movement with speed of more than 30 km/h was detected in experiment 1 but this was not an abnormal driving. The plotted figures also show some direction changing (from positive angle to negative angle or otherwise) but with lower speed and some maneuvers with speed of less than 27 km/h.

![Figure 5.11 Speed and direction for vehicle/driver 1 in Experiment 1](image-url)
Table 5.6 Result of experiments

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Number of detection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Experiment 1</td>
</tr>
<tr>
<td>Speed &gt; 90 km/h</td>
<td>7</td>
</tr>
<tr>
<td>Speed &gt; 110 km/h</td>
<td>0</td>
</tr>
<tr>
<td>Acceleration &gt; 35 km/h/3s</td>
<td>0</td>
</tr>
<tr>
<td>Deceleration &gt; 50 km/h/3s</td>
<td>0</td>
</tr>
<tr>
<td>Movement, LRL/RLR with speed &gt; 30 km/h</td>
<td>1</td>
</tr>
<tr>
<td>Movement, LRLR/RLRL with speed &gt; 30 km/h</td>
<td>0</td>
</tr>
</tbody>
</table>

No incident was detected in both experiments but the result shows that the developed system can be used in almost all traffic and weather conditions. Similar result for experiment 1 and 2 shows that worse weather conditions such as heavy rain do not affect GPS signal reception and RF signal transmission.
5.6 AIDEG SYSTEM PERFORMANCE

The performance of the proposed AIDEG was analyzed through three indicators, TTD, FAR and DR. In this system, TTD is defined as the elapsed time from the occurrence of an incident to the time the incident is detected by the algorithm in the MS. Thus, TTD is a sum of two components:

\[
TTD = t_1 + t_2
\]  

where \(t_1\) is the time wait for the time slot. If the modulated data is transmitted immediately in its time slot, thus \(t_1 = 0\). \(t_2\) is the time taken to send the modulated data to the MS. \(t_2\) depends on the distance between the vehicle and MS.

DR is the probability an incident is detected. In this case, DR is related to the number of equipped vehicle on the road and is not affected by the total number of incidents of other vehicles. The value can be calculated from the availability rate from Equation 3.3.

Number of coordinates for 1 vehicle in 60 minutes should receive = 3600/3 = 1200
Total number of coordinates for 5 vehicles should receive = 6000
But, total number of coordinates that is actually received;

Experiment 1 = 4860
Availability rate = (4860/6000) x 100% = 81 %

Experiment 2 = 4920
Availability rate = (4920/6000) x 100% = 82 %

Meanwhile, FAR depends on the quantity of signal lost during transmission between the transponder and MS. FAR could be minimized by filtering the received signal. In order to reduce false alarms in AID systems, most computer incident detection algorithms employ a persistent check method that requires discontinuities in traffic flow to persist for a specified period of time before an incident is signaled.
The overall result of performance indicator obtained from both experiments and simulation is in Table 5.7.

Table 5.7 TTD, FAR and DR for AIDEG system

<table>
<thead>
<tr>
<th></th>
<th>Time to Detect, TTD (µsec)</th>
<th>False Alarm Rate, FAR (%)</th>
<th>Detection Rate, DR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment 1</td>
<td>Min. 3.3 Max. 3000099</td>
<td>0</td>
<td>81</td>
</tr>
<tr>
<td>Experiment 2</td>
<td>Min. 3.3 Max. 3000099</td>
<td>0</td>
<td>82</td>
</tr>
<tr>
<td>Simulation 1</td>
<td>Min. 3.3 Max. 3000099</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Simulation 2</td>
<td>Min. 3.3 Max. 3000099</td>
<td>0</td>
<td>100</td>
</tr>
</tbody>
</table>

The value of the three performance indicators clearly illustrates the success of the developed incident detection. The changeable value of TTD is that if the modulated vehicle’s GPS data can be transmitted immediately in its time slot, the value of TTD is 3.3 µsecond (light signal travel time for 1 km). If the modulated GPS data has to wait for its time slot, and vehicle’s distance is 30 km from the MS, then the value of TTD is 3000099 µsecond (3 seconds interval plus light signal travel time for 30 km). Value of TTD in a simulation can be measured similar to the actual scenario even when the actual value is smaller because the transmission is only between two computers.

No error was recorded in both experiments and simulations, resulting in FAR of 0 %. The main reasons for a good FAR are the selected threshold value and filtering mechanism used in the algorithm. In the mean time, the DR is the value calculated from the availability rate. The value 81% and 82% are actually the value of GPS availability for experiment 1 and 2. These availabilities are determined from the number of modulated GPS signal received as compared to the number it should have received at the MS. Worst condition did not affect the GPS signal reception and RF transmission since the result and data received were almost comparable. Therefore, the incident detection method studied in this research is successful.
5.8 COMPARISON OF THE PROPOSED AID SYSTEM WITH SOME SIMILAR SYSTEMS

The proposed AID has been compared with some other systems in terms of performance indicator TTD, FAR and DR. Three IDSs have been considered. The multilevel traffic incident system introduced by Kamran and Hass (2007) has been discussed in section 2.5. The speed and confidence limit system and headway system has been proposed by Mussa and Upchurch (2002) in headway-based incident detection system. The comparison of these systems with the new system is summarized in Table 5.8.

Table 5.8 Comparison of the proposed system with some similar systems

<table>
<thead>
<tr>
<th>Proposed System (AIDEGS)</th>
<th>Multilevel Traffic Incident Detection System</th>
<th>Speed and confidence limit System</th>
<th>Headway-based System</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTD</td>
<td>3.3 µseconds to 3000099 µseconds</td>
<td>2.20 seconds</td>
<td>4.1 minutes</td>
</tr>
<tr>
<td>FAR (%)</td>
<td>0</td>
<td>1.23</td>
<td>0.20</td>
</tr>
<tr>
<td>DR (%)</td>
<td>82</td>
<td>75.30</td>
<td>48</td>
</tr>
</tbody>
</table>

The TTD of the proposed system is much better as compared to speed and confident system and headway based system which takes time of 2 minutes and more to detect. TTD for multilevel detection system is slightly lower than the maximum TTD for the proposed system but higher than the minimum TTD. Generally, the TTD of the new proposed system is better improved.

The novel system has excellent FAR with zero percent error as compared to the other systems. This is due to the accurate data received by the processing center and the exact filtering mechanism in the algorithm without ignoring the DR. Moreover, this system is not affected by traffic flows as compared to another AID. Finally, although the DR does not reach 100 percent, the value is still the highest as
compared to the other systems. Since DR is related to data availability, relocating the MS to higher altitudes could improve the DR.

5.9 SUMMARY

This chapter has presented the results of all the preliminary tests and experiments together with simulation for evaluating the performance of the proposed IDS. The method studied individual vehicle behavior only and all vehicles in the system are processed separately in one detection algorithm based on normal driver behavior in the preliminary field tests on the studied roads. The AIDEG system had been tested through two experiments, one in normal traffic and propagation impairment and the other one in the worst condition. Simulated data were used to generate higher speed and higher deceleration of vehicles and the outcomes successfully validate the algorithm. The result for real time monitoring shows excellent value of performance indicators. DR can be improved by placing the MS on higher altitudes where the LOS is better than the current MS. Furthermore, by placing a repeater at locations where LOS is poor, the TTD will be degraded by 3 to 6 seconds at certain areas because repeater needs another 3 to 6 seconds to transmit data to MS. However, the system performance depends on the availability of GPS signal and data transmission from vehicles to the MS.
CHAPTER VI

CONCLUSION AND RECOMMENDATIONS

6.1 INTRODUCTION

This chapter concludes the entire research on real time automated vehicle incident detection system using high accuracy GPS data. The abnormal behavior of a driver has an important effect on any incident on the road and in this study, GPS data is the major source of the developed incident detection system. Based on real time GPS signal, an overall conclusion and the manner in which the design the system can be successfully accomplished have been realized in this study. Some possible recommendations for future works are also suggested in this chapter. Most importantly, this study recommends that future researches should consider equipping GPS modems in all university vehicles and relocating the MS receiver antenna to the position of the highest altitude in Bandar Baru Bangi, probably by placing on the highest building or antenna tower in the area.

6.2 CONCLUSION

In this study, a new GPS-based AID approach, using only high accuracy GPS receiver and UHF radio channel for real time data transmission has been developed and proposed. The system has been verified, validated and analyzed through two experiments and simulations. This study has successfully obtained excellent values for the three AID performance indicators, namely the TTD, FAR and DR.

To achieve the first objective of the research which is to investigate the signal reception potential of using low cost high accuracy GPS data and data transmission
over RF for incident detection, preliminary field tests for data collection were carried out and data logging algorithm was developed. GPS receiver calibration was firstly conducted in order to obtain accurate reading. For the first step, GPS data were collected using the AIDEG system GPS at the GPS reference station at the Institute of Space Science, UKM for 24 hours and then the data were compared to the GPS reference coordinates. The result showed excellent value with very minimal error. In the second step, GPS data were collected around the UKM campus and then were plotted in Google Map using on line gpsvisualizer software. The result showed accurate GPS signal where no coordinates were plotted outside the road boundary. At the same time, data logging algorithm was designed for the purpose of collecting GPS signal around study area. The logging algorithm was developed using Microsoft vb.net and data analysis algorithm was developed using MATLAB.

MS planning was carried out to determine a suitable place for the MS. The planning was quite similar to cellular base station planning which required total signal coverage probably at the highest point and not too close to other cellular base stations. The GPS modem receiver was placed at some high altitude buildings with power supplies and air-conditioners in the UKM campus and the signals were then evaluated to determine the place with the strongest signal reception and minimal data error.

The process was followed by static positioning tests and mobile tests along the trunk roads in the study area. The aims were to evaluate GPS availability, reliability and accuracy in the area studied and simultaneously to determine the threshold parameters for the algorithm detection system. Static positioning test was conducted at four static test places for the duration of 24-hours and the mobile test was carried out in eight tests including in normal and heavy traffic conditions, and during the night and day time. The result showed signals of excellent quality received at both places, namely the GPS receiver locations (static and along the trunk roads) and the MS which received modulated GPS signal via RF transmission. After the data analysis was conducted, Bandar Baru Bangi, Selangor was then selected as the study area while the MS was identified to be located at an altitude of 110 meter at the Ibrahim Yaakob College.
To address the second objective which was to develop a new real time automatic response and alert system in an incident detection system, Microsoft vb.net programming language was used. This visual development tool was selected because of its capability to develop friendly graphic user interface (GUI) and to interface with other hardware such as GPS receiver via serial port. This is in comparison with other programming languages, namely MATLAB which has high ability with GUI development, but low performance with hardware interfacing, and C language which is excellent with interfacing but not friendly with GUI development. The other advantages of using Microsoft vb.net are the algorithm could be compiled into execution file and be used in other computers without installing vb.net and could also be integrated with other database management systems such as Microsoft Access. Additionally, some of the AID and traffic monitoring interface and data logging systems were used as comparison.

Finally, the last objective was to develop a new efficient automated incident detection system that is in conformance to AID’s standard performance with short TTD, zero FAR and higher DR as compared to the current systems. In order to achieve this, high accuracy GPS modem was integrated with incident detection algorithm. GPS modems were installed in the vehicles while the detection algorithm performed at the MS. In order to perform the shortest TTD and costless data communication, RF was used for data source transmission. To realize high detection performance, several threshold parameters were obtained for the preliminary field test such as maximum speed, maximum acceleration, maximum deceleration, maximum movement and speed, and finally the update time was inserted in the algorithm. Similar to any software development, algorithm training was done more than 100 times and filtering mechanisms were applied to maximize DR and to minimize TTD and FAR.

6.3 LIMITATION

The incident detection method proposed in this work is limited to vehicles equipped with GPS transmitters and could be detected by the receiver located at the MS only. The MS must be located at higher altitudes to attain good LOS. In order to achieve the
shortest time to detect, the range of coverage is a radius of 30 kilometers from MS and limited to only 50 vehicles. To enhance the coverage, the system needs another MS and which should be located at other places. To add another 50 vehicles or more, an additional receiver must be installed at the same MS. Performance of the system depends on the availability of the GPS signal and data transmission from the vehicles to the MS. Thus, the availability and reliability of the GPS signal should be checked before implementing this system in any area.

6.4 RECOMMENDATIONS FOR FUTURE WORK

The outcome of the system through experiments (drive testing) and simulation has opened up opportunities for more investigations to improve the system efficiently. This section presents some suggestions and recommendations that can be carried for further studies and future works. The followings are some of the many possible areas for future research and they can be divided into two aspects, namely instrumentation perspective and research perspective.

From the instrumentation perspective, the location of the MS receiver antenna needs to be relocated at higher altitudes so as to reduce transmission error and to obtain clearer LOS. High gain antenna must be used to improve signal quality. The antenna should be located at the highest altitude in Bandar Baru Bangi. The best way is by placing the antenna on a tower such as a telecommunications tower and positioning it far away from any mobile base station and overhead electrical transmission line to avoid any interference. In addition, at least four modem repeaters should be installed at four places in the study area to achieve 100 % DR. Mobile MS installed in vehicles such as a Highway Service Patrol that cruises along the trunk roads could improve the TTD and emergency response time. Other recommendations are to use lorries and buses for data collection and to use fifty vehicles for the drive test to convince any interested party of this system. Thus, a possible next step is to install the system in all university vehicles including buses and cars.

From the research perspective, the field test and drive test should be done at dedicated drive testing areas and involve professional drivers who can create
abnormal driving situation. This will make it more realistic rather than creating a simulation data to test the system’s algorithm. Apart from that, equipping the system in more than five vehicles in order to observe the transmission capability and interface screen capacity is also recommended.

Finally, it would be advantageous to further this research by applying the system that has been developed in another area such as an urban area with high buildings and traffic for the purpose of validating the findings of the present research.
REFERENCES


Asha, A. 1997. Incident detection in urban areas controlled by SCOOT. *IEE Colloquium on Incident Detection and Management*: 1-10.


Du, J., Aultman-Hall, L., 2006. Using spatial analysis to estimate link travel times on local roads, Transportation Research Board 2006 Annual meeting. paper number 0676.


RAVEON RV-M7-UC GPS MODEM SPECIFICATIONS

General

Frequency:
Model RV-M7-UC ................................................................. 450 – 480MHz
Size ................................................................. 5.0 X 3.76W X 0.95H
Weight ................................................................. 6 ounces (0.17kg)
DC input voltage .......................... 10-16V DC
Typical current draw, receiving, over-the-air rates < 4800bps ............... <80mA
Typical current draw, receiving, over-the-air rates >= 4800bps ............... <90mA
Current draw when transmitting data ......................................................... <1.5A
max, 1.2A typical at 2watts ......................................................... <2.7A at 5watts
Low Power Mode standby current (AT command) .......................... <30mA
Sleep Mode standby current (hardware control) .............................. <1mA
Frequency stability ........................................................................... ±1.5ppm
Over-the-air baud rates (programmable) ........................................ 1200, 2400, 4800,
........................................................................... 5142, 8000, 9600, 19200
Operating temperature range ......... -30ºC to +60ºC (-30ºC to +80ºC storage)
TX-RX and RX-TX turn-around time ........................................... <3mS
Power on time to operational ......................................................... <500mS
LPM Standby to operational ......................................................... <20mS
Internal fuse ................................................................. 3A mini blade

Transmitter
Maximum RF power output ................................................................. 0.1 - 5 watts
Maximum duty cycle ................................................................. 100% at 2W, 25% at 5W
Maximum transmit frequency ................................................................. ± 2.25kHz
RF Bandwidth ................................................................. 20Mhz, no-tune
Occupied bandwidth .11 kHz (12.5kHz channels)........... 15.3kHz (25kHz channels)
TX spurious outputs ................................................................. < -70dBc
Emissions designator............................................. 11K0F1D (12.5kHz channels)
15K3F1D (25kHz channels)

**Receiver**

Typical RX sensitivity (1% BER)
19200bps, 4-level, 25kHz channel .............................................. -108dBm
9600bps, 4-level, 12.5kHz channel ............................................. -108dBm
4800bps, 2-level ................................................................. -116dBm
2400bps .............................................................................. -116dBm
1200 .................................................. -119dBm
No-tune bandwidth ...................................................... 20MHz
RX selectivity ................................................................. -50dB
(12.5kHz channel spacing) ............................................. -65dB
(25kHz channel spacing)
Spurious and image rejection ........................................... -75dB
RX intermodulation rejection ........................................... -70dB
Conducted spurious emissions .................................... <-53dBm

**User Input and Output Signals**

Serial port baud rates........ 1200, 2400, 4800, 9600, 19200, 38400, 57600, 115200
Voltage levels ....................... RS-232, RS-422, and RS-485 complaint levels
Modem handshake signals ................. RTS, CTS, DTR, DSR, CD
RF I/O ................................................................. 50 ohm BNC
Power ...................................................... B+ input and Ground
Power Connector ...................... Phoenix 18 36 18 9 (Raveon P/N 1J165-3)
## APPENDIX B

### MODEM STRING

<table>
<thead>
<tr>
<th>Field</th>
<th>Usage</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$PRAVE</td>
<td>Raveon Proprietary Header</td>
</tr>
<tr>
<td>2</td>
<td>From ID</td>
<td>The ID of the transponder that transmitted its position over the air. It is a decimal number, 0 – 9999.</td>
</tr>
<tr>
<td>3</td>
<td>To ID</td>
<td>The ID that this position report was sent to. It is a decimal number, 0 – 9999.</td>
</tr>
<tr>
<td>4</td>
<td>Latitude</td>
<td>dddmm.mmmm format. It is signed. + is north, -is south. No sign means north. Note: typically there are 4 decimal places, but as few as 0 decimal places are possible. Null field if no GPS lock.</td>
</tr>
<tr>
<td>5</td>
<td>Longitude</td>
<td>dddmm.mmmm format. It is signed. + is east, -is west. No sign means east. Note: typically there are 4 decimal places, but as few as 0 decimal places are possible. Null field if no GPS lock.</td>
</tr>
<tr>
<td>6</td>
<td>UTC time</td>
<td>The UTC time at the time the transmission was made. Hhmmss format. Null field if no GPS lock.</td>
</tr>
<tr>
<td>7</td>
<td>GPS Status</td>
<td>0=not valid position. 1=GPS locked and valid position. 2=Differential or WAAS fix.</td>
</tr>
<tr>
<td>8</td>
<td>Num Satellites</td>
<td>The number of satellites in view</td>
</tr>
<tr>
<td>9</td>
<td>Altitude</td>
<td>The altitude in meters. Null field if no GPS lock.</td>
</tr>
<tr>
<td>10</td>
<td>Temperature</td>
<td>The internal temperature of the RV-M7 in degrees C. Typically this is 5-20 degrees above ambient.</td>
</tr>
<tr>
<td>11</td>
<td>Voltage</td>
<td>Input voltage to the device that sent this position.</td>
</tr>
<tr>
<td>12</td>
<td>IO status</td>
<td>A decimal number representing the binary inputs.</td>
</tr>
<tr>
<td>13</td>
<td>RSSI</td>
<td>The signal-strength of this message as measured by the receiver, in dBm. Note, if the message went through a repeater, it is the signal lever of the repeated message.</td>
</tr>
<tr>
<td>14</td>
<td>Speed</td>
<td>The speed of the device in km/hour, 0-255</td>
</tr>
<tr>
<td>15</td>
<td>Heading</td>
<td>The heading of the device 0-360 degrees</td>
</tr>
</tbody>
</table>
### Status

Status flags received from the device. Not all products support generating all status flag codes. NULL means no alerts.

- “P” means a proximity alert.
- “M” means man-down alert.
- “A” General alert, usually due to pressing an alert button.
- “C” Critical alert, usually due to pressing and holding alert button.
- “I” Impact alert.
- “V” Vibration
- “S” Service required on product.

### Spare

A spare field. May be used for UTC date in the future. Typically NULL.

### Checksum

The NMEA 0183 checksum.

---

**Example Sentence:**

```text
$PRAVE,0001,0001,3308.9051,-11713.1164,195348,1,10,168,31,13.3,-83,0,0,,*66
```

This example shows a unit at 33° 8.9051 north latitude and 117° 13.1164 east longitude. It is not moving (0 speed). Its signal strength was -83dBm. Its altitude is 168 meters.
APPENDIX C

PROCEDURE FOR GPS DISTANCE CALCULATION

Private Function JarakGPS(ByVal LatLocal As Double, ByVal LongLocal As Double, ByVal LatB As Double, ByVal LongB As Double) As Double

    Dim dLat, dLon, x, y, d As Double
    Dim R As Double = 6367442.5 ' meter
    Dim LatLocalRad, LatBRad, LongLocalRad, LongBRad As Double
    Dim Distance, a, b, c, e, f, g, h As Double

    LatLocalRad = (LatLocal / 180) * PI
    LongLocalRad = (LongLocal / 180) * PI
    LatBRad = (LatB / 180) * PI
    LongBRad = (LongB / 180) * PI
    a = Sin(LatLocalRad)
    b = Sin(LatBRad)
    c = Cos(LatLocalRad)
    e = Cos(LatBRad)
    f = Cos(LongLocalRad - LongBRad)
    g = Acos(a * b + c * e * f)
    h = (g / PI) * 180
    JarakGPS = 1.852 * 60 * h

End Function
APPENDIX D

PROCEDURE FOR GPS TRUE COURSE

Private Function TrueCourse(ByVal LatA As Double, ByVal LongA As Double, ByVal LatB As Double, ByVal LongB As Double) As Double
    Dim dLat, dLon, x, y, d As Double
    Dim LatARad, LatBRad, LongARad, LongBRad As Double
    Dim Distance, a, b, c, ee, f, g, h, k As Double
    Dim l As Double
    LatARad = (LatA / 180) * PI
    LongARad = (LongA / 180) * PI
    LatBRad = (LatB / 180) * PI
    LongBRad = (LongB / 180) * PI
    a = Sin(LatARad)
    b = Sin(LatBRad)
    c = Cos(LatARad)
    ee = Cos(LatBRad)
    f = Cos(LongARad - LongBRad)
    g = Acos(a * b + c * ee * f)
    h = (g / PI) * 180
    k = Acos(a * b + c * ee * f)
    If Sin(LongBRad - LongARad) < 0 Then
        l = Acos((b - a * Cos(k)) / (Sin(k) * c))
    Else
        l = 2 * PI - Acos((Sin(LatBRad) - Sin(LatARad) * Cos(k)) / (Sin(k) * Cos(LatARad)))
    End If
    If SpeedMobile(VehicleID, mn) = 0 Then
        TrueCourse = 0
    ElseIf LongA = LongB And LatA < LatB Then
        TrueCourse = 360
    ElseIf LongA = LongB And LatA > LatB Then
        TrueCourse = 180
    Else
        If ((l / PI) * 180) = 0 Then
            TrueCourse = 360
        Else
            TrueCourse = 360 - ((l / PI) * 180)
        End If
    End If
End Function
APPENDIX E

SPEED AND SPEED CHANGE

Test 1

Test 2

Test 3

Test 4

Test 5

Test 6

Test 7

Test 8
APPENDIX F

VEHICLE SPEED AND DIRECTION FOR MOBILE FIELD TEST

Test 1

Test 2

Test 3

Test 4

Test 5

Test 6

Test 7

Test 8
APPENDIX G

RESULT FOR SPEEDING-STOP TEST

a) Speed test 1

b) Speed test 2

c) Speed test 3

d) Speed test 4

e) Speed test 5

f) Speed test 6
Figure 5.10 Speed and direction for vehicle/driver 1. Left side in worst condition and right side in normal condition

Figure 5.11 Speed and direction for vehicle/driver 2. Left side in worst condition and right side is normal condition

Figure 5.12 Speed and direction for vehicle/driver 3. Left side in worst condition and right side is normal condition
Figure 5.13 Speed and direction for vehicle/driver 4. Left side in worst condition and right side is normal condition.

Figure 5.14 Speed and direction for vehicle/driver 5. Left side in worst condition and right side is normal condition.
PUBLICATIONS

JOURNALS


CONFERENCES


