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Architecture for Extracting Data from Vehicular Sensors

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Architecture for Extracting Data from Vehicular Sensors

By

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DECLARATION OF ORIGINALITY

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ABSTRACT

In this thesis we investigate an alternate source of vehicular information for collision avoidance systems and driver assistance applications, which is more accurate, reliable in all conditions and has minimum time lag. We have designed and developed an architecture, which enables us to read, analyze, decode and store the real-time vehicular data from the vehicle's electric sensors. We have designed two algorithms for decoding the raw data read from the vehicle's Controller Area Network (CAN) [7] bus, to which various electric components of the vehicle are connected to communicate the real-time data.

We have shown that the vehicular speed which is a very important parameter in the calculation of 'Time to Collision (TTC)' by collision avoidance algorithms [22] is more accurate, reliable and has higher polling rate, when calculated from the vehicle's CAN bus as compare to the other source of information i.e. GPS [6].

DEDICATION

To my father whose shower of blessings remains with me and always motivates me to accomplish the ambitions he had seen for me.

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LIST OF ABBREVIATIONS

1.	ABS	Anti-lock Braking System
2.	ACK	Acknowledge
3.	ARP	Address Resolution Protocol
4.	ASC	Automatic Stability Control
5.	AT	Auto Tracker
6.	BSM	Basic Safety Message
7.	CA	Constant Acceleration
8.	CAN	Controller Area Network
9.	CRC	Cyclic Redundant Check
10.	CTR	Constant Turn Rate
11.	CTRA	Constant Turn Rate and Acceleration
12.	CV	Constant Velocity
13.	DHCP	Dynamic Host Configuration Protocol
14.	DLC	Data Length Code
15.	DS	Dempster-Shafer
16.	DSRC	Dedicated Short Range Communications
17.	ECU	Engine Control Unit
18.	EEBL	Emergency Electronic Brake Light
19.	EMC	Electromagnetic Compatibility
20.	EMI	Electromagnetic Interference
21.	EoF	End of Frame
22.	ETC	Electronic Toll Collection

23. FCC	Federal Communications Commission
24. FIFO	First In First Out
25. GPS	Global Positioning System
26. ICMP	Internet Control Message Protocol
27. IDE	Identifier Extension
28. IFS	Intermission Frame Space
29. IP	Internet Protocol
30. IPT	Inverse Perspective Transform
31. ISO	International Organization for Standardization
32. ITS	Intelligent Transportation System
33. LAN	Local Area Network
34. LIDAR	Light Detection and Ranging
35. LRR	Long Range Radar
36. NHTSA	National Highway Traffic Safety Administration
37. OBD	On-board Diagnostics
38. OBU	On Board Unit
39. OEM	Original Equipment Manufacturer
40. RSE	Road Side Equipment
41. RTR	Remote Transmission Request
42. SoF	Start of Frame
43. SpaT	Signal Phasing and Timing
44. TCP	Transmission Control Protocol
45. TTC	Time to Collision

46. UDP	User Datagram Protocol
47. UKF	Unscented Kalman Filter
48. USB	Universal Serial Bus
49. V2I	Vehicle to Infrastructure
50. V2V	Vehicle to Vehicle
51. VANET	Vehicular ad-hoc Network

CHAPTER-1

INTRODUCTION

1.1 Overview

Vehicular safety technology has developed rapidly in the last two decades. Modern vehicles can protect occupants much better in the event of a crash, due to the advanced structural design techniques complemented by more stringent road standards, and some mandatory standard crash avoidance technologies. All these advances have made motor vehicles safer than they have ever been. However, there are still a significant number of annual crashes that could potentially be eliminated through expanded use of more advanced crash avoidance technologies. It has been estimated by National Highway Traffic Safety Administration (NHTSA) [5] that there are more than five million annual vehicle crashes with property damage, injuries and fatalities. So, if deployment of technology can help to avoid these crashes, the damage due to crashes never occurs.

Some of the most advanced collision avoidance technologies present on the vehicles today include cameras, on-board sensors and radar applications. These technologies may warn the drivers of impending collision thus helping them to take corrective actions. While these current technologies are highly beneficial, the Vehicle to Vehicle (V2V) communications [4] represent an additional step in helping to warn drivers of the impending collision threats. V2V communications use on-board dedicated short-range radio communication (DSRC) [8] [9] devices to transmit messages about a vehicle's location information, speed, heading, brake status, and other information to other vehicles. Information is received in the form of messages, with capabilities of range and line of sight, which can be more than twice of that of the current systems. This longer detection distance and ability to see around corners or through other vehicles helps V2V-equipped vehicles perceive some threats sooner than sensors, cameras, or radar can, and warn their drivers accordingly. V2V can be combined with other driver assistance applications to act as a complete system that cover the scenarios which are not covered by V2V alone, such as lane or road departure warning. A complete system could also augment system accuracy, potentially leading to improved warning timing and reducing the number of false warnings [5].

1.2 Motivation

According to the statistics published by NHTSA, a total number of 99,176 fatalities was reported in the United States, due to the vehicle traffic crashes during the period of 2012-2014, with the year 2012 having the maximum number of fatalities at 33,782 [47]. According to another data record published by NHTSA, more than 10 million motor vehicle accidents were reported every year in the US and economic cost of traffic crashes up till year 2010, was estimated to USD 242 billion [48] [49]. According to the '2013 National Statistics' given by NHTSA, total number of 30,057 fatalities and 1,591,000 injuries was reported due to road accidents in the US. These vehicle traffic crashes had also resulted in a property damage of USD 4,066,000 [49]. According to the 'Canadian Motor Vehicle Traffic Statistics 2012', total number of 123,963 vehicular collisions was reported and the related fatalities and serious injuries reported was 2077 and 10,655 respectively [50].

Researchers and technology experts from around the world are working to develop new ways to minimize the losses occurring due to traffic collisions. Various technologies such as Airbag System, and Anti-lock Braking System have been incorporated and mandated by vehicle manufacturers and traffic regulatory bodies over the period of time, which have proved highly beneficial to reduce the number of vehicle crashes and related losses. To add more sophistication, a lot of work is being carried on the improvement and development of collision avoidance algorithms. These algorithms incorporated with V2V communications are considered as very useful technologies to be incorporated in the next generation of vehicles. The accuracy of these algorithms depends on the availability of real time, reliable and accurate source of input parameters e.g. positioning information, speed and brake status. In this thesis, we focus on techniques for accurate and timely collection of various vehicular parameters (e.g. speed, engine rpm, brake status etc.), which can aid in the development of better collision avoidance algorithms and driver assistance applications.

1.3 Problem Statement

Currently, most of the collision avoidance algorithms rely on GPS [6] for the real-time situation parameters of the vehicles. For example, the collision warning system presented in [22] and [23], calculates 'Time to Collision (TTC)' between two vehicles using GPS information (e.g. longitude, latitude, speed, heading, altitude and acceleration) exchanged using V2V communications. Another system presented in [32], uses vehicular ad-hoc network (VANET) router, a GPS system, inertial sensors for measuring the speed, acceleration, and yaw rate and a long-range radar (LRR) to predict the future path of the vehicle. Since these systems work in real time conditions, so the input parameters need to be accurate, reliable in all conditions and have minimum time lag.

The data obtained from GPS signals is significantly less accurate during bad weather conditions, in urban downtown areas and tunnels, either because of the signal distortion, or no GPS signals are received in these conditions. Also, the polling rate of current GPS receivers is low with intervals up to 200 milliseconds, which may not be adequate for real-time systems like collision avoidance systems. Similarly, a system based on camera would have high maintenance costs and also may give less accurate warnings during bad weather conditions and at night. Furthermore, current source of information like GPS provides access to only a limited number of vehicular parameters like speed and acceleration. This has led to the development of collision avoidance algorithms with limited scope and accuracy. All these factors have resulted in inaccurate calculation of TTC [22], which resulted in wrong or no warnings of the impending collisions. So, there is a need to improve the source of vehicular information which should be more accurate, reliable in all conditions and has higher polling rate. Also, a number of additional important vehicular parameters like steering angle, brake status, yaw rate, turn indicator status etc. should be extracted, which could lead to the development of more sophisticated collision avoidance algorithms.

1.4 Solution Outline

We have found that there is a scope to get the information e.g. speed, acceleration and brake status directly from the vehicle instead of present sources e.g. GPS, while positioning information like longitude, latitude, altitude and heading still must be taken from GPS. Extracting data directly from vehicle's sensors would result in more accurate and real-time data with very less time lag. In modern vehicles, all the electric devices of the vehicle are connected to each other by a bus network called Controller Area Network (CAN) [7]. The vehicle's electric devices communicate with each other through CAN protocol, which helps the devices to access the most recent information from various components. Each message has a unique CAN ID present in the header which helps the devices to recognize different messages.

The CAN bus can be accessed using the OBD-II port [19] present in the vehicle. We have designed and developed a software application named CAN-Ethernet which uses an Ethernet dongle to connect to the OBD-II port of the vehicle. The CAN Ethernet software reads, analyzes, decodes and stores the CAN data read from the CAN bus in real-time. The software runs as a server application to act as a source of CAN data and enables up to five different client connections at the same time. Can-Ethernet software takes, as input, a DBC file [44], which defines the CAN IDs and other information helpful in decoding the CAN messages. We have designed two algorithms, one for little endian [51] and other for big endian byte order [51], that decode the CAN messages read from the CAN Bus. After decoding, the information is populated in data structures that store the real time value of each sensor parameter and also written to the log files. We are able to extract a number of vehicular parameters like speed, engine rpm, brake status, steering angle, yaw rate, accelerator pedal position, headlight status, wiper status, ambient temperature and ambient pressure. All these parameters information can prove very useful in developing and improving collision avoidance systems and driver assistance applications.

1.5 Thesis Organization

The remainder of our thesis is organized as follows. Chapter 2 gives the brief description about the Intelligent Transportation Systems (ITS) including V2V and V2I technologies. A brief introduction about CAN Bus protocol and some existing collision avoidance technologies is also provided in this chapter. Chapter 3 presents our proposed CAN-Ethernet application software architecture. Chapter 4 discusses and analyzes our test results. Chapter 5 concludes our work and identifies some possible directions for the future work.

CHAPTER-2

REVIEW OF LITERATURE

2.1 Introduction to Intelligent Transportation Systems

“Intelligent transportation systems (ITS) are advanced applications which, without embodying intelligence as such, aim to provide innovative services relating to different modes of transport and traffic management and enable various users to be better informed and make safer, more coordinated, and 'smarter' use of transport networks” [1]. In general, ITS is an application of advanced technologies which includes computers, sensors, communications, and various electronic devices to make commutation safer, quicker, energy efficient and environment friendly.

The growing congestion and safety problems in transportation networks along with infrastructural, environmental and land constraints have resulted in the demand of adequate and efficient use of the existing resources. The application of ITS is critical in solving such problems. Various sophisticated applications are already in use and are being developed to improve transportation around the world. For example, computers and communication systems are being integrated to provide link between vehicles, travelers and infrastructures to address the modern problems of traffic collisions and congestion to save precious lives and energy.

National ITS architectures for several countries were designed and planned, including the research area and transportation service. The American national ITS Architectures is shown in Figure 2.1.

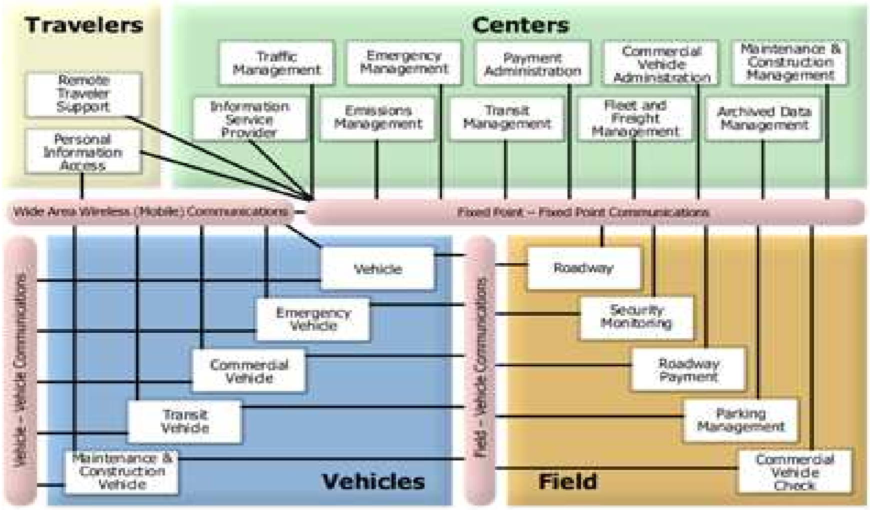


Figure 2.1: National ITS Architectures of America [2] [3]

A basic framework for developing an integrated transportation systems provided by ITS architecture is shown in Figure 2.2.

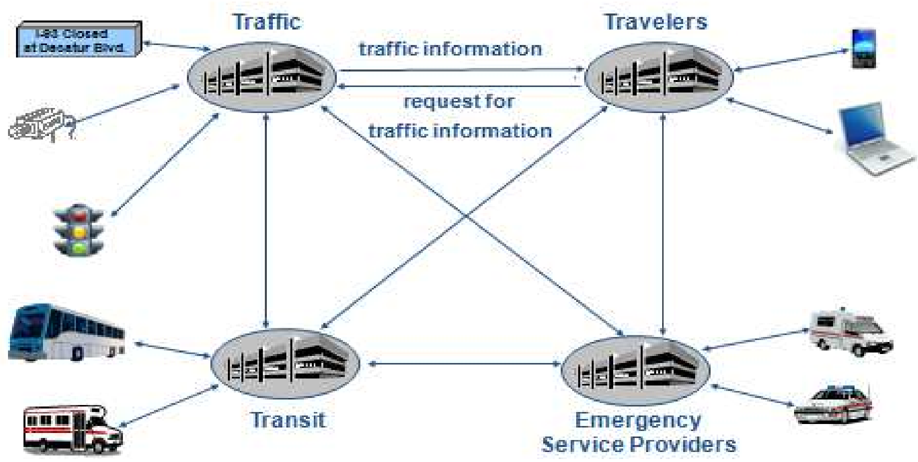


Figure 2.2: Framework for integrated transportation system [3]

2.2 Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) Communication

In V2I, the infrastructure plays a coordination role by gathering situation awareness information on traffic and road conditions and then suggesting or imposing certain behavior conditions on the vehicles. In other scenarios, vital information about traffic signals or pedestrian movement is transmitted to the vehicles thereby alerting the drivers to react in a timely fashion. In a more sophisticated scenario, the velocities and accelerations of vehicles and inter-vehicle distances would be suggested by the infrastructure on the basis of traffic conditions, with the goal of optimizing overall emissions, fuel consumption, and traffic velocities. The information can be broadcast to the vehicles or can be relayed to other vehicles by using multi-hop networking of the V2V.

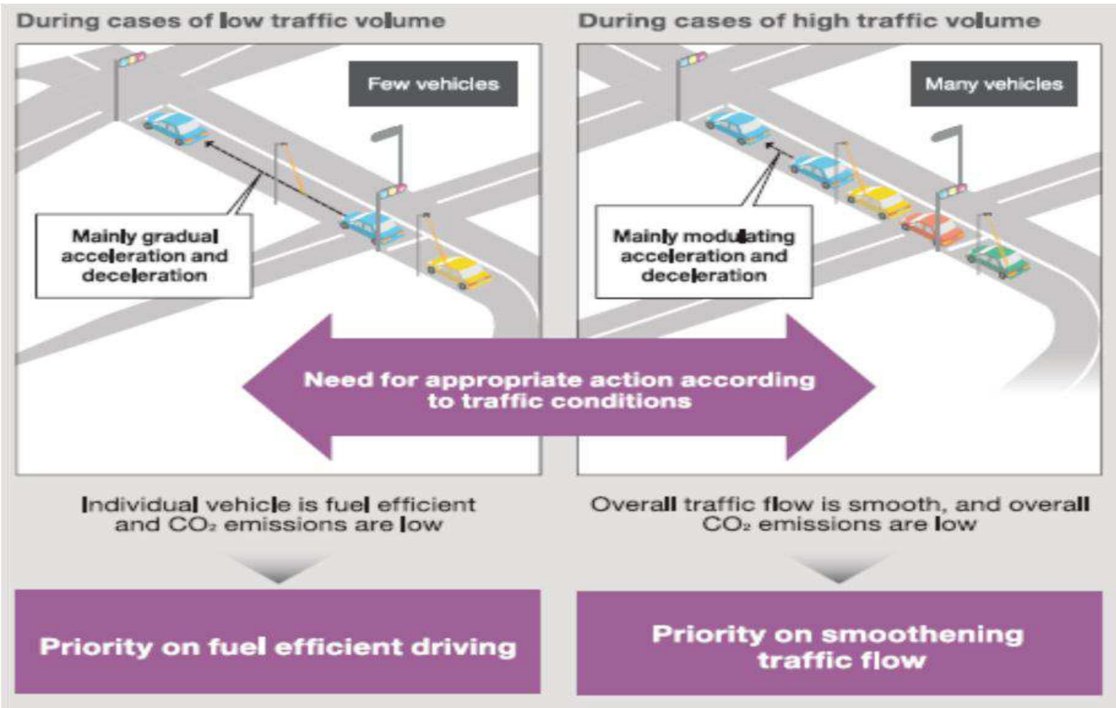


Figure 2.3: V2I controlled traffic situations [4]

The figure 2.3 shows two different traffic situations [4]. In the left panel, traffic density is low and the central infrastructure based controller acts to improve fuel efficiency and reduce emissions of individual vehicles, smoothing accelerations and decelerations; in the right panel, due to greater congestion, the infrastructure control is primarily concerned with depleting queues at intersections with an eye toward global fuel economy and emissions reduction.

V2V is a decentralized system as compared to V2I, which aims at organizing the interaction among vehicles and possibly developing collaborations among them [4]. In this system, vehicles periodically exchange information to make decisions for the future behavioral actions. In a general V2V scenario, when two or more vehicles come within a communication range, they connect automatically and make an ad-hoc network to share their position, direction, speed, acceleration, braking and various other parameters' data. The vehicles get their own parameters' data from various sources like Global Positioning Data (GPS) [6], Controller Area Network (CAN) [7], and Road Side Equipments (RSEs) [5]. The devices placed on the vehicles to receive, process and transmit the data are called On-Board Units (OBUs) [5]. These OBUs act as routers which enable the multi-hop transmission of the data to more distant vehicles and road side stations.

Figure 2.4 shows a visual representation of a V2V communication network.

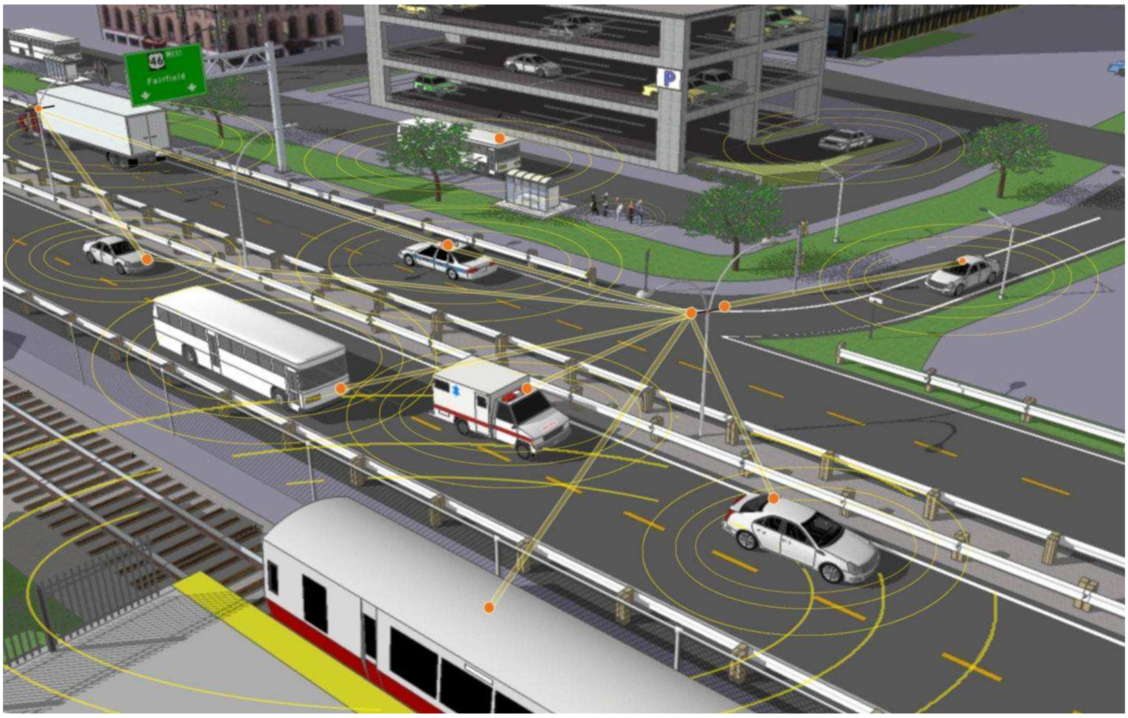


Figure 2.4: Visual Representation of V2V Communication [5]

The wireless communication is based on IEEE 802.11a, also known as Dedicated Short Range Communications (DSRC). A frequency spectrum of 5.9-GHz range has been allocated to support the development of safety applications based on V2I and V2V communication systems [5] [8].

2.2.1 Dedicated Short Range Communications Protocol

Dedicated Short-Range Communications (DSRC) is 75 MHz of spectrum at 5.9 GHz allocated by the Federal Communications Commission (FCC) to "increase traveler safety, reduce fuel consumption and pollution, and continue to advance the nation's economy [8]." It is developed to dedicatedly support V2V and V2I communications using a variant of IEEE 802.11a technology. DSRC would support safety-critical communications like collision warnings, as well as other valuable ITS applications such as Electronic Toll Collection (ETC), digital map update, etc. The versatility of DSRC greatly enhances the likelihood of its deployment by various industries and adaptation by the consumers.

The 2004 FCC ruling [9] specifies DSRC will have six service channels and one control channel. The control channel is to be regularly monitored by all vehicles. Safety messages, whether originated by vehicles or roadside transmitters, are to have priority over non-public safety communications. Therefore all safety messages are to be sent in the control channel. In the meantime, a licensed roadside unit could use the control channel to inform approaching vehicles of its services (often non-safety applications) and conduct the actual application in one of the service channels. For example, a roadside unit could announce a local digital map update in the control channel and transfer this data to interested vehicles in a service channel.

Table I illustrates the sort of DSRC data traffic characteristics being used in the standards deliberations [10] [11] [12]. The FCC has recognized safety messages and "safety of life" messages. Safety of life is to have the highest priority. The non-safety data transfers have the lowest priority. The non-safety communications happen for file transfers (e.g., infotainment) or transactions (e.g. toll collection). Transactions may require the exchange of two or three messages within a short time window (e.g. 20 ms).

Table I
Typical DSRC data traffic requirements

Applications	Packet Size(bytes)/ Bandwidth	Allowable Latency (ms)	Network Traffic Type	Message Range (m)	Priority
Intersection Collision Warning/Avoidance	~100	~100	Event	300	Safety of Life
Cooperative Collision Warning	~100/ ~10 Kbps	~100	Periodic	50 - 300	Safety of Life
Work Zone Warning	~100/ ~1 Kbps	~1000	Periodic	300	Safety
Transit Vehicle Signal Priority	~100	~1000	Event	300 – 1000	Safety
Toll Collection	~100	~50	Event	15	Non-Safety
Service Announcements	~100/ 2 Kbps	~500	Periodic	0 - 90	Non-Safety
Movie Download (2 hours of MPEG 1): 10 min download time	> 20 Mbps	N/A	N/A	0 - 90	Non-Safety

2.2.2 V2V Devices

Various types of V2V devices are available which are either placed inside the vehicle during manufacturing or can be installed as an aftermarket product in the vehicle.

All these types support different types of V2V and V2I safety applications. These devices can be categorized as follows.

2.2.2.1 Original Equipment Manufacturer (OEMs)

An OEM device is an electronic device integrated into a vehicle during vehicle manufacturing. A V2V system is integrated into these devices which is connected to the proprietary CAN busses [7] and can provide highly accurate information running in these busses. This vehicle information along with the data collected from the GPS receivers is used to generate Basic Safety Messages (BSMs) [5]. The integrated system both broadcasts and receives BSMs and also has a processor that can process the contents of the received messages to provide advisories and warnings to the driver of the vehicle in which it is installed. Because the device is fully integrated into the vehicle at the time of manufacture, vehicles with Integrated Safety Systems could potentially provide haptic warnings to alert the driver (such as tightening the seat belt or vibrating the driver's seat) in addition to audio and visual warnings provided by the aftermarket safety devices. The equipments required for an integrated OEM V2V system would consist of a general purpose processor, associated memory, a radio transmitter and transceiver, antennas, interfaces to the vehicle's CAN bus, and a GPS receiver. These types of integrated devices can be collaborated with other vehicle-resident collision avoidance systems to exploit the functionality of both types of systems.

2.2.2.2 Aftermarket Devices

Automotive aftermarket devices can be defined as any device with one or more functions in the areas of safety, comfort, performance or convenience, which are added to the vehicle after its original assembly. A V2V communication aftermarket device generally provides warnings and/or advisories to the driver similar to those provided by OEM installed V2V devices. These devices, however, may not be as fully integrated into the vehicle as an OEM device, and the level of connection to the vehicle can vary based on the type of aftermarket device itself. For example, an independent V2V aftermarket safety device could only connect to a power source, and otherwise would operate independently from the systems in the vehicle. Aftermarket V2V devices can be added to a vehicle at a vehicle dealership, as well as by authorized dealers or installers of automotive equipment. Some aftermarket V2V devices (e.g., cell phones with apps) are portable and can be standalone units carried by the operator or the passenger.

Table II [5] shows the details of all types of aftermarket devices that are employed in the vehicles.

Table II
Aftermarket Safety Device Types

Device type	Definition	Method of Installation	Functionality
Vehicle Awareness Device	Device is able to be connected to the vehicle for power source. Device provides Basic Safety Message for surrounding vehicles.	Device would need to be installed by a certified installer on vehicles not equipped with V2V technology to ensure correct antenna placement and security.	Transmits BSM
Aftermarket Safety Devices (i.e., Self-contained)	Device is connected to the vehicle for power source, Device transmits BSM and receives BSMs to support	This device only receives power from the vehicle; however, a certified installer would need to ensure correct	V2V Safety applications Receives and Transmits BSM Driver-Vehicle

	safety applications for the driver of the vehicle in which it is installed.	antenna placement and security.	Interface
Retrofit Safety Devices	Device is connected to the vehicle's data bus that provides BSM and safety applications for the driver of the vehicle in which it is installed.	This device needs to be connected to the vehicle's data bus, therefore would require an installer that can access this for the particular make of vehicle. Also, a certified installer would need to ensure correct antenna placement and security.	V2V Safety applications Receives and Transmits BSM Driver Vehicle Interface Integration into the vehicle data bus

2.2.2.3 Infrastructure Based Devices

Infrastructure based devices can be defined as devices that are co-located along with road side equipments that allow vehicles to receive information from the infrastructure. The road side equipments can be road signs, traffic signals etc. General applications that run on these devices are related to signal phasing and timing (SPaT), curve and curve speed warnings, traffic advisories etc.

2.2.3 V2V Safety Applications

V2V technology communicates via DSRC (radio signals) which offer 360 degree coverage. This communication allows vehicles equipped with V2V devices to track each other at times when they can be completely unaware of each other's presence. DSRC protocol has an operational range of up to 300 meters that facilitate identification of intersecting paths that potentially result in a crash if no vehicle takes necessary action. In addition, V2V systems are not affected by weather conditions, light, or conditions of road as in the case of other systems dependent on cameras or Light Detection and Ranging (LIDAR) [13].

In figure 2.5 various safety applications and scenarios they can address are shown.

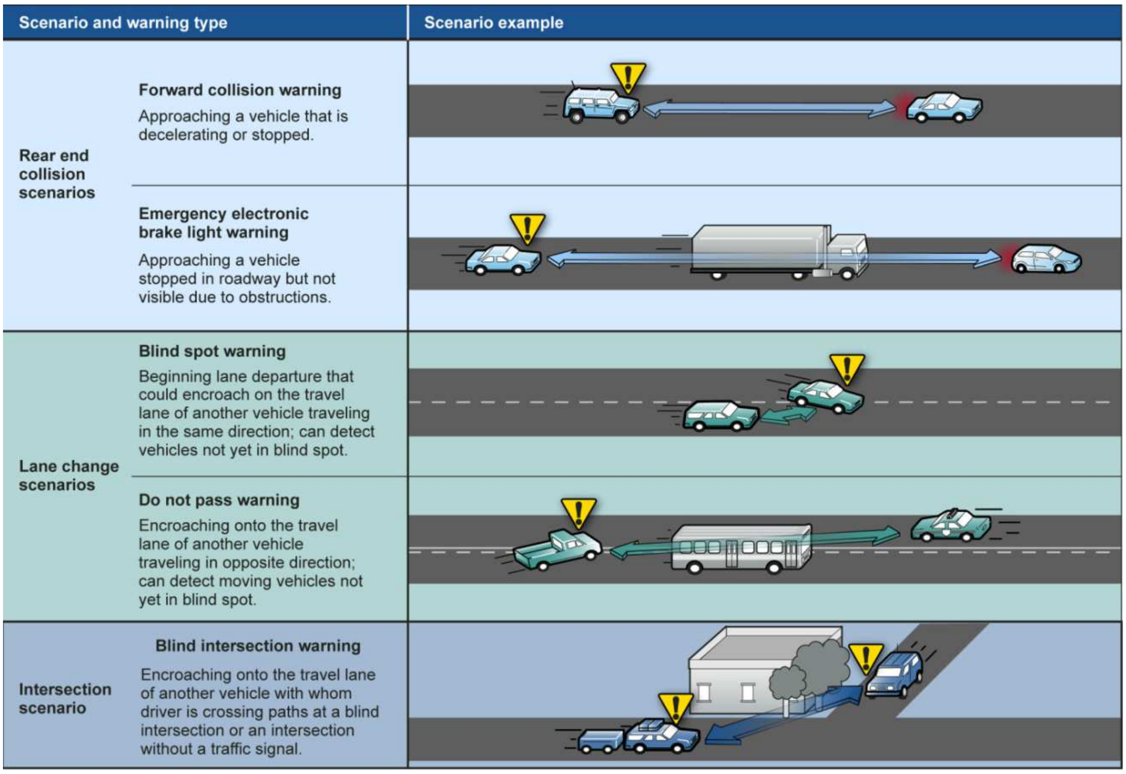


Figure 2.5: Examples of Crash Scenarios and Vehicle-to-Vehicle Applications [5]

2.3 Controller Area Network (CAN) Bus

There are many electronic devices in today's in-vehicle e.g. anti-lock braking system (ABS) and automatic stability control (ASC), and the number of these devices incorporated is increasing gradually. These devices need to communicate with each other. As a point-to-point communication would increase the wiring that would lead to increase in the vehicular weight, so the bus network is used for the multi point communication.

Controller Area Network or CAN bus designed and developed by Robert Bosch GmBh [7] is international standardized and defined in the ISO 11898-1 [16]. As a network specification for electric control system of vehicle, CAN has the capacity of real time control. The efficient use of these electronic devices through bus network has helped to reduce the oil consumption and air pollution, improve the ability, safety and comfort of the vehicle and make drive easy. Some of the electronic devices that are used are engine timer, auto tracker (AT) and accelerator paddle controller, anti-lock braking system (ABS), automatic stability control (ASC), intelligent air bag, air conditioning and sound device [14].

The Controller Area Network (CAN) is a serial communications protocol which efficiently supports distributed real-time control with a very high level of security [7]. CAN is one of the most popular in-vehicle networks. It simplifies the cable in vehicle, so the weight of the vehicle is reduced and easy to maintain and repair [15].

In figure 2.6 a general structure of the CAN network is shown. Many electronic devices are connected to CAN network and communicate with each other. The microcontroller in each electronic device communicate to CAN controller and CAN controller connects CAN bus via CAN driver. CAN network is composed of 2 lines and communicates by using difference of voltage level [7] [15].

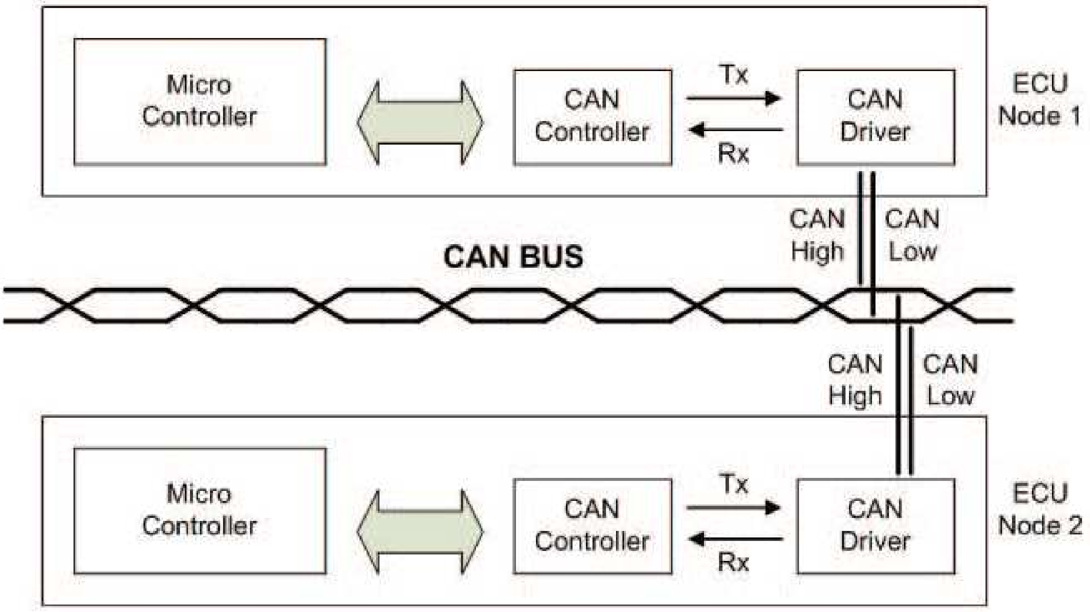


Figure 2.6: Structure of CAN Network [15]

The various advantages of CAN protocol are discussed as follows [14] [17] [18].

- Latency Time: This is defined as the time a transmitting node is ready to send information up until the time the transmission has been completed. CAN has the short latency time that is essential in the real-time control applications.
- Electromagnetic Compatibility (EMC) and Electromagnetic Interference (EMI): The performance is not affected by radiated emissions and susceptibility.
- Error Handling and Fault recovery: Less than one undetected error rate in the lifetime of the vehicle is considered reasonable. The ability to handle and recover quickly from faults was considered as an important factor for the CAN protocol.
- Data Consistency: Ensure the consistency of data across the network, particularly when sharing sensor information after eliminating duplications.
- Flexibility: Since vehicle configuration requirements may be different according to model variants and model years, it is necessary for ECU's to be interconnected

at different locations in the vehicle free from the need to redesign or re-qualify the system or sub-system.

- Expandability: It is possible for existing systems to be upgraded or added to over time without modification of the original system if the additional ECU's are listening nodes.
- Broadcasting: Support a multi-master broadcast communications system. In other words, every connected control unit has the same right to access the network.
- The protocol can take up to 2032 identifiers and support up to 1Mbps over 40 meters of twisted pair cable.
- Contention based with no data loss. Simultaneous transmissions are resolved via non-destructive bitwise arbitration.

2.3.1 CAN Frame Structure Format

The CAN protocol supports two message frame formats, the only essential difference being in the length of the identifier. The “CAN base frame” supports a length of 11 bits for the identifier, and the “CAN extended frame” supports a length of 29 bits for the identifier [16].

Figure 2.7 below shows a structure of the CAN data frame [15] [16]. A “CAN base frame” message begins with the start bit called "Start Of Frame (SOF)", this is followed by the “Identifier" which is used to specify the “CAN ID” of the sensor and the "Remote Transmission Request (RTR)" bit used to distinguish between the data frame and the data request frame called remote frame. If the message is used as a remote frame, the DLC contains the number of requested data bytes. The following field contains the

"Identifier Extension (IDE)" bit to distinguish between the CAN base frame and the CAN extended frame, as well as the "Data Length Code (DLC)" used to indicate the number of following data bytes in the "Data field". The "Data field" that follows is able to hold up to 8 data byte. The integrity of the frame is guaranteed by the following "Cyclic Redundant Check (CRC)" sum. The "Acknowledge (ACK) field" compromises the ACK slot and the ACK delimiter. The bit in the ACK slot is sent as a recessive bit and is overwritten as a dominant bit by those receivers, which have at this time received the data correctly. The end of the message is indicated by "End of Frame (EOF)". The "Intermission Frame Space (IFS)" is the minimum number of bits separating consecutive messages.

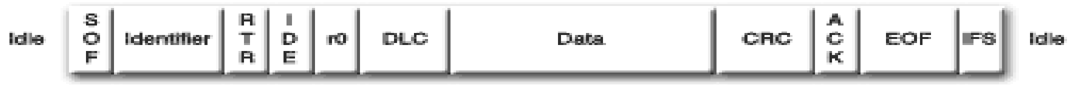


Figure2.7: A structure of CAN frame [16]

In the “CAN extended frame” the length of the identifier used is 29 bit. The 29 bit identifier is made up of the 11-bit base identifier and 18 bit extension. The distinction between CAN base frame format and CAN extended frame format is made by using the IDE bit, which is transmitted as dominant in case of an 11-bit frame, and transmitted as recessive in case of a 29-bit frame. The two frame formats coexist on the bus at the same time and “CAN base frame” always has the higher priority over the “CAN extended frame” in case of collision for the bus access.

There are four different types of frames transmitted in the CAN protocol [7].

1. A data frame carries data from a transmitter to the receivers.

2. A remote frame is transmitted by a bus unit to request the transmission of the data frame with the same identifier. The "Remote Transmission Request (RTR)" bit is used to distinguish between the data frame and the remote frame.
3. An error frame is transmitted by any unit on detecting a bus error.
4. An overload frame is used to provide for an extra delay between the preceding and the succeeding data or remote frames.

2.3.2 CAN Bus Data Extraction

There has not been any published material found explaining the ways for extracting and decoding the data from the CAN bus. CAN bus monitoring requires a CAN USB/Ethernet/WiFi device that could be connected to the vehicle’s OBD-II [19] port. A CAN application running on a computer is connected to this device and CAN frames are sent and received by this application through the CAN device.

In [20], the CAN bus monitoring is done using an USB-CAN device (Figure 2.8) and logging the read raw data in text format. The work is limited to passively monitor the CAN bus using device USB-CAN device without intending to decode the raw values. The hardware of USB-CAN smart card consists of power module, peripheral electric circuit, USB interface module and CAN interface module [21].

Figure 2.8: USB-CAN smart card [20]

The number of data bytes in the CAN frame received from the bus varies according to the CAN ID from where the bytes are received. The CAN device also has the capabilities of filtering and masking the CAN IDs. This helps to get the CAN frames from only selected CAN IDs which in turn helps to manage the huge of volume of data coming out. In figure 2.9 below, a sample window of the collected CAN frames is shown.

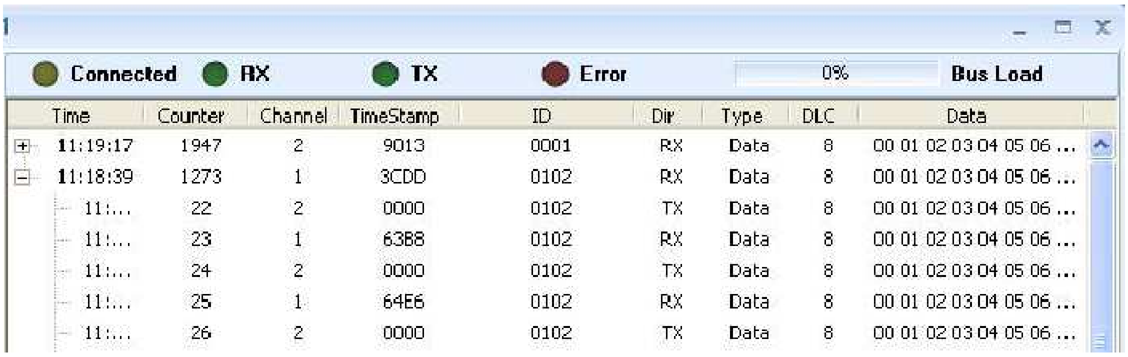


Figure 2.9: CAN frames display window [20]

2.4 Collision Avoidance Systems

A collision avoidance system is a vehicular safety system designed to avoid crashes or reduce their severity. The main idea of the design of these systems is to detect other vehicles in the collision range and then send warnings (audio or visuals) to increase driver's reaction time or act automatically (like braking or steering) to avoid an imminent crash. Various kind of detection mechanisms like all weather radar, camera, V2V and V2I communications are currently used so as to take the precautionary actions before an accident. Few of the most common new technologies are forward collision warning, autobrake, lane departure warning, lane departure prevention, adaptive headlights and blind spot warning.

2.4.1 Global Positioning System Data Based Systems

These types of systems use V2V and V2I communications to periodically exchange their GPS [6] location and movement information. Every vehicle has its own GPS receiver through which they get this information at a predefined polling rate. Vehicles exchange this information in the form of basic safety messages (BSMs) [5]. These messages are periodically transmitted and received by every vehicle using the DSRC protocol [8] [9]. The various parameters that are included in these messages are longitude, latitude, heading, altitude, speed, brake status and acceleration. Every vehicle processes the information received from these messages along with their own current information to decide whether there is an impending collision.

Fig. 2.10 illustrates how two vehicles *A* and *B* deploy the protocol of periodic information exchange to avoid collision [22] [23]. The two inner circles are collision zones of vehicles of *A* and *B* and the outer circle is communication cluster of *A*. Periodically vehicle *A* receives *B's* coordinates and it checks if their collision zones intersect. To do so, *A* makes use of the distance between the two vehicles (computed by the coordinates sent by *B*) and the collision zone radius (sent by *B* through the information packet). If the two vehicle's collision zones intersect, then vehicle *A* computes the next information message from vehicle *B*, so as to formulate vehicle *B*'s motion profile and compare it with its own motion profile. After computing that two vehicles are on collision course and will intersect at a point then vehicle *A* calculates the time to collision (TTC) and communicates the same to vehicle *B* [22] [23].

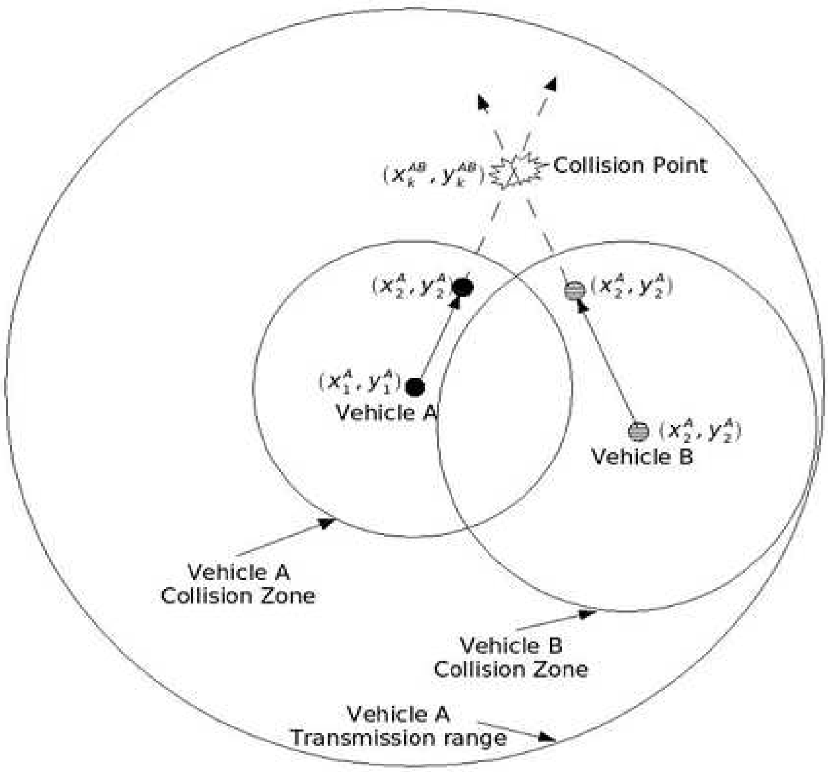


Figure 2.10: Graphical illustration of two vehicles A and B and their collision path [22]

In [24], [25] and [26] the positive impacts of V2V communication to avoid the rear end collisions are discussed. In figure 2.11, a graphical illustration of rear end chain collision is depicted. If vehicle *A* makes a sudden stop then seeing the brake lights of vehicle *A*, vehicle *N3* will apply emergency brakes and may be able to stop in time. But because of the line of sight limitation of brake light, it is likely that driver of vehicle *N6* will not know of the sudden braking of vehicle *A* unless vehicle *N6* brakes. This leads to the shortening of the reaction time for the driver of *N6* and which can lead to a rear end collision of *N6* with *N3*. But if the braking status of vehicle *A* is communicated through V2V communications then all the vehicles at its rear would be able some extra time to react appropriately. Also, if the vehicles are equipped with automatic braking systems, then vehicles at rear would be forced to stop before any impending collision. Similarly, the vehicles in the adjoining lanes would not be allowed to change the lanes at that moment through the lane change warnings.

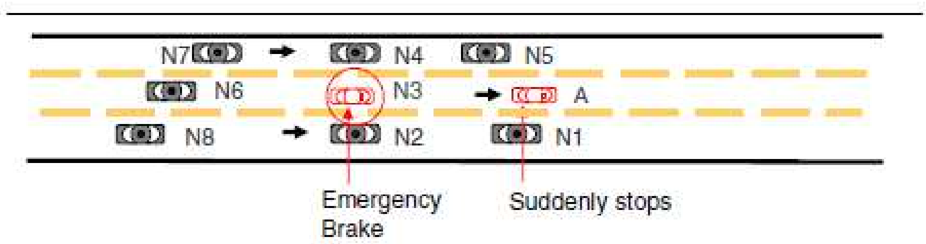


Figure 2.11: Graphical illustration of rear-end collision [24]

2.4.2 Other Novel Techniques

As most of the collision avoidance systems rely heavily on the GPS [6] data for the vehicle's position and movement detection, these systems suffer from the limitations of GPS. This has been well known that GPS signals provide significant less accurate information in bad weather conditions, subways, tunnels and city downtowns, so other novel techniques are being used for vehicle detection in the systems design.

In [27] a new method for detecting front vehicles in urban traffic was proposed. In this method a camera is installed on the front windshield of the vehicle. An IPT matrix which describes the relation between the image coordinate and the real world coordinate under the assumption that vehicles are on flat road was computed. After that vehicle candidates are extracted using AdaBoost [28]. The selected candidates were verified by existence of vertical and horizontal edges for more accurate detection results. The detected vehicle regions were corrected by shadow [29] and edges [30]. In [31] this proposed vehicle detection technique was further enhanced by adding features of rear-lights of vehicles and road characteristics. The accuracy of this technique was proved to be more than 90% when all the features were used together and even proved to be efficient during the rainy days.

In [32] a novel path prediction technique for the remote vehicle was proposed. In this method, every vehicle was equipped with a vehicular ad-hoc network (VANET) router, a GPS system and inertial sensors for measuring the speed, acceleration, and yaw rate. There was an unscented Kalman filter (UKF) [33] [34] [35] present for filtering all these values before they are broadcast to the network. Also, there was a long-range radar (LRR) mounted on the front bumper of the vehicle. Every vehicle transmits its filtered GPS and sensor information to the other vehicle and the receiving vehicle performs the data fusion of the information received from the LRR sensor and the VANET. Then path prediction algorithm based on dynamic motion models for predicting the future path of vehicles was called. Four motion models - Constant Velocity (CV), Constant

Acceleration (CA), Constant Turn Rate (CTR) and, CTRA (CTR + CA) were available. A Dempster-Shafer (DS) reasoning system [36], [37] was developed, with the task of finding the most suitable motion model at every processing cycle. The information sources of this system were the values of yaw rate, acceleration, and the road curvature extracted from the digital maps. According to these inputs, the output of the system will be the most probable motion model at the current processing cycle and its corresponding belief and plausibility values. Figure 2.12 shows the different motion models selected at different vehicular movements using DS reasoning system.

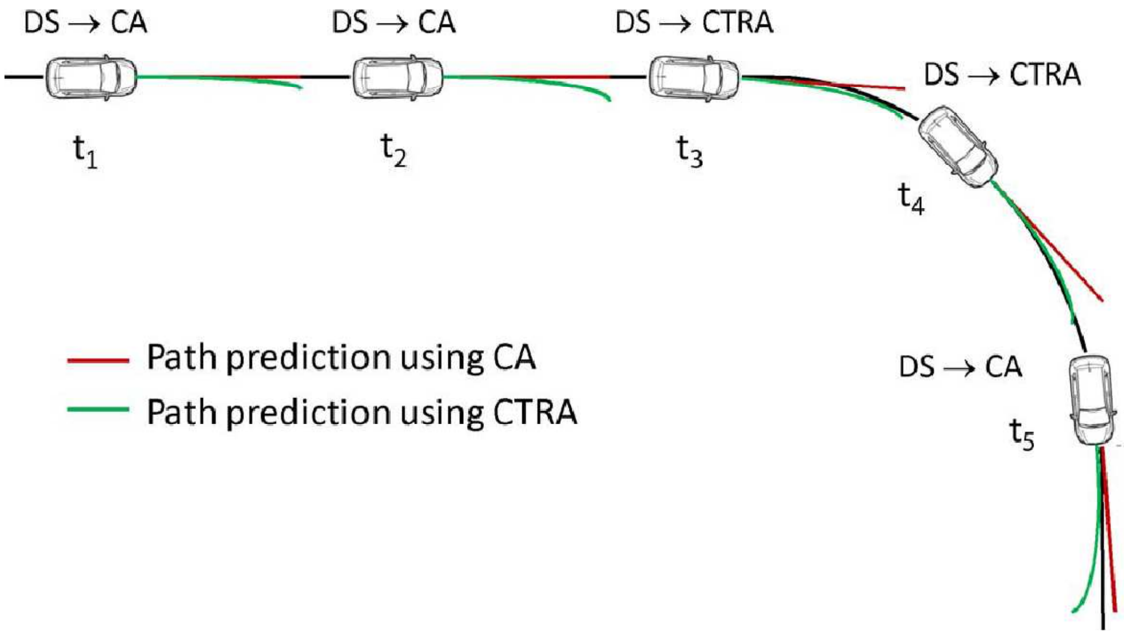


Figure 2.12: Path prediction using DS reasoning system [32]

In this chapter we have discussed the role of ITS for safer and efficient use of transportation networks. The incorporation of various V2V devices into the vehicles can result in avoiding various road accidents thus saving precious lives and money. We have also discussed the CAN protocol and structure of CAN bus network. The passive monitoring CAN bus provides us the access to large number of in-vehicle electronic device's real time data which could be used in various V2V and V2I applications. Finally, we have discussed the various methods and techniques used for avoiding different collision scenarios and also predicting the future vehicular paths.

CHAPTER-3

THESIS OBJECTIVE AND RESEARCH METHODOLOGY

3.1 Introduction

Collision avoidance systems and driver assistance applications have been implemented using different methodologies e.g. V2V communications, sensors data processing, and image processing and depend on input parameters from various different sources e.g. GPS, on-board sensors, long range radars, and cameras. The idea behind using different techniques is to get a system which would have accuracy and reliability in all conditions. More accurate and reliable systems would not only help to avoid many road accidents, thus saving lives and money, but also help to keep the environment clean by burning less fuel. In our research work, we have made an attempt to get a real time and reliable source of information which would not suffer from the limitations of other sources of information discussed in section 2.4.

In this chapter, we present the details of our framework. We present an architecture of a system that enables us to collect various sensor's data present in the vehicle itself. We have developed a software that could reside in the OBUs [5] and communicates with the vehicle's CAN [7] bus. The application was developed on Ubuntu [38] platform using C and C++ as languages. Through this architecture we are able to collect all sensor's data available in the CAN bus which includes speed, rpm, accelerator pedal position, brake status, headlights status, wipers status, left right indicator status, parking lights status etc. Since these parameters are collected in real time from the vehicle's CAN bus, they are proved to be more accurate which would help to increase the efficiency of the collision avoidance systems. In addition, the collection of additional parameters would help to develop or enhance the driver assistance applications like lane changing warning system. Also, these parameters are not affected by any changes in the conditions external to the vehicle.

3.2 Synopsis of Problems and Limitations

We have studied various sources of information used for collision avoidance systems and driver assistance systems like GPS, LRR or front and rear cameras. Since these systems work under real time conditions, they have the requirement of real time data with minimum lag. We have found that all of these sources have their limitations that reduce their usefulness for developing systems reliable in all weather and road conditions. For example, a system based on only GPS data would not be reliable in bad weather conditions, urban downtown areas and tunnels because of the distorted or no GPS signals received in these conditions. In addition the GPS signals have low polling rate of up to 200 milliseconds, which should be improved for real time applications like collision avoidance systems. Similarly, a system based on cameras would suffer from inaccuracies during bad weather conditions and at night. In addition it would incur high maintenance costs. An inaccurate system would either give wrong warnings to the driver or would not give a warning for an impending collision. We have also found that all these sources of information provide limited access to the full set of parameters that can be used for these systems. Various vital vehicular parameters like steering angle, accelerator paddle position, brake status, headlights status, left right indicators etc which could further enhance the performance of these systems are not available from these sources of information.

3.3 Statement of Objectives

The primary objective of our research is to come up with an architecture of a system and a generic application, which would enable us to communicate with the vehicular CAN bus so as to read, decode and analyze the real time data from various vehicular electronic devices/sensors. This would help us to have a reliable and more accurate source of information for various collision avoidance systems and driver assistance systems. We have the goal to provide an alternative to existing sources of information like GPS because of their limitations in different conditions. For example, the parameter vehicular speed is required as an input by all of the collision avoidance algorithms, and is currently taken from GPS data. This parameter's data can be taken directly from the vehicle's CAN bus which would help to remove the lags from speed taken from the GPS signals. Use of CAN bus data also ensures the continuous feeding of the updated information due to the high polling rate of 5-7 ms.

In this thesis research, we propose a generic system, which can be adapted for any vehicle and also would able to act as a common source of vehicular information for any number of driver assistance applications. The proposed system should have the following capabilities:

a) Ability to read and decode various vehicular parameters in real time and to test their accuracy.
b) Ability to test the accuracy of vehicular speed against the speed given by the GPS signals at the same time. An accurate and more frequent source of information

would certainly help to improve the calculation of the TTC [22] by the collision avoidance algorithms.

c) Ability to test the accuracy of brake status and the steering angle, which would be used in the rear end collision warning systems and lane changing warning systems respectively.

d) Ability to read and decode additional parameters like engine rpm, accelerator pedal position, yaw rate, headlights, wipers status, engine ambient temperature and engine pressure which are currently not being used as inputs in the collision avoidance algorithms and driver assistance applications due to their non-availability. The availability of these new parameters would help to improve the accuracy of the current systems and also would lead to the development of various other applications.

3.4 Research Methodology

The flow diagram of the architecture of our research methodology is depicted in figure 3.1. In our research, we have developed an application software named 'CAN-Ethernet' which resides in an OBU and makes a TCP [39] [40] connection with an Ethernet dongle that is connected to the CAN bus of the vehicle. The application software is designed to send specific commands to the Ethernet dongle, which are interpreted to the CAN specific format and used to requests raw data from the CAN bus. After receiving a legitimate command, electronic devices connected to the CAN bus respond by sending the requested data. The Ethernet dongle passes the received data to the CAN-Ethernet application software which is waiting for the response. After receiving the raw data, application analyzes the received raw data at bit level, and decodes it to a human readable form. The decoded data is then made available for collision avoidance algorithms and other applications residing in the same OBU. Also, it is made available to be transmitted to the other vehicles in the form of BSMs using DSRC antennas.

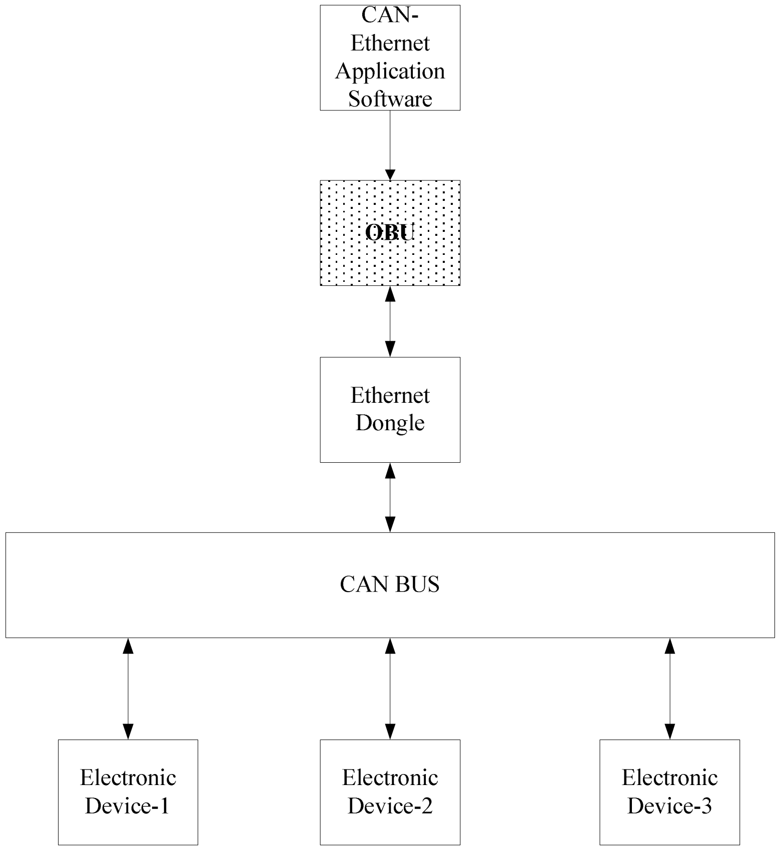


Figure 3.1: System Architecture Flow Diagram

The data read from the CAN bus is huge in volume, with a maximum data rate up to 320 KB/sec, and a maximum latency of $< 120\ \mu s$ for high priority messages. Since a huge volume of data is available in the CAN bus, the CAN-Ethernet application software was designed to read, analyze, decode and store the data in parallel so as not to get crashed while running.

3.4.1 Architecture of the System

The architecture of our system is generic and is applicable for any modern vehicle which has its electronic devices connected to the CAN bus. A vehicle is fitted with the GPS antenna to receive the GPS signals for longitude, latitude, heading etc information. This GPS antenna is connected with an OBU which is responsible for the all the calculations from the raw data, transmission and receiving of DSRC packets. The OBU is also connected to the Ethernet dongle with a CAT 5e cable [41]. Our CAN-Ethernet application software makes a TCP connection with the Ethernet dongle using this cable. The Ethernet dongle is connected to the CAN bus using CAN to OBD-II cable and helps to communicate with the CAN bus to collect the vital real time vehicular parameter's data like speed, steering angle, brake status etc.

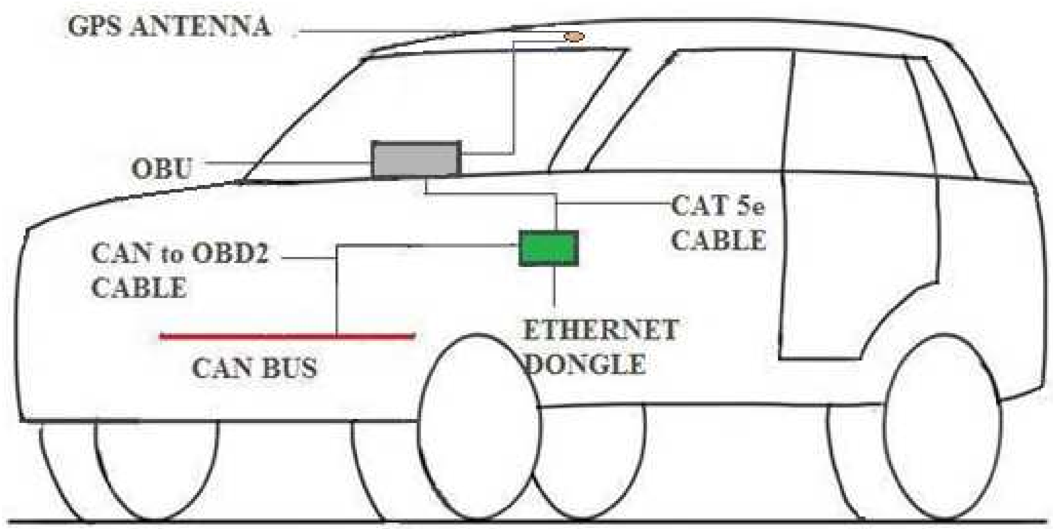


Figure 3.2: System Architecture

In figure 3.2 the architecture of the system is shown, which incorporates:

- **CAN Bus:** The vehicular bus to which all the electronic devices of a vehicle are connected to communicate with each other as discussed in section 2.3.

- **Ethernet dongle:** We have used an Ethernet dongle similar to the one discussed in section 2.3.2. The dongle has dimensions of 74 mm x 80 mm and operates on a 5V DC power supply. It has one Ethernet port to connect with a LAN cable and one RS232 port to make a serial connection. It has one CAN port to connect with the vehicle's CAN bus using CAN to OBD-II cable.
- **CAN to OBD-II Cable:** The cable as shown figure 3.4 is used to provide CAN signals from the vehicle to the CAN dongle. It has a 16-pin OBD-II male connector and a 9-pin D-Sub socket female in accordance with CiA 102 [16].

Figure 3.3: CAN to OBD-II Cable

- **OBU:** We have used an OBU shown in figure 3.5 named LocoMate, marketed by Arada Systems, Windsor. This device is integrated with GPS, Bluetooth, and high power 802.11p radios.

Figure 3.4: OBU (LocoMate), Arada Systems, Windsor [42]

- **CAT 5e Cable:** Cat 5e cable has four twisted pairs in a single cable jacket. It's an unshielded twisted cable pair designed specifically for high signal integrity. It is commonly used for 100Mbit/s networks, but with IEEE 802.3ab defined standards can also support 1000BASE-T – gigabit Ethernet [41].
- **GPS Antenna:** The GPS antenna we have used shown in figure 3.7 draws about 10 mA and gives an additional 28 dB of gain. It is magnetic so it sticks to the top of vehicle.

Figure 3.5: GPS Antenna [43]

The communication with CAN bus through Ethernet port of our dongle is shown in figure 3.8. The dongle we used, also supports RS232 line to make a serial connection with the CAN bus. However, the communication path we followed in our CAN-Ethernet application software is through Ethernet port which is highlighted in Gray and dotted boxes. The TCP connection is initialized using the IP address of the dongle, which is provided through our CAN-Ethernet application software. After the connection is successfully established, a formatted command packet for requesting the CAN data is sent to the CAN-Ethernet, which is interpreted by the Command Interpreter. The Command Interpreter validates the received packet, extracts the required data bytes and sends it to Protocol Converter. The Protocol Converter converts the received bytes to the CAN protocol format and sends it to the CAN bus through CAN S/W and CAN H/W data buffers. The CAN bus responds to the sent command with the sensor's raw data, which are read by the Protocol Converter. The Protocol Converter converts the received bytes to the dongle's packet format and sends it to the Command Interpreter through the RS232 data buffer. The Command Interpreter adds the identifying bytes to the packet and sends it to the CAN Ethernet. Our CAN-Ethernet application software which was continuously waiting for the response packets, reads, validates and then decodes the received packets.

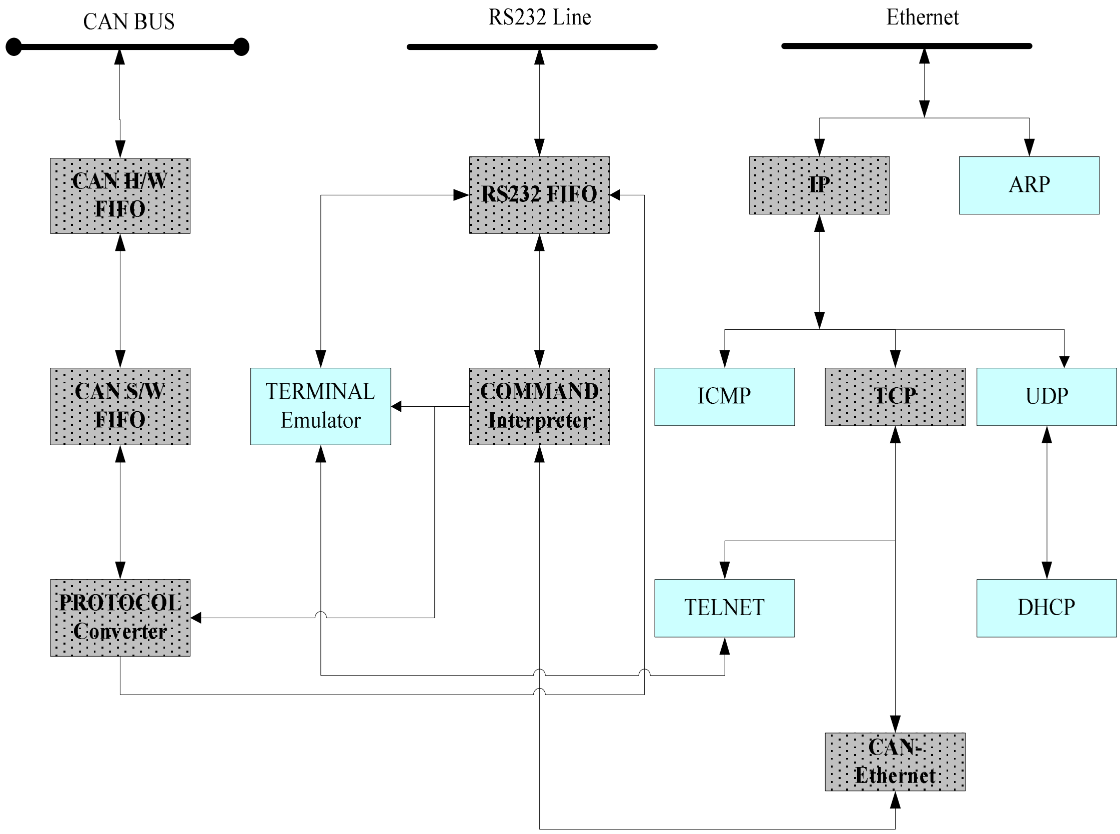


Figure 3.6: CAN-Ethernet Gateway Flow Diagram

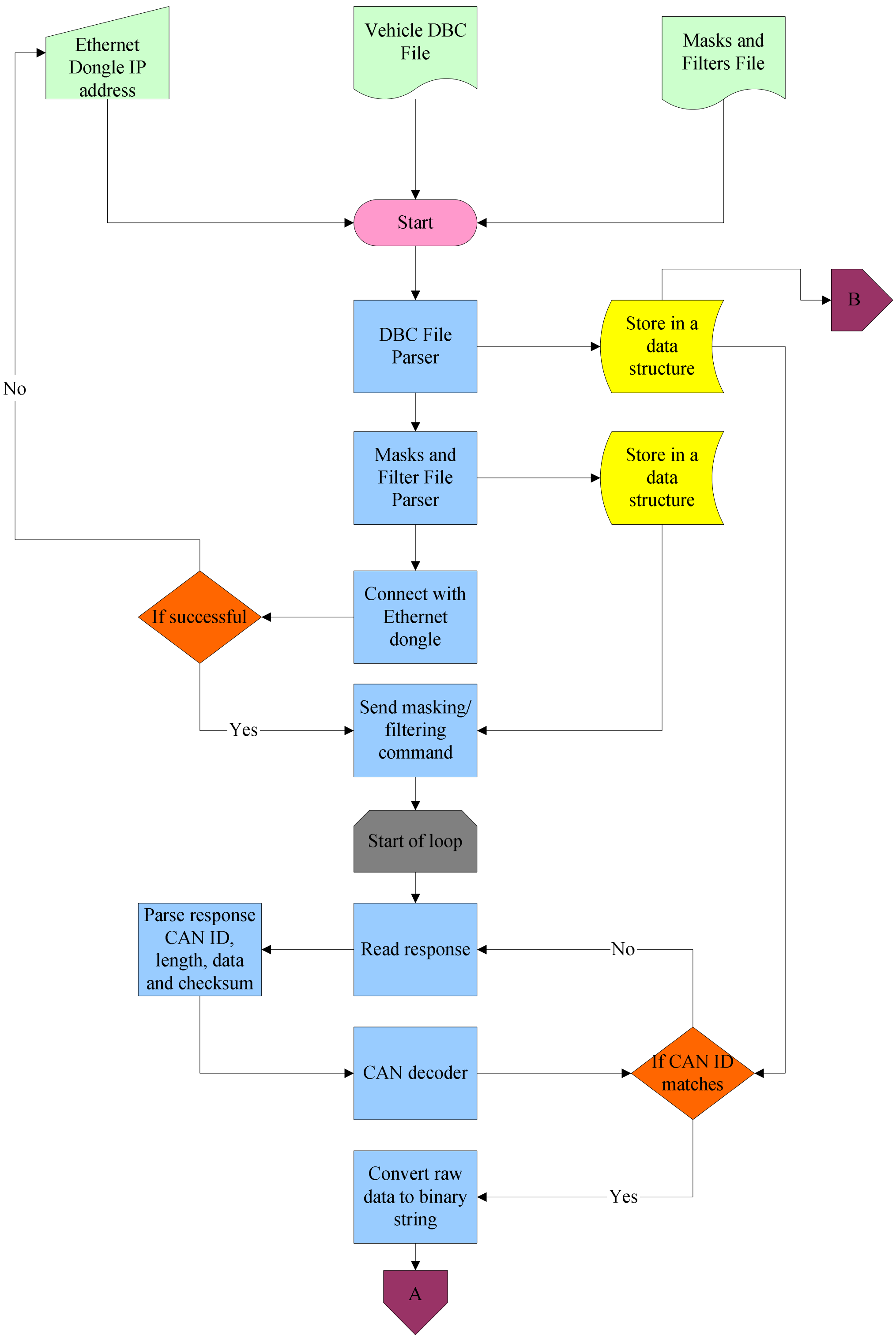
3.4.2 Software Architecture

CAN-Ethernet application software is developed in C /C++ language on Ubuntu platform. The application takes three inputs as arguments: IP address of the dongle, vehicle's CAN DBC file [44] and Masks and Filters file. The DBC file, which is a proprietary format of Vector Informatik GmbH [44], is unique for every vehicle model. A DBC file contains all electronic devices data decoding information including the CAN ID assigned to those devices at the time of manufacturing, for a particular vehicle. In figure 3.9, a screenshot of CAN DBC file is shown, which gives the information about the CAN ID and expected length of data frame for a vehicular sensor in the line starting with 'BO_'. The following lines starting with 'SG_' gives the information about all the signals expected in the received data frame. The information includes Start bit, Length, Byte order (Endianness), Value type (Signed or Unsigned), Scale, Offset, Range (minimum and maximum value) and Units.

```
BO_ 520 Braking: 8 Vector__XXX
 SG_ ABS_BrkEvt : 6|1@1+ (1,0) [0|1] "" Vector__XXX
 SG_ FullBrk_Actv1 : 7|1@0+ (1,0) [0|0] "" Vector__XXX
 SG_ BRK_ACTIVE : 23|1@1+ (1,0) [0|1] "" Vector__XXX

BO_ 533 VEH_SPEED: 7 Vector__XXX
 SG_ VEH_SPEED : 7|16@0+ (0.0078125,0) [0|511] "km/h" Vector__XXX
 SG_ ABS_PRSNT : 50|1@0+ (1,0) [0|0] "" Vector__XXX
 SG_ ESP_PRSNT : 51|1@0+ (1,0) [0|0] "" Vector__XXX
 SG_ ESP_AVL : 55|1@0+ (1,0) [0|0] "" Vector__XXX

BO_ 566 Steering: 8 Vector__XXX
 SG_ SteeringWheel_Angle : 5|14@0+ (0.5,-2048) [-2048|2047] "Degrees" Vector__XXX

BO_ 584 Wipers_Doors: 8 Vector__XXX
 SG_ PARK_BRK_EGD : 27|1@0+ (1,0) [0|0] "" Vector__XXX
 SG_ FrontWiperInUse : 26|1@0+ (1,0) [0|0] "" Vector__XXX
```

Figure 3.7: Screenshot of CAN DBC file [44]

In CAN-Ethernet application software, we parse DBC file information and store it in a data structure to be able to use it for decoding purposes. We also parse the third argument of our application which is Masks and Filters file. The masking and filtering information gives us the capability to request CAN data from only specific vehicle sensors. For example, using masking and filtering we could request the data from only 'Vehicle Speed' sensor by setting it to CAN ID = 533. The default mask and filter is set to value of '0' to get data from all the vehicle sensors. In figure 3.10 the complete flow diagram of our CAN-Ethernet application software is shown.


Ethernet Dongle IP address
Vehicle DBC File
Masks and Filters File
Start
DBC File Parser
Store in a data structure
B
No
Masks and Filter File Parser
Store in a data structure
If successful
Connect with Ethernet dongle
Yes
Send masking/ filtering command
Start of loop
Parse response CAN ID, length, data and checksum
Read response
No
CAN decoder
If CAN ID matches
Convert raw data to binary string
Yes
A

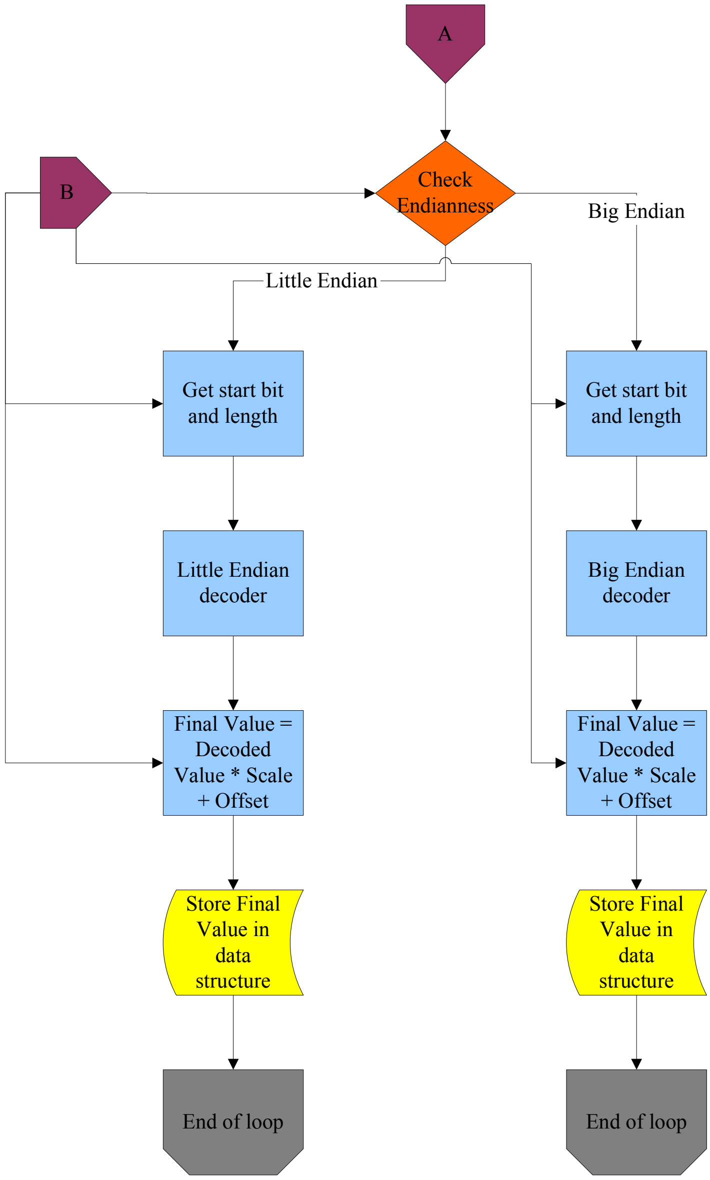


Figure 3.8: Software Architecture Flow Diagram

The final decoded value of the vehicle's sensors is stored in a data structure which is continuously updated with the new values. This application runs as a server in the OBU and accepts client connections from the other applications requiring CAN information. Upon receiving a request our application dumps whole data structure to the client. This way, it is able to provide real time CAN information to collision avoidance applications and other driver assistance applications running in the same OBU. In figure 3.11 and figure 3.12, a screenshot of raw data capture and a sensor's decoded values is shown respectively.

```
Response: 08 03 00 00 00 02 74 02 01 82 ff ff
Response: a0 04 00 00 21 de 16 0b 23 06 00 40
Response: 08 03 00 00 00 02 74 42 00 82 ff ff
Response: 15 02 00 00 00 00 29 64 2a 1d 00
Response: 08 03 00 00 00 02 74 42 00 82 ff ff
Response: 08 03 00 00 00 02 76 42 01 82 ff ff
Response: 15 02 00 00 00 00 29 64 2a 1d 00
Response: ff 03 00 00 00 00 2d 2a 00 00
Response: 08 03 00 00 00 02 76 42 01 82 ff ff
Response: 08 03 00 00 00 02 76 02 00 82 ff ff
Response: 15 02 00 00 00 00 29 64 2a 1d 03
Response: 08 03 00 00 00 02 76 02 00 82 ff ff
Response: 08 03 00 00 00 02 76 42 01 82 ff ff
Response: 15 02 00 00 00 00 29 64 2a 1d 03
Response: 08 03 00 00 00 02 76 42 01 82 ff ff
Response: ff 03 00 00 00 00 2d 2a 00 00
Response: 08 04 00 00 ff 00 4f 00 fe 0f f0 00
Response: 08 03 00 00 00 02 76 02 00 82 ff ff
```

Figure 3.9: Screenshot of Raw data

```
11:12:43:710    VEH_SPEED: 32.468750
11:12:43:710    ABS_PRSNT: 0.000000
11:12:43:710    ESP_PRSNT: 0.000000
11:12:43:710    ESP_AVL: 0.000000
11:12:43:713    EngineSpeed: 902.000000
11:12:43:714    SteeringWheel_Angle: -3.000000
11:12:43:720    FullBrk_Actv: 0.000000
11:12:43:720    BrkEnbl_LCM: 0.000000
11:12:43:721    BRK_ACT_LCM: 0.000000
11:12:43:721    YawRate: 0.519989
11:12:43:721    REF_VEH_SPEED: 511.500000
11:12:43:721    LAT_ACCEL: 0.160000
11:12:43:721    TSC_SUPP: 0.000000
11:12:43:721    TSC_EN: 0.000000
11:12:43:721    ESP_PD_SUPP: 0.000000
11:12:43:721    ESP_PD_EN: 0.000000
11:12:43:721    EngineSpeed: 898.000000
11:12:43:724    SteeringWheel_Angle: -3.000000
11:12:43:724    PARK_BRK_EGD: 0.000000
11:12:43:725    FrontWiperInUse: 0.000000
11:12:43:725    BrakeSwitch: 1.000000
11:12:43:725    BATT_VOLT: 14.900001
11:12:43:725    Odometer: 64318.601562
11:12:43:730    ESP_Disabled: 0.000000
11:12:43:730    PrkBrake_Indicator: 0.000000
```

Figure 3.10: Screenshot of Sensor's Decoded Values

3.4.3 Software UML Class Structure

The CAN-Ethernet application software is designed using object oriented approach and the feature of running the application software as a server is added using a separate thread, thus making it a multi-threaded system. There are eight core classes designed in the software architecture with additional interface specific classes as required. The UML class diagram in figure 3.13 shows the object architecture of the CAN-Ethernet application software.

1) **can_main class:** The can_main is the main class of the software. It is responsible for the following activities:
    - Validating the three input parameters i.e Ethernet dongle's IP address, vehicle specific DBC file and Filters file.
    - Initializing the log file based on the current date and timestamp.
    - Parsing the Filters file and storing the values in a data structure.
    - Initializing the thread of can_server class.
    - Initializing the dbc_parser class to parse the input dbc file.
    - Initializing the can_utils class.

    First the software initializes the can_main class and validates the three required input parameters. After validating, it checks for the existence of the log file with the current date and timestamp and creates a new file otherwise. It opens the Filters file provided as the argument and parses its contents to store in a data structure present in support_functions. It creates a new thread for can_server class which runs continuously in a separate thread. It opens an instant of dbc_parser class passes the DBC file provided as argument to it for parsing. It passes the IP address of the dongle which is also provided as argument to the can_utils class instance.

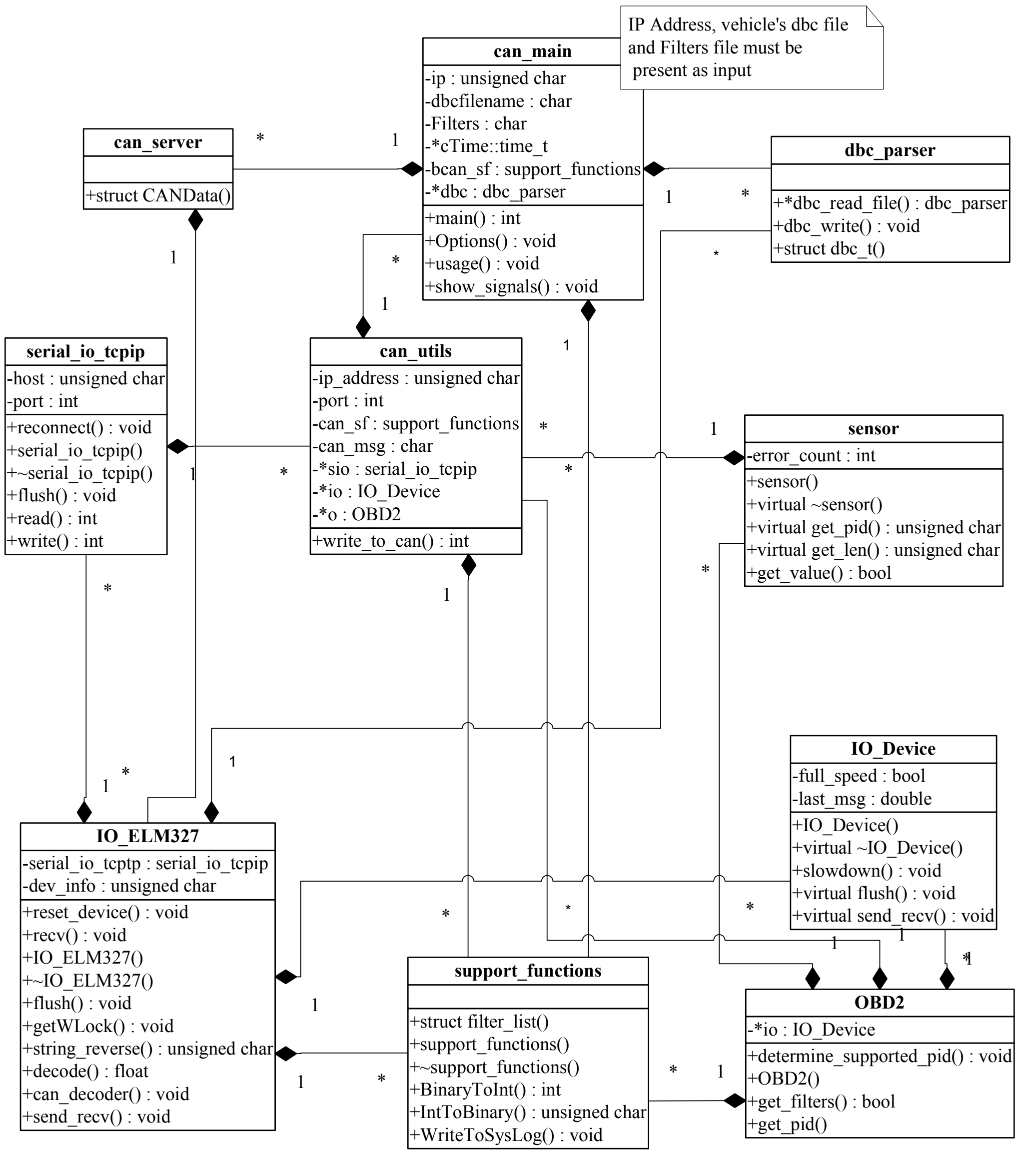


Figure 3.11: CAN-Ethernet Application Software UML Class Diagram

2) **can_server class:** The can_server class is designed to include the capability of behaving as server while running. The CAN-Ethernet application can currently handle up to five client connections simultaneously with capability of more with some modifications. The main roles and activities of this class are as follows:

- Maintaining a data structure named CANData, with the current updated decoded values of all the vehicular sensors provided in the dbc file.
- Creating a connection queue and initializing the read file descriptors to handle the input from the clients.
- Waiting for the client request and responds by dumping the pointer of the whole data structure CANData to the client.

3) **dbc_parser class:** The main purpose of designing dbc_parser class is to get the useful information present in the dbc file, which is required for decoding the raw values read from the vehicle's CAN bus. Following are the main activities of this class:

- Reading the input dbc file and validates its authenticity.
- Maintaining a data structures for storing the CAN id, sensor name and expected length of the data field from the CAN bus.
- Maintaining a data structure for storing the signal information in a CAN id i.e. signal name, start bit, length, byte order (Endianness), value type (Signed or Unsigned), scale, offset, range (minimum and maximum value) and units.
- Printing the parsed dbc file information.

4) **can_utils class:** The can_utils class is designed to handle the initialization of creating the connection to the Ethernet dongle and initializing the instances of the IO_Device class and OBD2 class. The roles performed by this class are as follows:

- Responsible for sending the IP address and port number to the serial_io_tcpip class for creating a TCP connection with the Ethernet dongle interface.
- Creating an instance of the IO_Device class and then creating new session of the IO_ELM327 using this instance since IO_Device class was inherited by the IO_ELM327 class.
- Initializing an instance of OBD2 class and calling sensors class operations using this instance.

5) **serial_io_tcpip class:** The serial_io_tcpip class is designed to handle all the communication with the CAN-Ethernet dongle. The main functions of this class are as follows:

- Responsible for creating a connection with the Ethernet dongle and maintaining the created file descriptor and also, trying for reconnection if connection is not established successfully until time out.
- Writing the command packet to the TCP session using the created file descriptor which is required to be sent to the CAN bus.
- Reading the raw data from the TCP session using the created file descriptor from the CAN bus.

6) **OBD2 class:** The OBD2 class is designed to handle the formatting of the command packet required to be sent to the CAN bus. The Ethernet dongle, we used, has an interface in it, which accepts command packet in a specific format. It includes a static PID, length, mask0, mask1, filter0, filter1, filter2, filter3, filter4, filter5 and checksum. For example, to send a packet to the CAN bus so as to listen everything over it, we have to format the packet as 0x85, 0x08, 0x00000000, 0x00000000, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x8D. The PID was set by the manufacturer of this Ethernet dongle so it shouldn't be changed while the other fields of the packet can be changed according to the requirements.

7) **IO_ELM327 class:** This class handles bulk of the work of the CAN-Ethernet application software. The member functions of this class communicate with the serial_io_tcpip class member functions to send and receive data byte by byte. Apart from this, it handles analyzing, decoding and recording of the data read from the CAN bus. The roles and responsibilities of this class are as follows:

    - Reading the formatted packet created in the OBD2 class and writing it to the CAN bus through serial_io_tcpip class.
    - Waiting for the response from the CAN bus and then reading the response byte by byte.
    - Analyzing the each byte read and differentiating it based on the specified response format.
    - Decoding the data bytes based on the information read from the data structures maintained by the dbc_parser.

- Populating the CANData data structure maintained by the can_server with the decoded vales of the sensor parameters.
- Recording the decoded values in the created log files.

After writing the command packet on the TCP session, the recv() member function of the class waits for the CAN bus response. Since, the Ethernet dongle formatted the response packet before sending it over the TCP session, so the response packet is expected in a definite format. The first byte is always the response PID which was set by manufacturer to 0x85. The next byte expected is length of the data bytes, then the data bytes and in the end checksum byte. After verifying the checksum, the data bytes are separated from the received packet. In the data bytes, the first four bytes give the CAN id, which are decoded and matched with the CAN ids parsed from the dbc file. If a match is found, the byte order of the signals contained in the data bytes is determined. Two algorithms, one for decoding based on big endian byte order (Motorola) [51] shown in Appendix A and other for little endian byte order (Intel) [51] shown in Appendix B, are designed to decode the data bytes using the start bit and length information from parsed dbc file. Final value of the raw data is then calculated by applying the scale and offset information to the decoded value. These final calculated values are populated in the CANData data structure and logged into the log file. The CANData data structure always holds the latest values of the sensor parameters as the old values are continuously replaced with the new values.

8) **support_functions class:** The support_functions class contains common functions that are used throughout the entire system. Specific functions that are

commonly used by all objects (for example, BinaryToInt, IntToBinary, WriteToSysLog etc…) are defined in here. Objects that wish to use the common function definitions simply just instantiate a support_fucntions object and use its capabilities.

In this chapter we have discussed the detailed architecture of the system we have used, describing the physical linking of the various modules of the system. We have shown and explained the various physical equipments we have used in our research work. We have also demonstrated the internal communication functionality of the Ethernet dongle, we have used. We have thoroughly explained the CAN-Ethernet application software we have developed. We have shown the detailed steps that we had taken to build this software to be generic and applicable for any vehicle. Finally, we have explained the algorithms we have designed to decode the raw data from the vehicle's CAN bus and populate it in the data structure to be used by collision avoidance algorithms and driver assistance applications by making client-server connections.

CHAPTER-4

RESULTS AND ANALYSIS

In this chapter, we discuss about our test setup, comparison of the results and analysis of the data from various vehicular sensors.

4.1 Test Setup

We have done the testing of our software with the cooperation of Arada Systems, Windsor [42]. We got the access to a testing vehicle, provided by the US Department of Transportation for testing V2V and V2I related applications, through Arada Systems. The vehicle we used for our testing is Jeep Grand Cherokee (Year: 2007) and Arada Systems also helped us to obtain the dbc file of this vehicle model. We have used the Arada Systems' OBU (Locomate) as discussed in section 3.4.1, for installing and running our software application CAN-Ethernet. This OBU is fixed in the provided vehicle and connected to the Ethernet dongle, which is connected to the OBD-II port of the vehicle's CAN bus. The OBU is also connected to a GPS antenna and has the built-in capability of recording and processing the GPS signals. We have made the adjustments in our software application, so as to bring the capability of recording the CAN data and GPS data together into the data log files we are maintaining. We have driven the test vehicle at various different locations and times to record the CAN and GPS data together. We have covered parking lots, downtown areas and highways while testing, to check the behaviour of GPS signals at different locations and different speeds. To do the comparisons between GPS and CAN data, we parsed the fields collected in the log files into a worksheet through a custom script program written in Python [45].

4.2 Comparison of CAN Speed and GPS Speed

In this section, we have compared the CAN speed against GPS speed at different locations and the results show that there may be a significant discrepancy between the actual vehicle speed (based on CAN data) and the speed calculated from GPS signals. In the remainder of this chapter, we will refer to the speed based on CAN data as *CAN speed* and that calculated from GPS signals as *GPS speed*. We have found that the error in *GPS speed* increases during the events of braking or acceleration of the vehicle.

4.2.1 Test Results at a Parking Lot

The first test we conducted was at a parking lot in Troy, USA. This test was done on a clear sunny day, so we expected comparatively less interference from atmospheric conditions on GPS signals. In figure 4.1, the *CAN speed* and the *GPS speed* are plotted together on the left y-axis, with total number of records on the x-axis. We have found that there is a visible deviation of the *GPS speed* as compared to the more accurate *CAN speed*. Also, the deviation is much higher when the vehicle is either accelerating or braking as compare to when running at a constant speed. Due to the fact that the polling rate for *CAN speed* is much higher as compare to the *GPS speed*, the GPS receivers take some extra time to recognize the frequent changes in the speed.

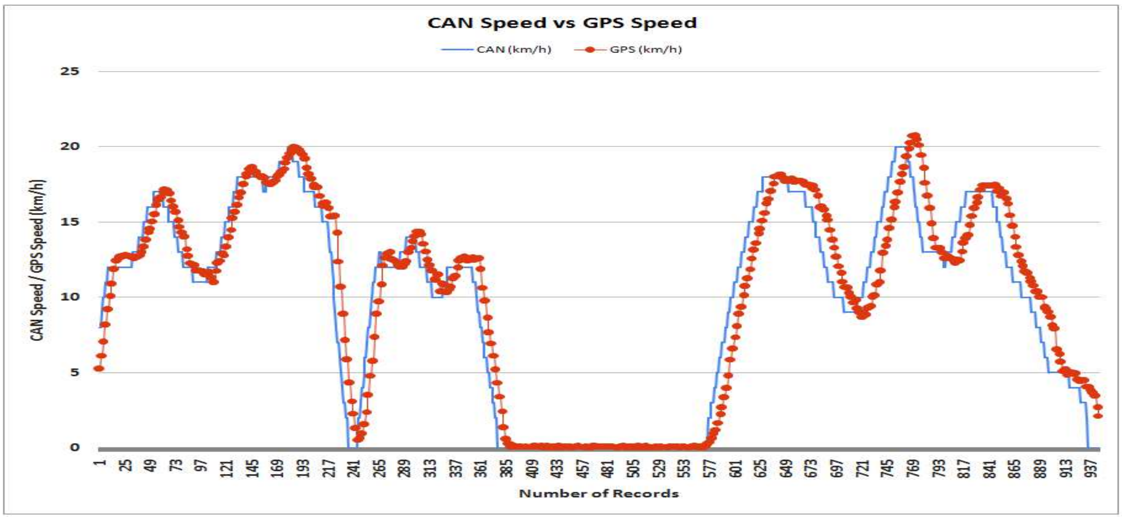


Figure 4.1: Comparison CAN Speed and GPS Speed at a Parking Lot

We calculated the *GPS error* in speed by subtracting *GPS speed* from *CAN speed* at a given time and then plotted the calculated *GPS error* against the *CAN speed* as shown in figure 4.2. The *CAN speed* and *GPS error* are plotted on the left y-axis and right y-axis respectively, with total number of records on the x-axis. Left and right y-axis is used to clearly plot the negative values of the *GPS error*. We found that the *GPS error* has reached up to -7 km/h when the vehicle was braking and coming to stop from a speed of 20km/h. On other instances, the *GPS error* ranges from -5 km/h to 5 km/h on certain changes in speed at different times.

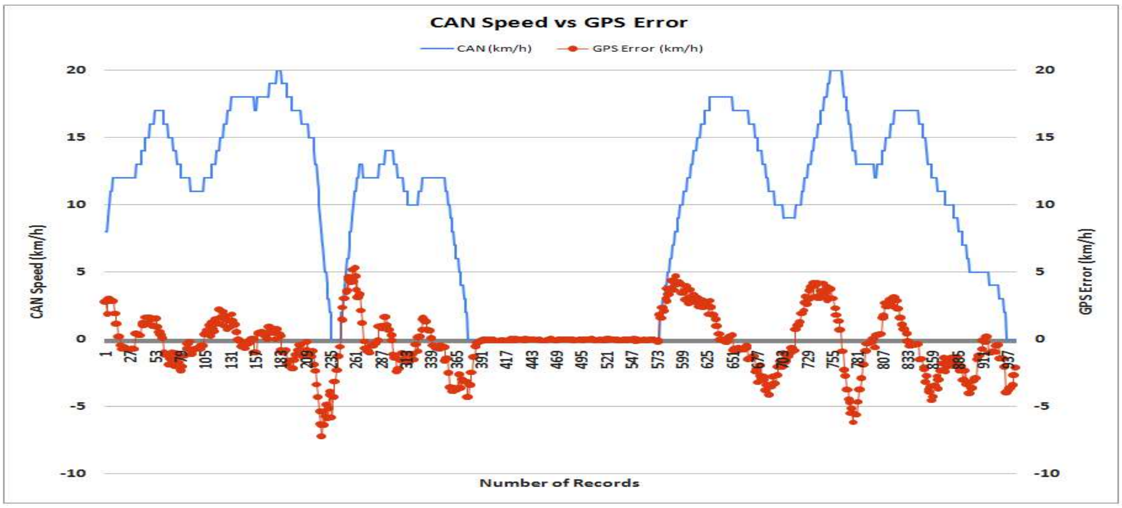


Figure 4.2: Comparison of CAN Speed and GPS Error at a Parking Lot

4.3.2 Test Results at a City Road

The second test was conducted at Stephenson Highway, Troy, USA. This test was conducted on a day with overcast conditions and we have found similar trends in the deviation of the *GPS speed* from the *CAN speed*. The *CAN speed* and *GPS speed* are plotted on the left y-axis and right y-axis respectively, with total number of records on the x-axis. In figure 4.3, it can be seen that *CAN speed* curve is more consistent and visibly moves away from *GPS speed* curve during acceleration or braking events. The two curves minimize their gap during constant speed of the vehicle.

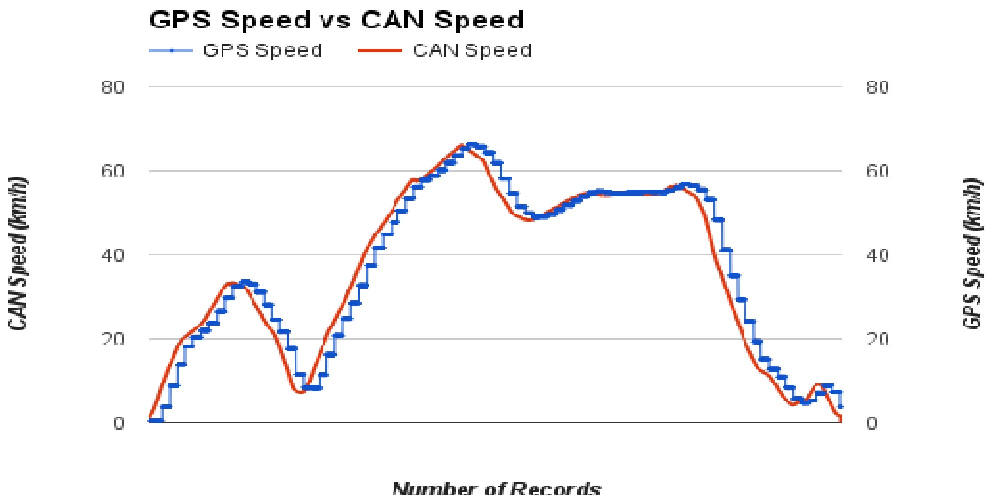


Figure 4.3: Comparison CAN Speed and GPS Speed at a City Road

In figure 4.4, the calculated *GPS error* is plotted against *CAN speed* and we have found that when the vehicle speed drops from around 60 km/h to 5 km/h, the *GPS error* reaches to -14 km/h. Similarly, *GPS error* reaches close to 8 km/h, when vehicle accelerates from 10 km/h to 65 km/h. We have also found that, some magnitude of the *GPS error* is always present even when the vehicle runs at constant speed.

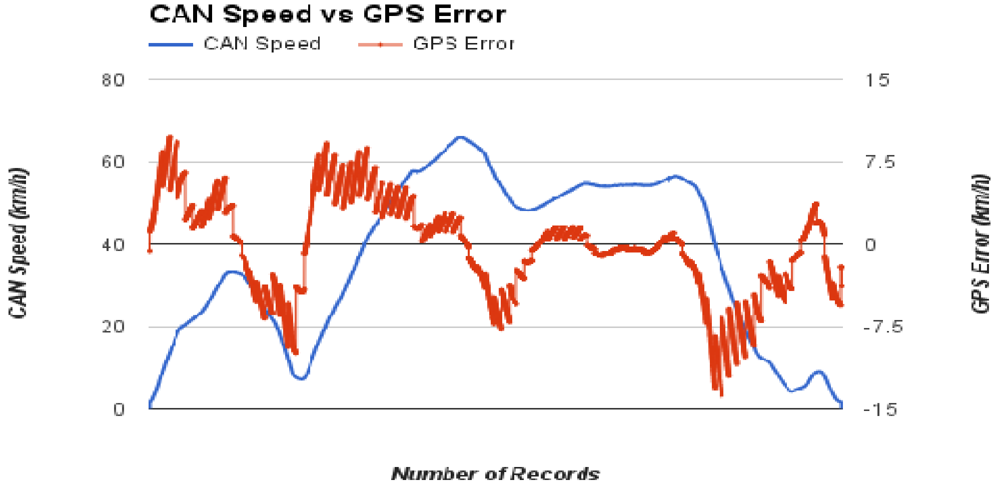


Figure 4.4: Comparison of CAN Speed and GPS Error at a City Road

4.3.3 Test Results on a Highway

The third test was conducted at I-75 from Troy to Detroit, USA, on a day with overcast conditions. In figure 4.5, we plotted the *GPS speed* and *CAN speed*, recorded during the test journey. We have found the two curves almost merge with each other, when the vehicle was going at around 100 km/h but some deviation is seen when the speed is lowered.

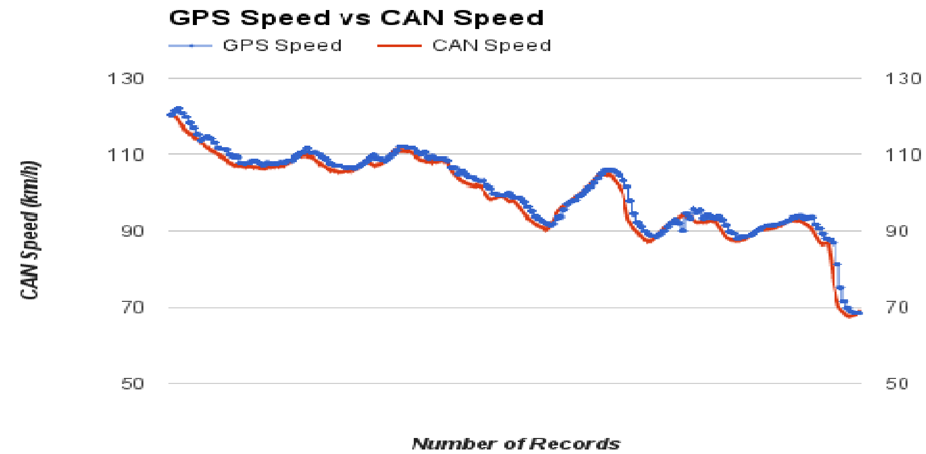


Figure 4.5: Comparison CAN Speed and GPS Speed on a Highway

In figure 4.6, the calculated *GPS error* is plotted against the *CAN speed*. We have seen that the *GPS error* is between 0 to -5 km/h when the vehicle was going at around 110 km/h. The *GPS error* reaches to maximum of -12 km/h when the speed is lowered from around 95km/h to 70 km/h.

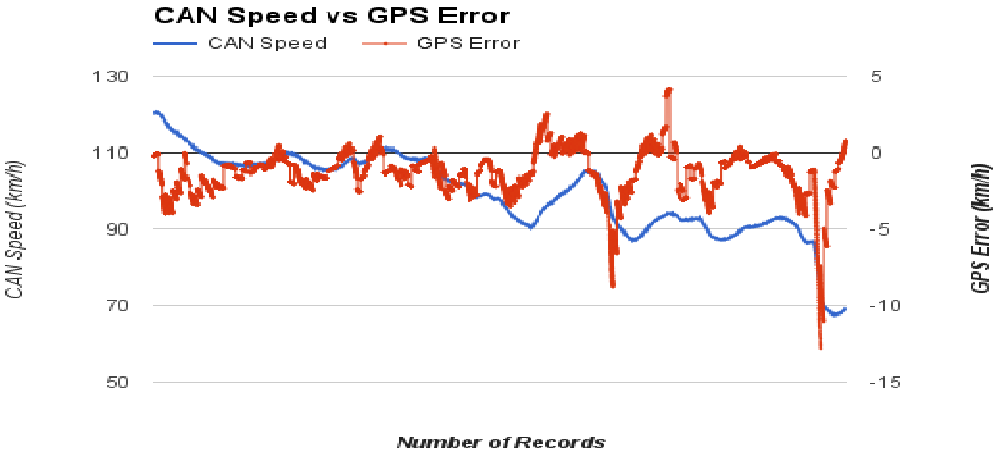


Figure 4.6: Comparison of CAN Speed and GPS Error on a Highway

4.3.4 Test Results at Downtown

The fourth test was conducted in downtown locations at Detroit, USA. In figure 4.7, we have plotted the *GPS speed* and *CAN speed* recorded from the test. We have found that there is a constant deviation of the *GPS speed* curve from the *CAN speed* curve. Also, while testing we have found that the GPS signals were not consistent due to the multipath problem [46] of these signals.

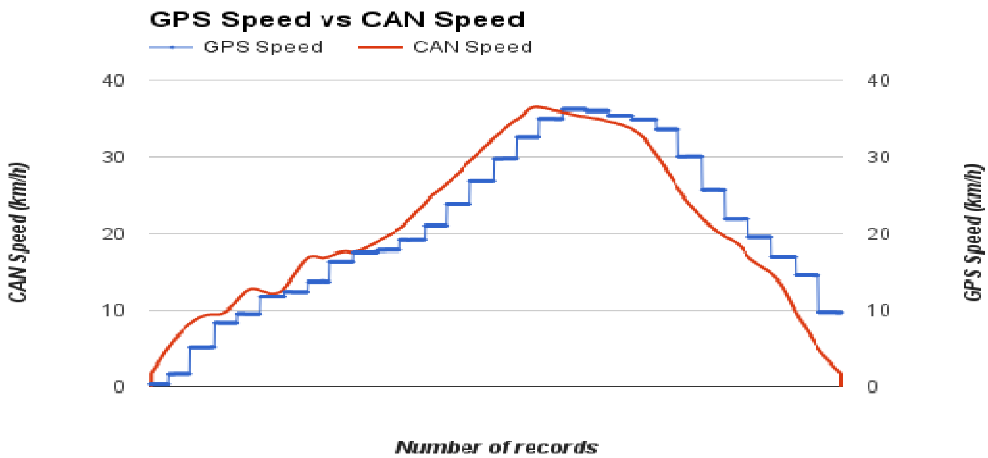


Figure 4.7: Comparison CAN Speed and GPS Speed at Downtown

In figure 4.8, the calculated *GPS error* is plotted against *CAN speed* and we have found a constant error of around +5 km/h when the vehicle was accelerating from 0 km/h to 35 km/h. The *GPS error* reaches to maximum of -10 km/h during the braking event of the vehicle, when the speed came down from 35 km/h to 0 km/h.

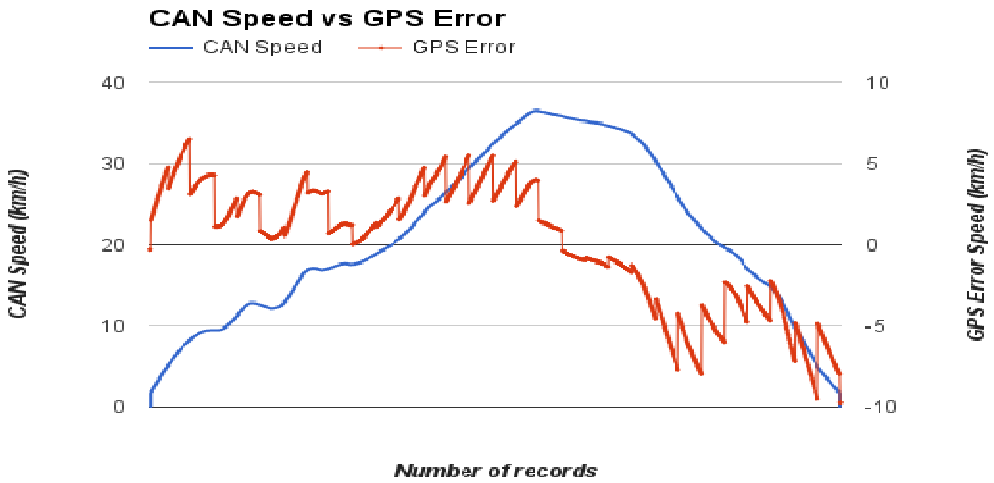


Figure 4.8: Comparison of CAN Speed and GPS Error at Downtown

4.3 Other Vehicular Sensor's Data

We were also successfully able to get data from various other vehicular sensors like Engine RPM, Accelerator pedal position, Steering Angle, Brake Status, Headlights Status, Wipers Status and Yaw rate. All these parameters can play a very vital role for the future collision avoidance algorithms and driver assistance applications. As the data from these sensors is collected in real time from the vehicle's CAN bus, the accuracy of the algorithms and applications will increase and, will result in fewer delays. For example, the current Emergency Electronic Brake Light (EEBL) applications rely on either decrease in the front vehicular speed or image processing of the front cameras, to recognize the front vehicle's braking. But with data available from the CAN bus, the braking information of the front vehicle can be directly transmitted to the rear vehicle, that will improve the reaction time of the driver in the rear vehicle and will help to avoid more collisions. Also, the brake status of the front vehicle can be sent directly to multiple vehicles through multi-hop communication, thus helping to avoid incidents like highway chain collisions.

In this chapter we have discussed the comparisons of CAN speed and GPS speed recorded simultaneously during different test drives. We have shown that there is always some difference between the speed recorded from GPS signals and the speed calculated from the CAN data. The difference is seen much more prominent and reaches near to 15 km/h on certain occasions of vehicle's acceleration or braking. We have also found that the speed calculated from CAN data is more consistent due to the high polling rate of data from the CAN bus which helps to record even the slight changes in the speed. In addition, we have also discussed about the number of other vital parameters we calculated that can help in improving existing collision avoidance algorithms and in developing new applications.

CHAPTER-5

CONCLUSION & FUTURE WORK

5.1 Conclusion

Due to the increase in the number of the vehicular collisions and loss of lives and property, a lot of work is being carried out towards the development of the collision avoidance and driver assistance applications. Researchers from all around the world are working to develop new techniques and systems, which could improve the existing algorithms and applications to provide a stable system to the vehicle manufacturers. In this thesis, we have developed a CAN-Ethernet application software, which will help to provide a better alternative to existing sources of vehicular information like GPS. We have shown that the vehicular speed calculated from data read from the CAN bus by our CAN-Ethernet application is more accurate and consistent as compare to the speed taken from the GPS signals. This is due to the higher polling rate of data available from the CAN bus and also due to directly accessing the vehicle's speed sensor to obtain the relevant data. We have shown that the errors in the speed given by the GPS signals are higher during the events of the vehicle's acceleration and braking. The improvement in the calculation of the vehicular speed, which is a vital input parameter in the collision avoidance algorithms, will certainly improve the calculation of the TTC [22]. As we know that most of the collisions occur either during hard braking of the vehicles or during sudden accelerations, a more accurate and consistent knowledge of the vehicle's speed and, in turn, more accurately calculated TTC will help to generate timely warnings to the drivers and thereby help to improve their reaction times.

In addition, we are also able to calculate information of various other vital parameters from the vehicle's CAN bus like braking status, steering angle, engine RPM, accelerator pedal positions, yaw rate, headlights status, wipers status, engine ambient temperature, engine pressure etc. The real time information of all these parameters will certainly help to improve and develop various collision algorithms and drivers assistance applications.

5.2 Future Work

In our thesis work, we are able to extract information of various electronic sensors attached to the CAN bus. The information of some of the parameters was not available before, so they were not used in the collision algorithms and driver assistance applications. An important direction for future work would be to develop new collision avoidance algorithms which utilize these additional parameters' information. Another work can be to get access to more CAN IDs of the vehicular sensors and to calculate and use the additional information.

REFERENCES

1. Official Journal of the European Union, “Directive 2010/40/eu of the European Parliament and of the Council of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport”, Available at “http://ec.europa.eu/transport/themes/its/road/action_plan/,” Aug 6, 2010, pp L 207/1- 207/13.
2. Xinping Yan, Hui Zhang and Chaozhong Wu, “Research and Development of Intelligent Transportation Systems,” in 11th International Symposium on Distributed Computing and Applications to Business, Engineering & Science, Oct 19-22, 2012, pp 321-327.
3. National ITS Architecture Version 7.0, “http://www.its.dot.gov/arch/in dex.htm,” July 10, 2012.
4. Tariq Samad and Anuradha Annaswamy, “Vehicle-to-Vehicle/Vehicle-to-Infrastructure Control From The Impact of Control Technology,” IEEE Journals and Magazines, www.ieeecss.org, 2011, Vol. 31, pp 26-27.
5. National Highway Traffic Safety Administration Report, “Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Application,” Available at http://www.nhtsa.gov/About+NHTSA/Press+Releases/NHTSA-issues-advanced-notice-of-proposed-rulemaking-on-V2V-communications, August 2014.
6. http://www.loc.gov/rr/scitech/mysteries/global.html, June 22, 2011
7. Robert Bosch, “CAN Specification Version 2.0,” Available at http://www.bosch-semiconductors.de/media/pdf_1/canliteratur/can2spec.pdf

8. Federal Communications Commission, FCC 99-305. “FCC Report and Order,” Available at https://transition.fcc.gov/Bureaus/Engineering_Technology/News_Releases/1999/nret9006.html,” October 1999.

9. Federal Communications Commission, FCC 03-024. “FCC Report and Order,” Available at “https://info.publicintelligence.net/JSC-03-024.pdf,” February 2004.

10. B. Cash, “IEEE briefing on 5.9 GHz concepts and band plan,” Presentation in DSRC standardization monthly meeting, 2002.

11. H. Krishnan and C. Kellum, “Use of communication in vehicle safety application,” Internal Report of General Motors Company, 2002.

12. Jean Walrand and Pravin Varaiya, “High-performance Communications Networks,” By Morgan Kaufmann, 2nd edition, 2000.

13. http://oceanservice.noaa.gov/facts/lidar.html, May 29, 2015

14. Wang Xing, Huiyan Chen and Huarong Ding, “The Application of Controller Area Network on Vehicle,” in Vehicle Electronics Conference, 1999. (IVEC '99) Proceedings of the IEEE International, Vol. 1, pp 455-458.

15. Sewon Lee, Bong-Su Cho, Yong-June Choi and Kwang-Ryul Baek, “Implementation of MOST/CAN Network Protocol,” in Electrical and Controlling Engineering (ICECE), International Conference on 16-18 Sept. 2011, pp 5974-5977.

16. http://www.can-cia.org/, Aug 20, 2015.

17. IS0 11898 Vehicle-Digital Information Interchange-High Speed Communication Controller Area Network (Version l), 1993.1 1.

18. IS0 Open System Interconnect (OSI) Model, IS0 7498.

19. http://www.obdii.com/connector.html, Aug 20, 2015.

20. Renjun Li, Chu Liu and Feng Luo, “A design for Automotive CAN Bus Monitoring System,” in IEEE Vehicle Power and Propulsion Conference (VPPC), September 3-5, 2008, Harbin, China, pp 1-5.

21. PDIUSBD12 Product data. Rev. 08.Philips, 20 December 2001.

22. Ashwin Gumaste, Rahul Singhai and Anirudh Sahoo, “IntelliCarTS: Intelligent Car Transportation System,” Proc. IEEE LANMAN, June 2007.

23. Ashwin Gumaste, Rahul Singhai and Anirudh Sahoo, “Intelligent Vehicular Transportation System (InVeTraS),” in Australasian Telecommunication Networks and Applications Conference, December 2nd – 5th 2007, Christchurch, New Zealand, pp 58-63.

24. Xue Yang, Jie Liu, N.F. Vaidya and Feng Zhao, “A Vehicle-to-Vehicle Communication Protocol for Cooperative Collision Warning,” in Proceedings of the First Annual International Conference on Mobile and Ubiquitous Systems: Networking and Services, IEEE, 2004, pp 114-123.

25. M.J.F. Ashrafi, S. Yousefi, H. Karimi, S.M. Hosseini, H. Rostami and H.R. Ataeian, “Highway Chain Collision Avoidance using Inter-Vehicular Communications,” in 3rd International Conference on Computer and Knowledge Engineering, October 31 & November 1, 2013, Ferdowsi University of Mashhad, pp 135-140.

26. Liang Li, Guangquan Lu, Yunpeng Wang and Daxin Tian, “A Rear-end Collision Avoidance System of Connected Vehicles,” in IEEE 17th International

Conference on Intelligent Transportation Systems (ITSC) October 8-11, 2014. Qingdao, China, pp 63-68.

27. Jong-Min Park, Hyun-Chul Choi and Se-young Oh, “Real-Time Vehicle Detection in Urban Traffic Using Adaboost,” Proc. Of IEEE/RSJ International Conference on IROS, pp. 3598 –3603, 2010.
28. Paul Viola and Michael J. Jones, “Robust Real-Time Face Detection,” International Journal of Computer Vision 57(2), 2004, pp 137–154.
29. A. Khammari, F. Nashashibi, Y. Abramson, Y and C. Laurgeau, "Vehicle detection combining gradient analysis and AdaBoost classification," in Intelligent Transportation Systems, 2005. Proceedings IEEE 2005, pp 66-71.
30. Gwang Yul Song, Ki Yong Lee, and Joon Woong Lee, “Vehicle detection by edge-based candidate generation and appearance-based classification,” Intelligent Vehicles Symposium, 2008 IEEE, June 2008, pp 428-433.
31. Guan-Yu Chen, Po-Chun Shen, Chao-Yi Cho, M.S. Vinay and Jiun-In Guo “A Forward Collision Avoidance System Adopting Multi-feature Vehicle Detection,” in Consumer Electronics - Taiwan (ICCE-TW), 2014 IEEE International Conference on 26-28 May 2014, pp-125 – 126.
32. P. Lytrivis, G. Thomaidis, M. Tsogas and A. Amditis, Member, IEEE; “An Advanced Cooperative Path Prediction Algorithm for Safety Applications in Vehicular Networks,” in IEEE Transactions on Intelligent Transportation Systems, Vol. 12, No. 3, September 2011, pp 669-679.

33. Simon Julier and Jeffrey K. Uhlmann, “A general method for approximating nonlinear transformations of probability distributions,” Robot. Res. Group, Dept. Eng. Sci., Univ. Oxford, Oxford, U.K., 1996.

34. Eric A. Wan and Rudolph Van der Merwe, “The unscented Kalman filter,” in Kalman Filtering and Neural Networks, S. Haykin, Ed. New York: Wiley, 2001, pp. 221–280.

35. M. Tsogas, A. Polychronopoulos and A. Amditis, “Unscented Kalman filter design for curvilinear motion models suitable for automotive safety applications,” in Proc. 8th Int. Conf. Inf. Fusion, Philadelphia, PA, July 25-28, 2005.

36. A.P. Dempster, “A generalization of Bayesian inference,” J. R. Stat. Soc., Ser. B, vol. 30, no. 2, pp. 205–247, 1968.

37. Glenn Shafer, “A Mathematical Theory of Evidence,” Princeton, NJ: Princeton Univ. Press, 1976.

38. http://www.ubuntu.com/, Aug 20, 2015.

39. R. Braden (ed.), “RFC 1122, Requirements for Internet Hosts – Communication Layers,” October 1989.

40. R. Braden (ed.), “RFC 1123, Requirements for Internet Hosts – Application and Support,” October 1989

41. http://www.axisnetworkcabling.com/voice-data-cabling-installers-company.html, Aug 5, 2015.

42. http://www.aradasystems.com, Aug 5, 2015.

43. http://www.adafruit.com/products/960, Aug 10, 2015.

44. http://www.vector.com/vi_candb_en.html, Aug 10, 2015.

45. https://www.python.org/, Aug 10, 2015.

46. K. Yedukondalu, A.D. Sarma and V.S. Srinivas, "Estimation and mitigation of GPS multipath interference using adaptive filtering," Progress In Electromagnetics Research M, Vol. 21, pp. 133-148, 2011.

47. http://www-nrd.nhtsa.dot.gov/Pubs/812160.pdf, June 2015.

48. http://www.census.gov/compendia/statab/2012/tables/12s1103.pdf, Aug 16, 2015.

49. http://www-nrd.nhtsa.dot.gov/Pubs/812139.pdf, Aug 16, 2015.

50. http://www.tc.gc.ca/media/documents/roadsafety/cmvtcs2012_eng.pdf, Aug 16, 2015.

51. http://www.cs.umd.edu/class/sum2003/cmsc311/Notes/Data/endian.html, Aug 20, 2015.

APPENDICES

Appendix A

Big Endian Algorithm

Input: Data bytes, RcvDataLen

Output: FinalDecodedValue

Receive CAN ID = Data byte shift by 4 bytes of total data bytes

FOR ByteCounter = 4 to RcvDataLen

BinaryValue = IntToBinaryString(Data[ByteCounter])

END FOR

LenBinaryValue = BinaryValue.length()

FOR i = 0 to LenBinaryValue -8; i += 8

Push Back in vector ByteStrings(substr of BinaryValue(i,8))

END FOR

StartBitCount = 0

FOR ByteNum = 0 to ByteStrings.size()

Byte = ByteStrings[ByteNum]

RevByte = string reverse(Byte)

FOR RevBitPos = 0 to not RevByte.size()

IF (StartBitCount == datastructure -> signal -> bit_start)

BitPos = 7 – RevBitPos

BitPos = 8 * ByteNum + BitPos

FinalString = SubString of BinaryValue (BitPos, datastructure -> signal -> length)

DecodedValue = BinaryToInt(FinalString)

FinalValue = (DecodedValue * datastructure -> signal -> scale) + (datastructure -> signal -> offset)

ELSE

StartBitCount++

END IF

END FOR

END FOR

Appendix B

Little Endian Algorithm

Input: Data bytes, RcvDataLen

Output: FinalDecodedValue

Receive CAN ID = Data byte shift by 4 bytes of total data bytes

FOR ByteCounter = 4 to RcvDataLen

BinaryValue = IntToBinaryString(Data[ByteCounter])

END FOR

LenBinaryValue = BinaryValue.length()

FOR i = 0 to LenBinaryValue -8; i += 8

Push Back in vector ByteStrings(substr of BinaryValue(i,8))

END FOR

StartBitCount = 0

FOR ByteNum = 0 to ByteStrings.size()

Byte = ByteStrings[ByteNum]

RevByte = string reverse(Byte)

FOR RevBitPos = 0 to not RevByte.size()

IF (StartBitCount == datastructure -> signal -> bit_start)

BitPos = 7 – RevBitPos

BitPos = 8 * ByteNum + BitPos

BitPos = BitPos – (datastructure -> signal -> bit_len - 1)

FinalString = SubString of BinaryValue (BitPos, datastructure -> signal -> length)

DecodedValue = BinaryToInt(FinalString)

FinalValue = (DecodedValue * datastructure -> signal -> scale) + (datastructure -> signal -> offset)

ELSE

StartBitCount++

END IF

END FOR

END FOR

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