Merge Assist System Using GPS and DSRC Based Vehicle-to-Vehicle Communication

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Dedication

I dedicate this to my parents and siblings for their continuous support and dedicated partnership for success in my life.

Abstract

One potential area to improve driver safety and traffic mobility is around merge points of two roadways e.g., at a typical freeway entrance ramp. Due to poor visibility because of weather or complex road infrastructure, on many such entrance ramps, it may become difficult for the driver on the merging/entrance ramp to clearly see the vehicles travelling on the main freeway, making it difficult to merge. A fundamental requirement to facilitate many ADAS functions including a merge assist system is to accurately acquire vehicle positioning information. Accurate position information can be obtained using either sensor-based systems (camera-based, RADAR, LiDAR) or Global Navigation Satellite Systems (GPS, DGPS, RTK). For these systems to work well for practical road and weather conditions, advanced techniques and algorithms are needed which make the system complex and expensive to implement. In this report, the author proposes a merge assist system by acquiring the relative positioning of vehicles using standard GPS receivers and DSRC based V2V communication. The DSRC equipped vehicles travelling on the main freeway and on the entrance-ramp will periodically communicate their positioning information with each other. Using that information, the relative trajectories, relative lane and position of all DSRC equipped vehicles travelling on the main freeway, will be calculated and recorded in real time in the vehicle travelling on the entrance ramp. Finally, a merge time cushion will also be calculated which could potentially be used to assist the driver of the ramp vehicle to safely merge into the freeway.

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LIST OF ABBREVIATIONS

- DSRC: Dedicated Short-Range Communication
- GNSS: Global Navigation Satellite Systems
- GPS: Global Positioning System
- DGPS: Differential Global Positioning System
- RTK: Real-Time Kinematic
- V2V: Vehicle to Vehicle
- V2I: Vehicle to Infrastructure
- ADAS: Advance Driver Assistance Systems
- Dr: Relative Distance (Distance between two vehicles w.r.t each other)
- DL: Lateral Distance (Horizontal or lateral distance between two vehicles)
- Ce: Curvature Error (Error introduced in the estimation of Lateral Distance due to the curvature of the road)
- DL’: Effective Lateral Distance (Lateral Distance minus Curvature Error)
- θD: Differential Heading (The difference of headings of any two vehicles)
- LW: Lane Width

CHAPTER 1: INTRODUCTION

1.1 Background

Intelligent Transportation Systems joint program office of the US Department of Transportation continues to be committed to the use of dedicated short-range communication (DSRC) for active safety applications using vehicle to vehicle (V2V) and/or vehicle to infrastructure (V2I) communication [1]. One potential area to improve driver safety and traffic mobility is around merge points of the two roadways e.g., at a typical freeway entrance ramp. Usually, the speed of the vehicles travelling on a freeway is much higher than the speed of the vehicles on a merging ramp. To avoid a potential crash, merging vehicles stop or slow down to yield to faster moving traffic before merging and speeding up. Sometimes, drivers of the merging vehicles cannot see the fast-moving vehicles on the main freeway due to natural growth or weather-related effects e.g., accumulated snow barriers. Occasionally, even when the driver on the merging ramp can see the vehicles travelling on the main road, it is difficult to judge if it is safe to merge. While a cautious driver could disturb the traffic flow by waiting long enough, a rushed driver could jeopardize safety. According to one study, 36% of the total freeway accidents analyzed were on the entrance ramps [2], and according to another study, nationally 20–30 % of total truck accidents occur on or near ramps [3].

When vehicles are merging on a freeway, both driver safety and traffic efficiency could be at risk if not managed properly. During the rush hour, ramp metering is used to improve traffic efficiency on freeways which also indirectly improves driver safety by reducing the risk of crashes [4]. In a research work to provide merge assistance using DSRC based V2I and V2V communication, three application scenarios namely emergency vehicle routing, merge assistance, & pedestrian crossing warning were chosen as desired goals, and a merge assistance scenario for increasing safety and mobility on motorway ramps was depicted focusing on merging of the heavy vehicles but the work is limited to conceptual level [5]. Similarly, some theoretical work has also been done on collision avoidance and cooperative adaptive cruise control systems using DSRC based

V2V communication [6 - 10]. However, no practical system has been demonstrated to our knowledge, using DSRC based V2I and/or V2V communication to facilitate safe merging.

For critical safety applications such as merge-assist or lane-change-assist systems require only the relative positions of surrounding vehicles with lane-level resolution to allow a given vehicle to differentiate the vehicles in its own lane from the vehicles in adjacent lanes [11]. Therefore, in the approach presented in this research, we have focused on acquiring the relative trajectories of surrounding vehicles using standard GPS receivers—without any additional correction system—and DSRC-based V2V communication. Our approach to acquire relative trajectories is based on the fact that a major part of GPS positioning error, caused by atmospheric effects, is highly correlated over a vast geographical area [12] [13]. Therefore, multiple GPS receivers of the same kind on different vehicles in close proximity tend to have a similar atmospheric error at a given time. The common atmospheric error could be canceled out to obtain a more accurate estimate of the relative distance between any two vehicles as compared to the absolute position of each vehicle. Utilizing this approach, we have successfully acquired relative trajectories of vehicles traveling in multiple lanes, as well as identified the relative lane of vehicles travelling toward a merging junction using DSRC-based V2V communication and standard GPS receivers. The accuracy of the relative lane identification was sufficient to facilitate many critical ADAS functions such as; merge assist system etc.

1.2 Project overview

The conceptual approach of the project is described in Figure 1.1, where traffic is shown to merge on a fast-moving two-lane freeway. Each vehicle approaching the merging junction is assumed to be equipped with DSRC device and a global positioning system (GPS) receiver. All vehicles on main freeway periodically communicate their position information (latitude and longitude) to the merging vehicle (shown in yellow) using DSRC based V2V communication. After the DSRC device of the merging vehicle acquires the position information of all the vehicles around the merge junction, it calculates necessary parameters to estimate merge time cushion which helps the driver to safely merge into the freeway. These necessary parameters are: Acquiring the accurate relative trajectories of the vehicles, identifying the relative lane and position of the vehicles around the merging junction, identifying the vehicle of concern which could interfere with the merging of the ramp vehicle.

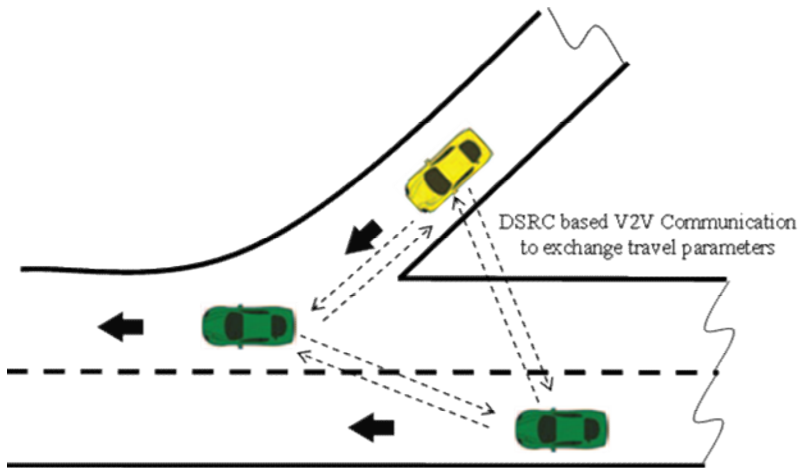

Figure 1.1: The schematic diagram of a vehicle travelling towards a two-lane freeway merge junction. All vehicles' trajectories will be recorded and processed in real time in the vehicle trying to merge into the freeway (shown in yellow).

1.3 Objectives

The goal of this project is to design and implement a merge assist system using DSRC based V2V communication which helps the driver of the ramp vehicle to safely merge into the freeway. The main objectives to achieve this task are:

1.3.1 Acquisition of Relative Position Accuracy

One of the critical aspects in the successful accomplishment of the proposed project is to accurately estimate travel parameters, e.g., location, speed, and direction of travel. Although, the absolute position accuracy of today's standard GPS receivers is not very accurate, relative position accuracy is much more reliable. This is due to the fact that a major part of GPS positioning error, caused by atmospheric effects, is highly correlated

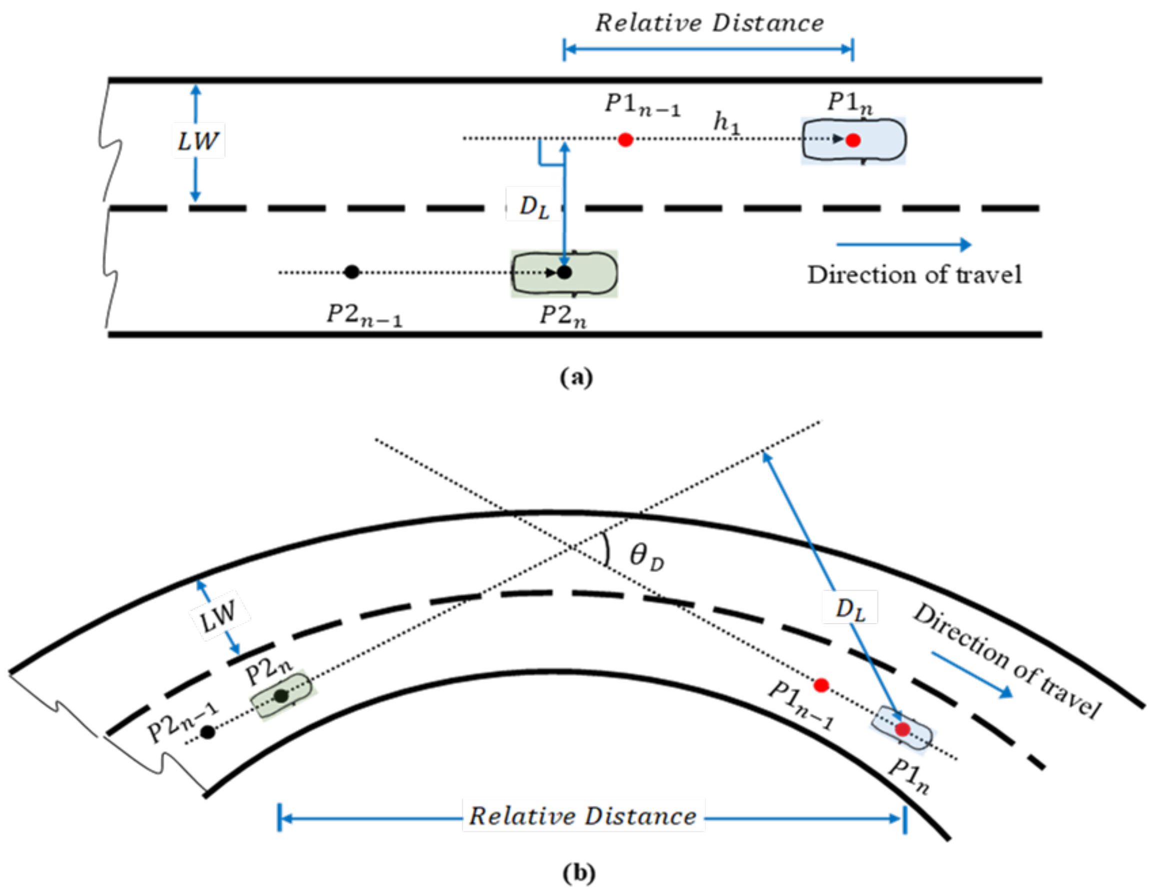

Figure 1.2: Schematic diagram of two vehicles illustrating the concept of relative lane identification on (a) straight road, and (b) curved road. Where $P1n$ and $P2n$ are the position coordinates of vehicle 1 and vehicle 2 at $t = n$, and $P1n{-}1$ and $P2n{-}1$ are the position coordinates of vehicle 1 and vehicle 2 at $t = n{-}1$.

over a vast geographical area [12,13]. Therefore, multiple GPS receivers of the same kind on different vehicles in close proximity tend to have a similar atmospheric error at a given time. The common atmospheric error could be canceled out to obtain a more accurate estimate of the relative distance between any two vehicles as compared to the absolute position of each vehicle. Utilizing this approach, we have successfully acquired the relative trajectories of vehicles traveling in multiple lanes toward a merging junction with an accuracy of less than half of the lane width using DSRC-based V2V communication and standard GPS receivers [14]. The accuracy of the acquired relative trajectory was sufficient to differentiate vehicles traveling in adjacent lanes of a multiple-lane freeway. This phase of the project has already been carried out in our lab previously under the supervision of Dr. Hayee. Therefore, we will not go into too much detail.

1.3.2 Relative Lane and Position Identification of Surrounding Vehicles

To safely merge into the freeway, the ramp vehicle is required to yield to the traffic travelling on the main freeway which could potentially interfere with the merging especially the vehicles travelling in the right most lane of the freeway. Therefore, it is crucial that we know the relative lane and position of all the vehicles on the freeway travelling towards the merging junction.

The relative lane of any two vehicles on a straight road segment is decided based upon the lateral distance (D_L) between the two vehicles, as shown in Figure 1.2(a). If the absolute value of D_L ($|D_L|$) is less than ½ of the lane width (LW) of the road, the two vehicles are said to be in the same lane. Similarly, if $|D_L|$ is more than ½ LW but less than 1½ LW, the two vehicles are said to be in the adjacent lanes. The sign of D_L helps distinguish the right lane from the left lane. Figure 1.2(a) illustrates that D_L can be precisely estimated using a Point-Line equation because of the road being a straight segment. However, this estimation of D_L using the Point-Line equation becomes erroneous for a curved road segment because of the error due to the degree of curvature of the road, as illustrated in Figure 1.2(b). Although on a curved road segment (Figure 1.2b) the true D_L between the two vehicles should be less than ½ LW because they occupy the same lane, the calculated D_L between the two vehicles appears to be larger than LW. Hence, D_L calculated using the Point-Line equation can no longer be used as such for relative lane identification. Therefore, it is necessary to first estimate the increase in D_L to adjust the calculated D_L between the two vehicles before estimating their relative lane. The increase in D_L depends upon the curvature of the road and can be estimated using differential heading (θ_D) and relative distance (D_r) between the two vehicles. For simplicity, the increase in D_L between the two vehicles is termed as curvature error (C_e) in this report.

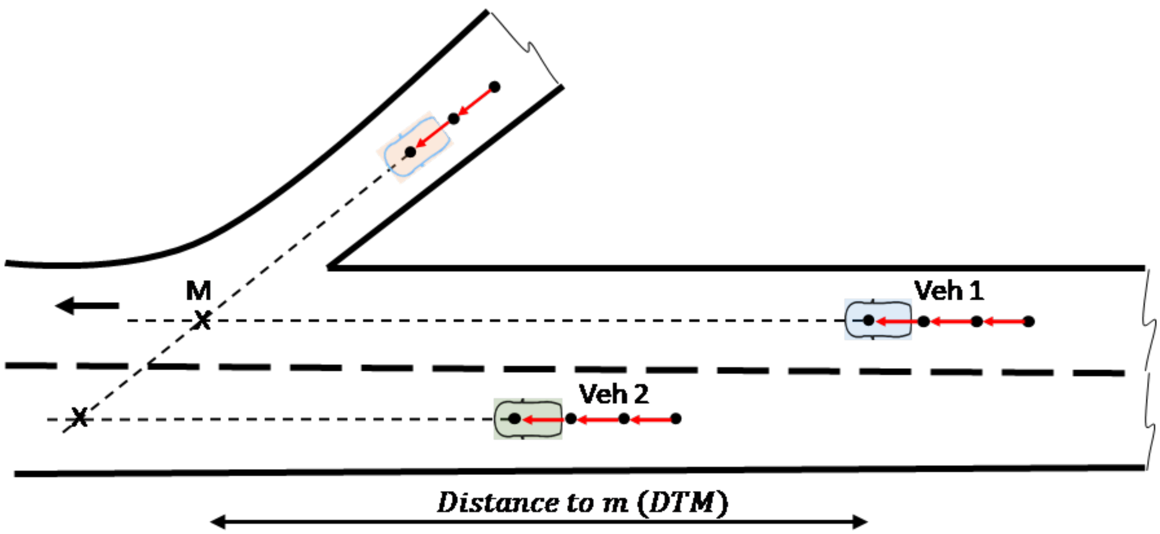

Figure 1.3: Typical merging scenario, where vehicle 1 is travelling towards the common merging point 'M' and could interfere with the merging of the ramp vehicle.

We have worked on normalizing this curvature error to find an effective lateral distance which can be used for accurate relative lane identification for both straight and curved road segments simultaneously. We performed extensive field tests on I-13, a two-lane freeway in Duluth, MN, and the results showed that the relative lane and position of surrounding vehicles can be identified in real time with 100% accuracy regardless of the degree of curvature of the road when the distance between the two vehicles was less than 50m.

1.3.3 Merge Time Cushion

Merge time cushion is the time for the vehicle on the right most lane to reach to the common merging position, M, of the merging vehicle and the vehicle on the right most lane as shown in Figure 1.3. Once the DSRC communication is established between the vehicles on the main freeway and the vehicle on the merge junction, and relative positions of the vehicles are calculated in the DSRC device of the vehicle on the merge junction, it will be determined which vehicle is on the right most lane of the freeway which could interfere with the merging of the vehicle on the merge junction. Once lane determination is confirmed, using the speed of the vehicle on the right most lane, a merge time cushion will be estimated to show how much time is needed for the right most vehicle to reach to the common merging point 'M'. The merge time cushion will be updated continuously in real time and it may slightly change depending upon the speed of the vehicle on the rightmost lane of the freeway and/or the geometry of the merging ramp. Please note that if there is only one vehicle traveling towards the merging junction on the freeway, it will be considered to be in the right most lane. Furthermore, the vehicle leading ahead in the right most lane towards the merging junction will be chosen for merge time cushion calculation.

1.4 Related Work

Autonomous, or self-driving cars, require a high level of situational awareness to operate safely and efficiently in real-world conditions [15]. For fully autonomous vehicles and Advanced Driver Assistance Systems (ADAS) such as; Lane Keeping, Blind Spot Detection, Merge Assist System, Vehicle Detection or Auto Cruise Control, it is necessary to know the position of the car in the lane it occupies [16-18]. However, the absolute position of the vehicle has limited interest by itself, particularly for road safety applications. What is generally needed, is their position relative to the road network and to its various objects of interest such as intersections, road edges, traffic lights, or other vehicles [16].

Position information is a fundamental requirement for many vehicular applications such as navigation, intelligent transportation systems (ITSs), and location-based services (LBSs) [19]. Accurate positioning information can be obtained using either sensor-based systems (Image processing, Radar, Lidar etc.) or Global Navigation Satellite Systems (GNSSs) [14]. Sensor-based systems rely on vision or laser-based sensors to acquire the relative positions of surrounding vehicles [20-23]. However, environmental factors such as weather, variable lighting conditions, absence of line-of-sight (LoS) and worn out road markings can adversely affect the performance of these systems [24]. Guizhen Yu et al. in [25] proposes a real-time lane detection method using image processing, which despite being complex and relatively expensive, does not work well when an obstacle on the road is similar to lane lines, or where the lane line is missing for a long time. Most of these vision-based or sensor-based systems such as proposed in [26] and [27] suffer in challenging environment. On the other hand, GNSS-based technologies such as Global Positioning System (GPS) cannot predict the position of a vehicle with lane-level accuracy without using a correction or augmentation system e.g., differential GPS technology, inertial sensors, gyroscope, and/or high-resolution maps [28-32]. There are some reports of achieving lane-level accuracy using differential GPS receivers and/or image processing techniques, which makes the system complex and relatively expensive [33-35]. Therefore, a system that can efficiently acquire the relative trajectories of the vehicle using inexpensive equipment would be an important milestone to facilitate not only a Merge Assist System, but also many other basic safety applications.

1.5 Dedicated Short-Range Communication (DSRC)

Dedicated Short-Range Communication (DSRC) is a bi-directional short to medium range wireless communication technology that designed for automotive communication. A conceptual demonstration of this technology is shown in Figure 2.1. DSRC applications primarily targets the transportation industry and the following features of DSRC technology enable it to improve drivers' safety and traffic mobility.

• Designated licensed bandwidth: Federal Communications Commission (FCC) exclusively allocated 75 MHz bandwidth in the 5.9 GHz band.

• Full protocol support: IEEE 802.11p extends 802.11 wireless communication protocol family to support critical safety applications.

• Fast Network Acquisition: Active safety applications require the immediate establishment of communication and frequent updates.

• Low Latency: Active safety applications must recognize each other and transmit messages to each other in milliseconds without delay.

• High Reliability when Required. DSRC works in high vehicle speed mobility conditions and delivers performance immune to extreme weather conditions (e.g. rain, fog, snow, etc.).

The application of DSRC technology falls into two categories: Vehicle to Vehicle (V2V) communications and Vehicle to Infrastructure (V2I) communications.

1.5.1 Vehicle to Vehicle (V2V) communications

DSRC technology enables vehicles to exchange their travel information on the road. For example, vehicle's travel speed and travel direction can be shared with other vehicles, so that potential collisions could be prevented. Drivers' awareness of surrounding vehicles also can be improved. This is especially helpful when drivers are near merging ramps or intersections where there is limited or no line-of-sight to other vehicle. Augmenting vehicular platoon with DSRC technology can help it achieve better speed and distance control.

1.5.2 Vehicle to Infrastructure (V2I) communications

V2I communications further explore the potentials of DSRC technology. For example, DSRC communication devices installed on frequently congested road intersections can help broadcast messages to nearby vehicle to inform drivers of choosing alternative routes. Near slippery road section or sharp turn area, well placed DSRC devices could give warnings to drivers about incoming high-risk road conditions.

CHAPTER 2: RELATIVE LANE AND POSITION IDENTIFICATION

As discussed earlier, the necessary parameters to accurately estimate the merge time cushion in order to facilitate the ramp vehicle to safely merge into the freeway are; Acquiring the accurate relative trajectories of the vehicles, identifying the relative lane and position of the vehicles around the merging junction, identifying the vehicle of concern which could interfere with the merging of the ramp vehicle. In Chapter 2, the authors proposed and demonstrated a method of estimating accurate relative trajectories of surrounding vehicles with lane level resolution using standard GPS receivers and Dedicated Short-Range Communication (DSRC) based Vehicle to Vehicle (V2V) communication. In that work, we exploited the higher accuracy of relative distance between the two GPS receivers in close proximity. The results showed that the relative distance accuracy between the GPS receivers was less than half a lane width.

In this chapter, we will discuss a methodology to estimate the relative lane and position of surrounding vehicles in real time to cost effectively facilitate many critical ADAS functions, including Merge Assist System and other systems such as blind spot detection, overtake, and forward collision warning systems etc. Field tests were performed to evaluate the proposed methodology on a two-lane freeway having sharp curved road sections designed for a maximum degree of curvature for a speed of 120 kmh. The field test results show that the relative lane and position of surrounding vehicles can be identified in real time with 100% accuracy regardless of the degree of curvature of the road as long as the distance between the two vehicles is less than 50 m.

2.1 Methodology

The objective of this research is to use DSRC based V2V communication and standard GPS receivers to identify relative lanes and positions of surrounding vehicles in real time, which helps in estimating the merge time cushion. Each vehicle equipped with DSRC equipment transmits and receives Basic Safety Message (BSM) every 100 msec to and from its neighboring vehicles. Among other data, BSM originating from each vehicle at any given time contains its position information in terms of longitude and latitude. When any given vehicle has received position information from its neighboring vehicles, it performs the required calculations as proposed in this report to estimate their relative lane and position with respect to its own. The details of those calculations are described as follows.

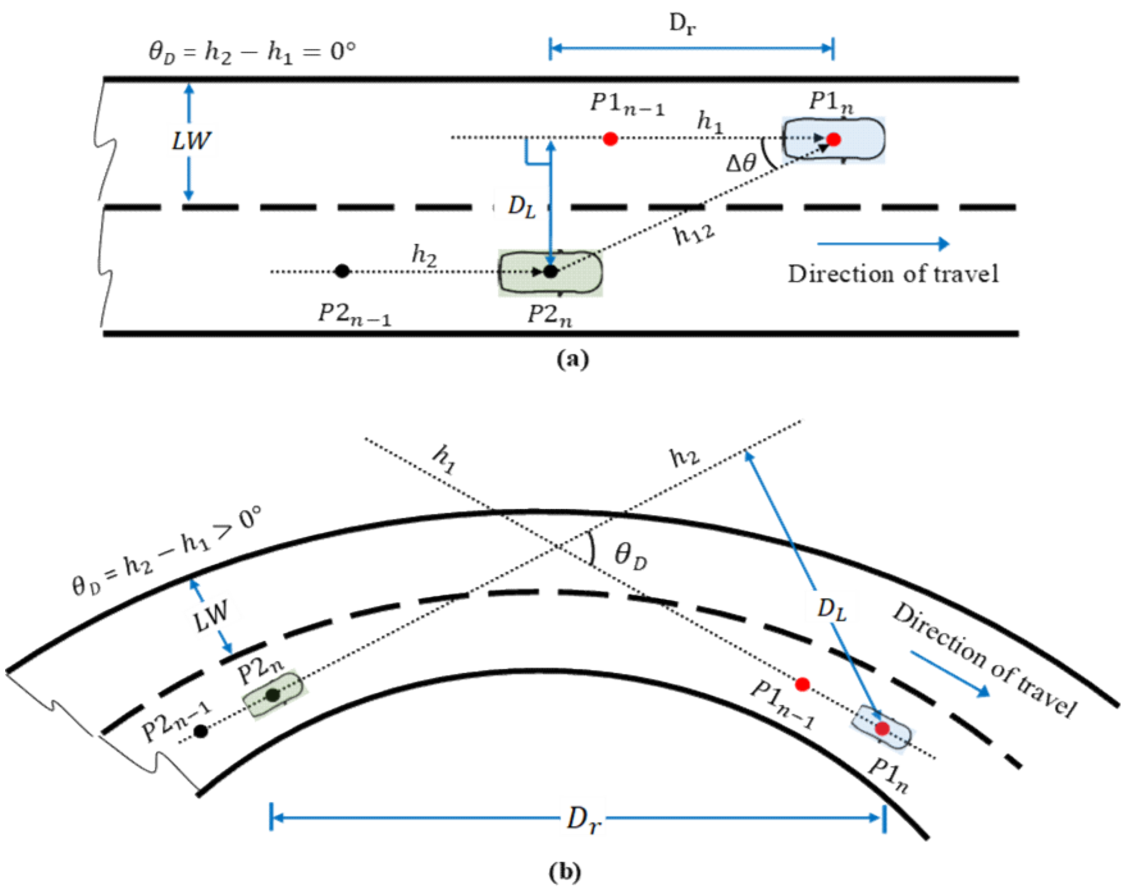

Figure 2.1: Schematic diagram of two vehicles illustrating the concept of relative lane identification on (a) straight road, and (b) curved road. Where h1 and h2 are the headings of vehicle 1 and vehicle 2, respectively. P1n and P2n are the position coordinate points of vehicle 1 and vehicle 2 at t=n, and P1(n−1) and P2(n−1) are the position coordinate points of vehicle 1 and vehicle 2 at t=n−1. LW is the lane width of the road.

The relative lane of any two vehicles on a straight road segment is decided based upon the lateral distance (D_L) between the two vehicles, as shown in (a). If the absolute value of D_L ($|D_L|$) is less than ½ of the lane width (LW) of the road, the two vehicles are considered to be in the same lane. And if $|D_L|$ is more than ½ LW but less than 1½ LW, the two vehicles are considered to be in the adjacent lanes. The sign of D_L helps distinguish the right lane from the left lane.

$$D_L = \left[\frac{(x1_n - x1_{n-1})(y1_{n-1} - y2_n) - (x1_{n-1} - x2_n)(y1_n - y1_{n-1})}{\sqrt{(x1_n - x1_{n-1})^2 + (y1_n - y1_{n-1})^2}} \right] \quad (1)$$

For this research, D_L between any two vehicles is calculated using Point-Line formula in equation (1) which requires at least two distinct rectangular position coordinates of one vehicle: $P1_n(x1_n , y1_n)$ and $P1_{n-1}(x1_{n-1} , y1_{n-1})$, and one position coordinate of another vehicle: $P1_{n-1}(x1_{n-1} , y1_{n-1})$, as shown in Fig 1(a).

It should be noted that BSM contains GPS position coordinates in terms of longitude and latitude which is first converted to rectangular coordinates using Universal Transverse Mercator (UTM) conversion method [36] before using eq (1). To correctly identify relative lane of any two vehicles at any given time n, it is necessary that one of the two position coordinates of one vehicle and the position coordinate of the other vehicle are taken at the same time.

2.1.1.1 Curvature error and its estimation

The above method precisely calculates D_L only when the two vehicles are on a straight road segment which can be differentiated from a curved road segment by calculating the differential heading (θ_D) between the two vehicles at any given time. If θ_D is negligibly small the two vehicles are considered to be on a straight road segment regardless of their relative distance (D_r) from each other, as shown in Fig. 2.1(a). However, when the two vehicles are on a curved road segment, θ_D is no more negligible as illustrated in Fig. 2.1(b), where the two vehicles are shown on a curved road segment occupying the same lane. Although on a curved road segment (Fig. 3.1b) the true D_L between the two vehicles should be less than ½ LW because they occupy the same lane, the calculated D_L between the two vehicles appears to be larger than LW. Hence, D_L calculated using the method described above can no longer be used as such for relative lane identification. Therefore, it is necessary to first estimate the increase in D_L to adjust the calculated D_L between the two vehicles before estimating their relative lane.

The increase in D_L depends upon the curvature of the road and can be estimated using θ_D and D_r between the two vehicles. For simplicity, the increase in D_L between the two vehicles is termed as curvature error (C_e) in this report and can be estimated using eq (2).

$$C_e = 2\, D_r \,.\, sin\left({}^{\theta_D}/_2\right) \qquad (2)$$

C_e is proportional to both θ_D and D_r. The absolute value of C_e ($|C_e|$) is plotted as a function of D_r for 2, 4 and 6 degrees of θ_D in Fig. 2.2(a), and as a function of θ_D for 40, 80 and 120 m of D_r in Fig. 2.2(b). For a straight road segment when θ_D between the two vehicles is small, $|C_e|$ remains small even when the two vehicles are far from each other. However, for a curved road when θ_D between the two vehicles is large, $|C_e|$ can be much larger even when the two vehicles are not far from each other. As can be seen from Fig. 3.2, $|C_e|$ can be much larger than LW especially for sharper curves i.e., large θ_D even

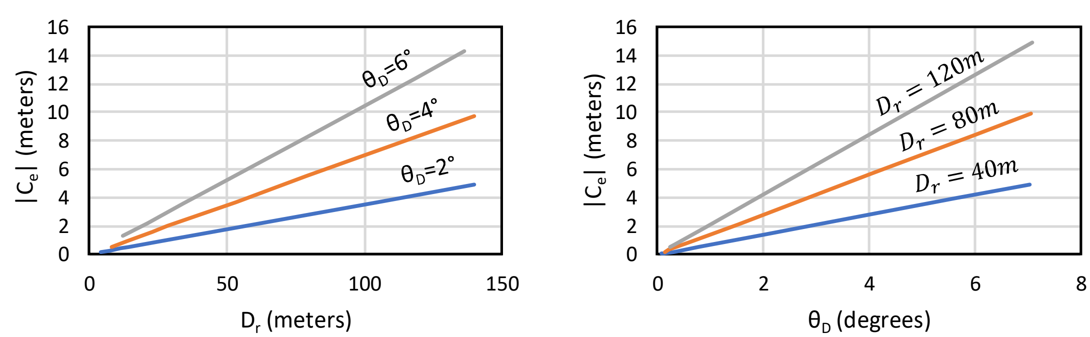

Figure 2.2: Absolute value curvature error (a) as a function of Dr for fixed values of θD and (b) as a function of θD for fixed values of Dr.

when D_r between the two vehicles is relatively small.

Using eq (2), C_e can be estimated by calculating θ_D and D_r between any two vehicles at any given time, for any road segment regardless of the degree of curvature of the road. Once C_e is estimated, it can be subtracted from the calculated D_L to determine the effective lateral distance (D_L'). Instead of using D_L which works well only on a straight road segment, D_L' can be used to identify the relative lane between the two vehicles on any road segment regardless of the curvature of the road. Using D_L', the relative lane decision for same, right and left lanes is made using equations (3), (4), and (5), respectively. Although eq (4) and (5) are for the adjacent lanes, the boundaries of D_L' can be extended in these equations to estimate next to adjacent relative lanes on both right and left sides. It should be noted that for this research, LW was assumed to be 3.6 meters (12 feet) for the freeway lane width [37].

$$-\frac{1}{2}LW < D_L' < \frac{1}{2}LW \qquad (3)$$

$$\frac{1}{2}LW < D_L' < 1\frac{1}{2}LW \qquad (4)$$

$$-1\frac{1}{2}LW < D_L' < -\frac{1}{2}LW \qquad (5)$$

2.1.2 Relative Position Identification (Trailing ahead or behind)

In addition to identifying the relative lane of surrounding vehicles, the relative position of the vehicles is also vital in many ADAS functions, such as blind spot and overtake warning systems etc. Typically, a blind spot warning system needs to estimate if another vehicle is traveling behind it at a short distance in the adjacent lane. Similarly, an overtake warning system would need to estimate if another vehicle is speeding up from behind at a critical distance in order to issue a warning.

To determine if a given vehicle is trailing ahead or behind the other vehicle, heading between the two vehicles (h12), and the heading (h1) of the other vehicle, as illustrated in Fig. 1(a), are needed. With those two headings, $\Delta\theta$ (Fig. 1a) is calculated using (6). If $\Delta\theta$

$$\Delta\theta = h_1 - h_{12} \qquad (6)$$

> 90 degrees, then the given vehicle is ahead of the other vehicle and if $\Delta\theta < 90$ degrees, then the given vehicle is behind the other vehicle.

2.1.3 Precision in Heading Calculation

It is important to mention that the precision in heading calculation is critical for relative lane estimation. Heading of each vehicle is calculated by using at least two position coordinates estimated by standard GPS receivers which is susceptible to error and noise [38]. Therefore, to improve the accuracy of calculated heading and hence reliability of the proposed system, a rigorous method is used to estimate the headings of the two vehicles. Heading of each vehicle at any given time is calculated using five consecutive position coordinates instead of two. The heading of each vehicle at the most current position (P_n) is calculated using most recent 5 consecutive position coordinates (P_n, P_{n-1} … P_{n-4}) as shown in Fig. 2.3. The vehicle heading is taken as the average of the two headings calculated between P_{n-1} and P_{n-3}, and P_{n-4} and P_n. Similarly, D_r between the two vehicles at their current positions is calculated as the distance between the middle of the 5 points, i.e., P_{n-2} of both the vehicles. Subsequently, D_L in any given vehicle is calculated

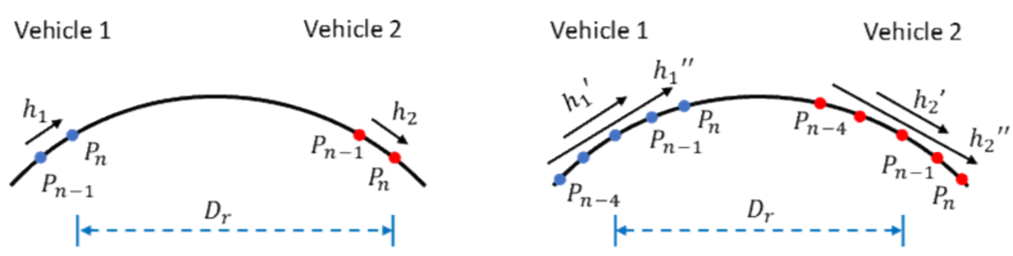

Figure 2.3: (a) Schematic illustration of finding heading of each vehicle using (a)conventional 2-Pointmethod, and (b) 5-Pointmethod.

by taking the average of the two lateral distances calculated using one position coordinate P_{n-2} of the given vehicle and the two position coordinates of the other vehicle, first using P_n and P_{n-4}, and then using P_{n-1} and P_{n-3} (Fig. 2.3).

2.2 Field Tests

To evaluate the methodology described above to identify relative lane and position of surrounding vehicles in real time, field tests were performed on a freeway having both straight and curved segments. Two vehicles were used in the road test. Each of the two vehicles was equipped with DSRC equipment and a standard GPS receiver.

Field tests were conducted between Exit #245 and #249 on I-35 in Duluth, MN, which is a two-lane Freeway. Both vehicles were driven back and forth between the two exits, a total of six times (12 runs) occupying a different lane and/or position each time. In the first two trials (4 runs), both vehicles occupied the same lane (right lane) with relative position of vehicle 1 being switched from trailing ahead in the first trial to trailing behind in the second trial. In the remaining four trials, both vehicles occupied different lanes with their relative lane and/or position being changed each time. In each of the total 12 runs of 6 trials, both vehicles travelled ~6.5 km one way on the freeway while D_r between them was varied between 5 to 150 m, maintaining their relative lane and position with respect to each other.

While travelling on the road, both vehicles exchanged BSMs with each other and performed calculations in real time to determine relative lane and position of the other vehicle with respect to its own. The results were displayed in real time on a laptop computer in each vehicle interfaced with the DSRC device. The typical screen shots of the two laptop screens displaying real-time results in two vehicles are shown in Figure 2.4, where the right screen shot is from the vehicle traveling ahead of the other vehicle on the right lane, and the left screen shot is from the vehicle traveling behind on the left lane. The real-time results not only show the relative lane and position of the vehicle but also D_r which was helpful to maintain the desired distance between the two vehicles during the trials. In each of the 6 trials (12 runs), the two vehicles travelled a round trip of about ~13 km and the relative lane and position of the two vehicles was maintained in both directions of travel in each trial. Both vehicles exchanged BSMs and performed necessary calculations to identify relative lane and position of the other vehicle every 100 msec. The average speed of both vehicles was varied between 110 km/h and 120 km/h so it took about 200 seconds to cover 6.5 km each way in any given run. Therefore, in any given run, a decision about relative lane and position of the other vehicle was repeated about 2,000 times producing a total of about 24,000 set of calculations or decisions in all 12 runs.

In each set of calculations; both vehicles, upon receiving a new position coordinate from each other, calculate D_L, θ_D, D_r and C_e as explained in methodology section. Using D_L and C_e, D_L' is calculated which is used to decide the relative lane of the other vehicle according to the rules described in methodology section (equations 3 - 5). After making decision about relative lane, each vehicle also performs necessary calculations as explained earlier to determine relative position of the other vehicle.

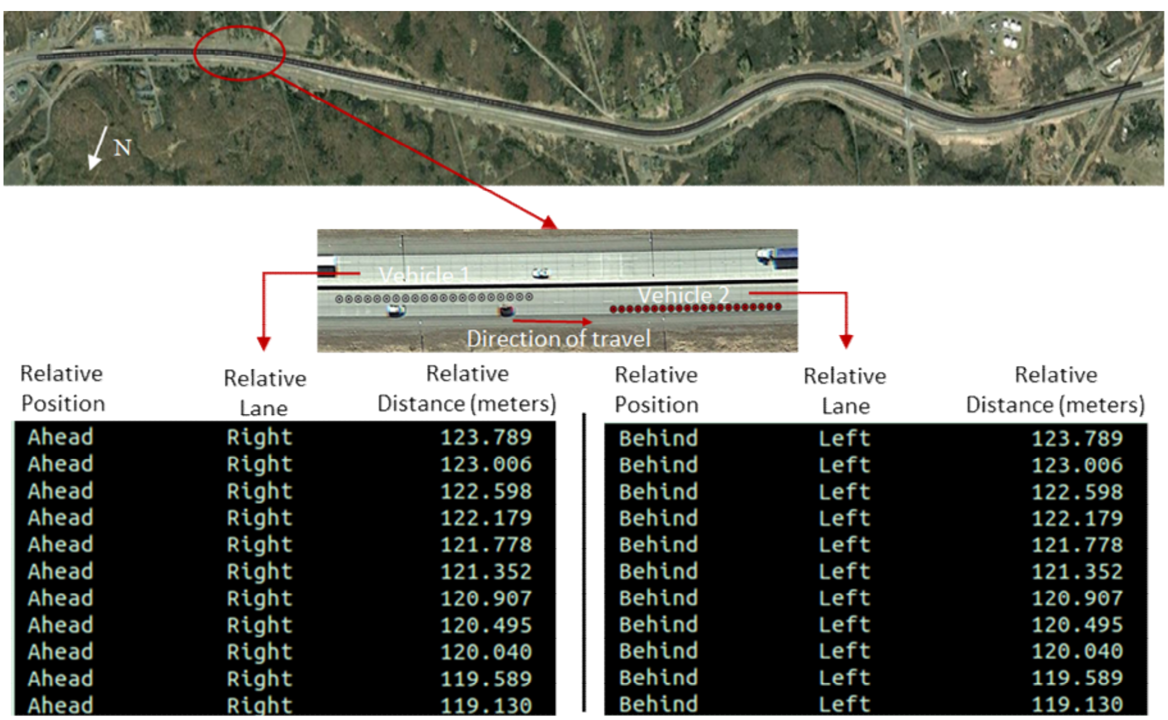

Figure 2.4: The corresponding road map where the field tests were performed is shown at the top. A zoomed-in portion of the road is shown in the middle along with a few trajectory points of the two vehicles in one of the field tests. The bottom two pictures are the screenshots of the two laptops in vehicle 1 and 2 showing the relative position and lane of the other vehicle with respect to its own in real time.

2.3 Results and Discussion

In each of the 12 runs, both vehicles performed calculations followed by a decision about the relative lane and position of the other vehicle every 100 msec. The necessary set of calculated parameters to be used in (6) to determine the relative position of the vehicle are much less prone to noise as long as D_r between the two vehicles is more than a few meters. As a result, at every time instance of all 12 runs, the decision of both vehicles to determine relative position of each other was 100% accurate because the relative distance between the two vehicles at any given time was at least 5 m during the entire field tests. Therefore, in this section, the detailed calculation results for relative position identification will not be discussed any further. On the other hand, the calculated parameters especially θ_D, needed to be used in (2) to determine the relative lane are much more sensitive to noise. Therefore, at some time instances of the 4 out of 12 runs of the field tests some erroneous decisions in relative lane determination were observed. There were a total of 314 errors observed in those 4 runs, most of which occurred on the curved section of the road especially when the two vehicles were far from each other. However, in the remaining 8 of the 12 runs, the relative lane decision was 100% accurate. The accuracy of lane estimation is calculated as the percent ratio of the number of erroneous decision and the total number of decisions made.

2.3.1 Example 1: Trial with only few errors

A typical set of calculations of one of the two vehicles is shown in Figure 2.5(a) where $\boldsymbol{D_r}$ and $\boldsymbol{\theta_D}$ are plotted versus time travelled, for one of the 4 runs with errors. In this run, $\boldsymbol{D_r}$ between the two vehicles varied between 30 and 100 m and $\boldsymbol{\theta_D}$ varied between -2 and +2.5 degrees as evident from Figure 2.5(a). The map of the road section where the two vehicles traveled during the field tests is also shown on the top of the Figure 2.5 to provide context of travelling position of the two vehicles. As $\boldsymbol{\theta_D}$ between the two vehicles is directly correlated with the degree of curvature of the road as well as $\boldsymbol{D_r}$, it is larger when the vehicles are on curved section of the road (higher degree of curvature) especially when $\boldsymbol{D_r}$ is also large. In Figure 2.5(b), corresponding $\boldsymbol{C_e}$ is plotted versus time showing that C_e is large when θ_D is large and small when θ_D is small. As discussed earlier, C_e is subtracted from D_L to determine D_L' which is used to decide the relative lane of the two vehicles. The corresponding D_L' is also shown versus time in Figure 2.5(b). In this run, both vehicles were travelling on the same lane, so D_L' should be between ±1.8 m because LW was taken to be 3.6 m. As seen in Figure 5(b), D_L' is between the bounds of ±1.8 m at all time instances (~2000) except for 4 times around 16 seconds' time mark when it slightly crosses the upper bound of threshold (1.8 m) making a wrong decision on relative lane. Those 4 erroneous decisions are also highlighted in Figure 2.5(a) with a grey mask.

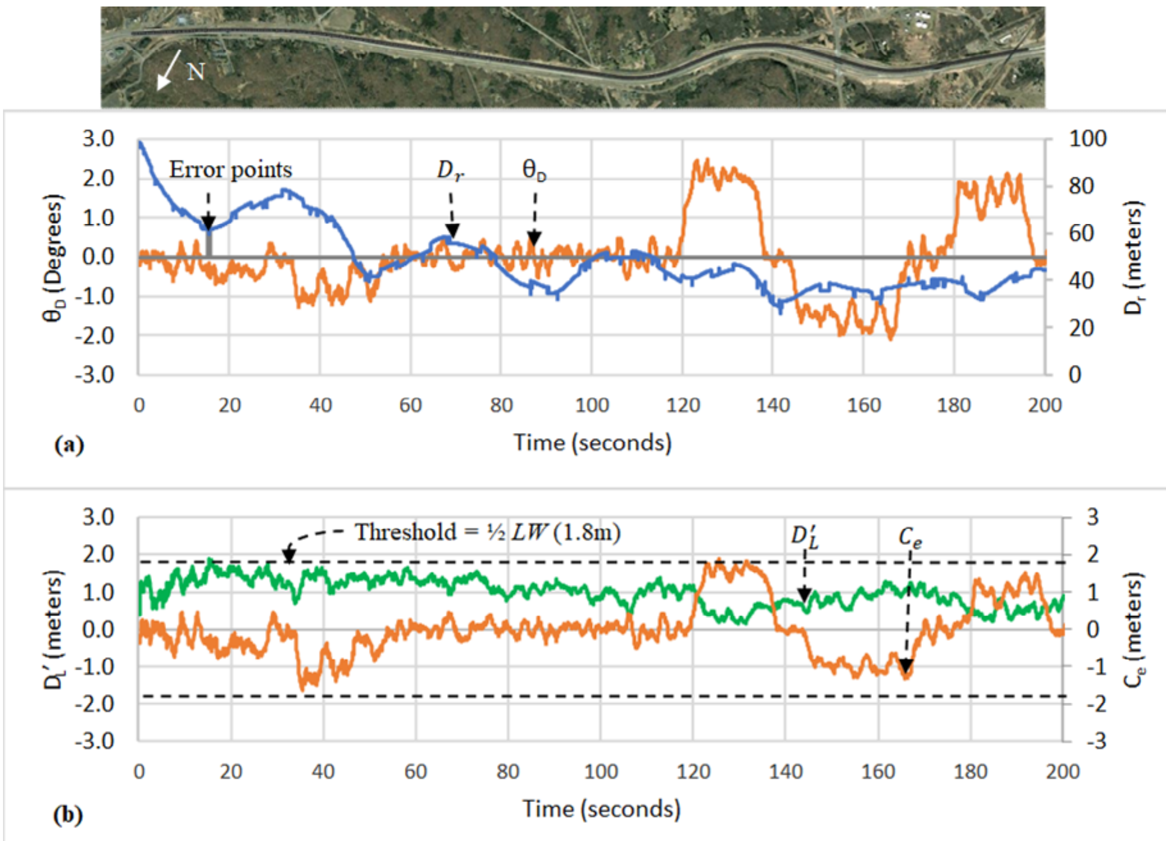

Figure 2.5: (a) θ_D and D_r vs time and (b) Ce and D_L' vs. time, for field test run #1 where many erroneous lane decisions were observed. The erroneous decisions are shown with grey mask in (a). The corresponding road map of the field test is shown on the top of the figure.

2.3.2 Example 2: Trial with more errors

Similar to the run in Figure 2.5 where 4 errors occurred, in another run out of total 4 runs with errors, only 8 errors were experienced. Although, these two runs had only a few errors (4 and 8), the remaining two out of the 4 runs with erroneous decisions had relatively large number of continuous errors. For one of those two runs, the calculated $\boldsymbol{D_r}$ and $\boldsymbol{\theta_D}$ between the two vehicles versus time is shown in Figure 2.6(a). In this run, $\boldsymbol{D_r}$ between the two vehicles was varied between 20 and 120 m whereas $\boldsymbol{\theta_D}$ between the two vehicles varied between -4 and +5 degrees. The peak values of $\boldsymbol{\theta_D}$ occurred around the curved section of the road where $\boldsymbol{D_r}$ between the two vehicles was also large (>80 m), as can be seen in Figure 2.6. The larger values of $\boldsymbol{\theta_D}$ resulted in much larger values of $\boldsymbol{C_e}$ as shown in Figure 2.6(b), where corresponding $\boldsymbol{C_e}$ is plotted versus time. In this run, $\boldsymbol{C_e}$ varies between -6 m and +8 m taking higher values on the curved sections of the road where both $\boldsymbol{D_r}$ and $\boldsymbol{\theta_D}$ are larger, as can be seen from the corresponding map of the road on the top of the Figure 2.6. Along with $\boldsymbol{C_e}$, $\boldsymbol{D_L'}$ is also plotted versus time in Figure 2.6(b). The two vehicles were traveling on two adjacent lanes in this run, so $\boldsymbol{D_L'}$ should be either between 1.8 to 5.4 m or -5.4 to -1.8 m for correct lane identification. The threshold lines are shown in Figure 2.6(b) to illustrate that $\boldsymbol{D_L'}$ crossed the threshold bound for relatively longer periods of time resulting in erroneous relative lane decision. This occurs on the sharper curved sections of the road when $\boldsymbol{D_r}$ between the two vehicles is also large (> 80m) so that $\boldsymbol{C_e}$ becomes too large (> 6m) to be corrected using proposed methodology.

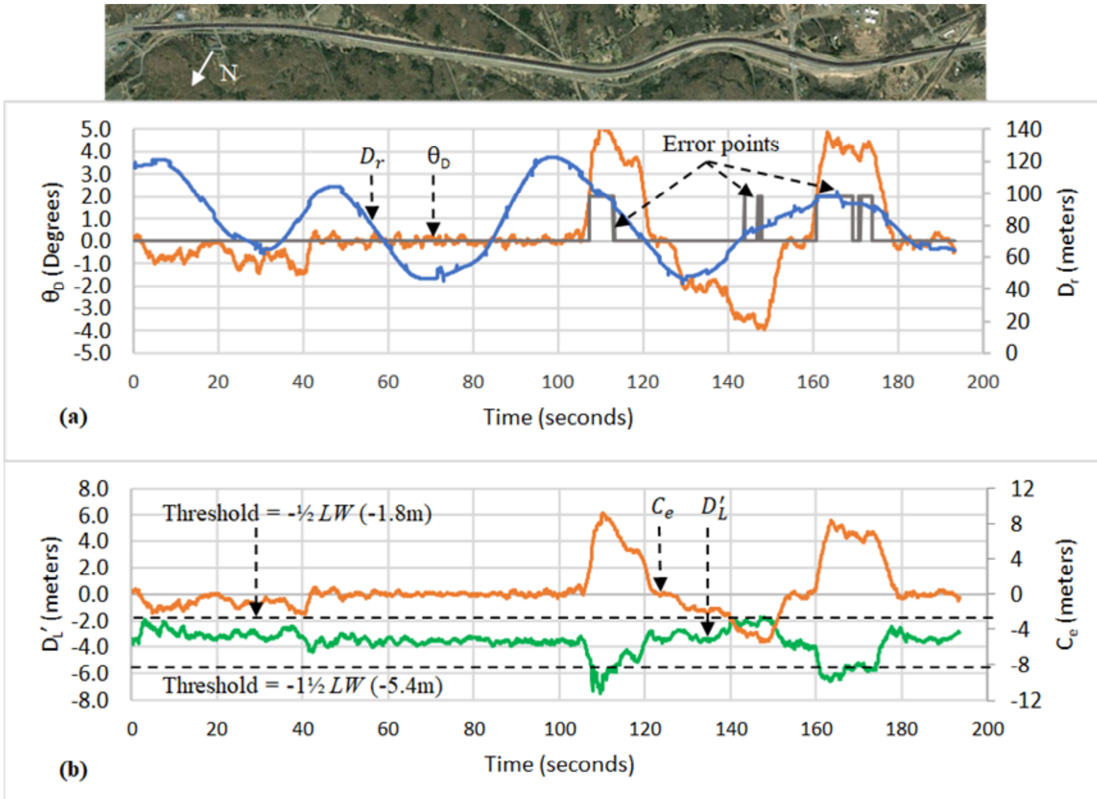

Figure 2.6: (a) θ_D and D_r vs time and (b) C_e and D_L' vs. time, for field test run #5 where many erroneous lane decisions were observed. The erroneous decisions are shown with grey mask in (a). The corresponding road map of the field test is shown on the top of the figure.

2.3.3 Error Analysis

The relative lane identification error was highly correlated with $|C_e|$ with likelihood of error increasing with larger values of $|C_e|$. The values of $|C_e|$ ranged from almost zero for the straight road section to up to 10 m for the curved road sections during all 12 runs. To find the boundaries of reliable relative lane decision, the range of values for both D_r and θ_D for fixed values of $|C_e|$ were calculated and are shown in a contour plot in Figure 5(a) where D_r is plotted versus θ_D for 1, 2, 3, 4, 5, and 10 m of $|C_e|$. Similarly, the acquired values of $|C_e|$ during the field tests, in terms of its corresponding D_r and θ_D, from all ~24,000 time instances in 12 runs are also superimposed on the contour plot of Fig. 3.7(a). For all except 314 time instances, the calculated value of C_e resulted in correct relative lane identification of the two vehicles. For those 314 time instances resulting in erroneous relative lane identification, the acquired values of $|C_e|$ are shown in a similar contour plot in Fig. 2.7(b). As can be seen from Figure 2.7(b), most of the time the erroneous lane decision was made where the value of $|C_e|$ was quite large due to the two test vehicles being on the curved sections of the road resulting in a large value of θ_D (>3 degree) where D_r is also large (>80m).

Fig. 2.7(b) also shows that there was no erroneous decision in relative lane identification in all 12 runs regardless of the degree of curvature of the road when the D_r was less than 50m. The overall accuracy of relative lane decision for all 12 runs is summarized in Table 1 for different values of D_r. The accuracy decreases when D_r increases on curved sections of the road resulting in larger values of $|C_e|$. However, for straight sections of the road, values of $|C_e|$ remain small even for larger values of D_r resulting in improved accuracy. Therefore, a limit on the value of $|C_e|$ may be imposed to improve accuracy of lane identification to accommodate curved sections of the road where $|C_e|$ becomes large. For example, for up to 150 m D_r, the overall accuracy is 98.67% without limiting $|C_e|$ but can be improved to 99.71%, and 99.96% by limiting $|C_e|$ to 5 and 3 m, respectively (Table 1). It should be noted that by limiting $|C_e|$, relative lane decision would not be performed in some cases in which $|C_e|$ is larger than the specified limit. However, for those safety applications, for which the relative lane and position of the surrounding vehicles is needed only within a small relative distance of each other, limiting $|C_e|$ will not exclude many cases of practical interest.

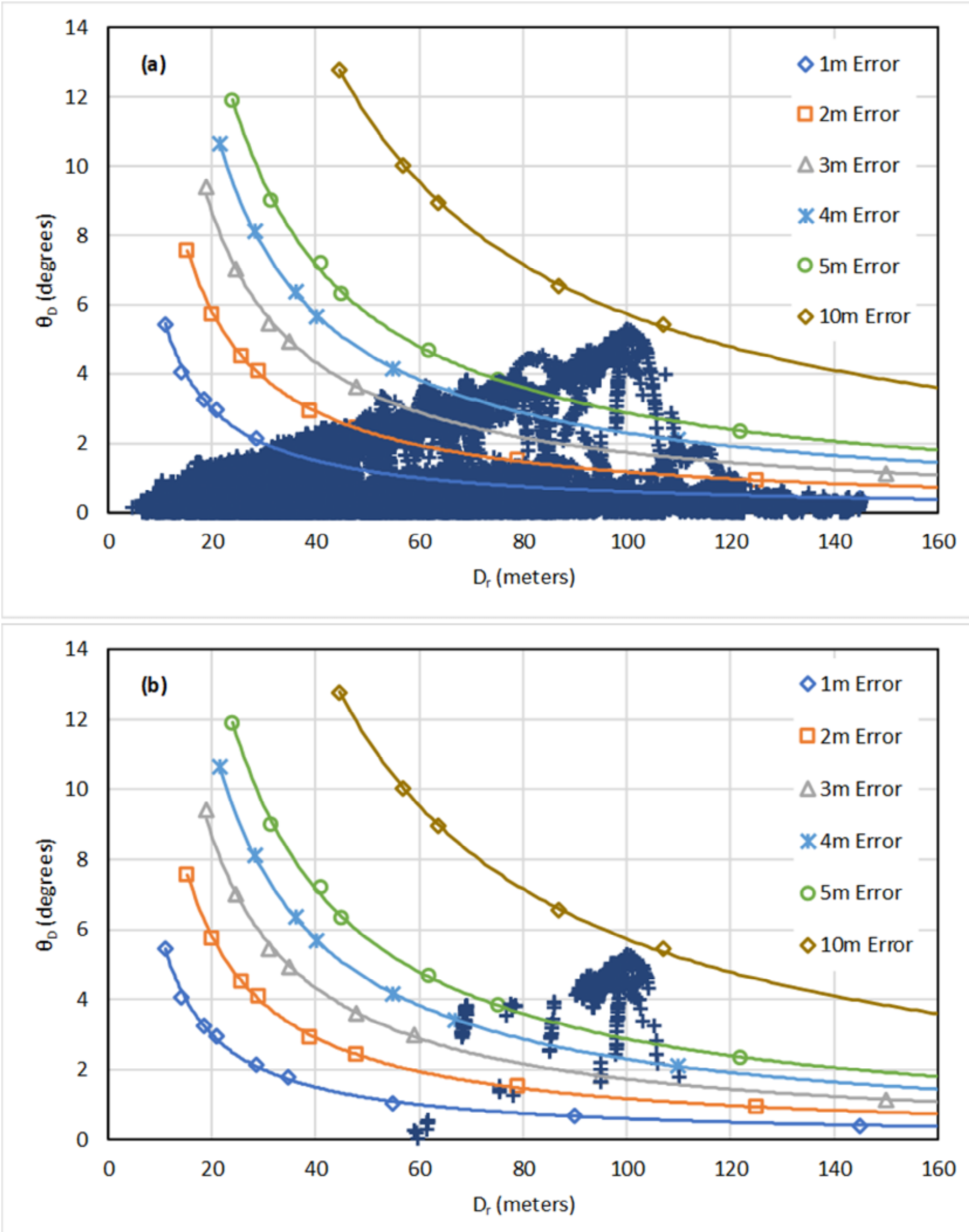

Figure 2.7: The contour plot of θ_D vs. D_r for fixed values of calculated |Ce | (1m, 2m 3m, 4m 5m, and 10m). All acquired values of |Ce | in real time during the entire duration of field test are superimposed in (a), and only those acquired values of |Ce | where an erroneous relative lane decision was made are superimposed in (b).

CHAPTER 3: MERGE TIME CUSHION

Merge time cushion is defined as the time required for the vehicle in the right most lane of the freeway to arrive at the common merging point which could potentially interfere with the merging of the ramp vehicle. DSRC equipped vehicles travelling on the freeway and on the merging-ramp will periodically communicate important traffic parameters such as their location, direction of travel, and speed, to each other. Using that information, the relative trajectories of all DSRC equipped vehicles travelling on the freeway will be acquired and then processed in real time to identify their relative lane and position. Once the relative lane and position of the vehicles traveling on the freeway are identified, a merge time cushion will be estimated which could potentially be used as an important parameter to develop a merge assist application.

The idea of merge time cushion is shown in Figure 3.1, where one vehicle is shown at a merge junction of a freeway and two more vehicles are shown on the main freeway. Once the DSRC communication is established between the vehicles on the main freeway and the vehicle on the merge junction, and relative positions of the vehicles are calculated in the DSRC device of the vehicle on the merge junction, it will be determined which vehicle is on the right most lane of the freeway which could interfere with the merging of the vehicle on the merge junction. Once lane determination is confirmed, using the speed of the vehicle on the right most lane, a merge time cushion will be estimated which is the time for the vehicle on the right most lane to reach to the common merging position, M, of the merging vehicle and the vehicle on the right most lane as shown in Figure 3.1. The merge time cushion will be updated continuously in real time and it may slightly change depending upon the speed of the vehicle on the rightmost lane of the freeway and/or the geometry of the merging ramp. Please note that if there is only one vehicle traveling towards the merging junction on the freeway, it will be considered to be in the right most lane. Furthermore, the vehicle leading ahead in the right most lane towards the merging junction will be chosen for merge time cushion calculation.

There are typically two distinct scenarios in calculating merge time cushion w.r.t the geometry of the freeway ramp. Figure 3.1 illustrates a scenario when the vehicle on the merging ramp merges into the freeway in a relatively straight path (case 1), whereas Figure 3.2 shows a scenario where the freeway ramp is a sharp curve and vehicle merges into the freeway in a curved path (case 2). In figure 1 θ_{Rn} and θ_{Rn-1} are the headings of the vehicle traveling on the ramp. Similarly, θ_{Fn} and θ_{Fn-1} are the headings of the vehicles travelling on the freeway. 'M (P_x, P_y)' is the merging point where the trajectories of the vehicles travelling on the ramp and freeway intersect each other.

$$\Delta\theta_R = \theta_{Rn} - \theta_{Rn-1}$$
$$\Delta\theta_F = \theta_{Fn} - \theta_{Fn-1}$$

To distinguish between case 1 and case 2, we calculate $\Delta\theta_R$. If Δθ_R≃0° or less than a certain threshold, we consider that the vehicles is travelling in a straight path (case 1). Similarly, if $\Delta\theta_R$ > threshold, we consider that the vehicle is travelling on a curved path (case 2).

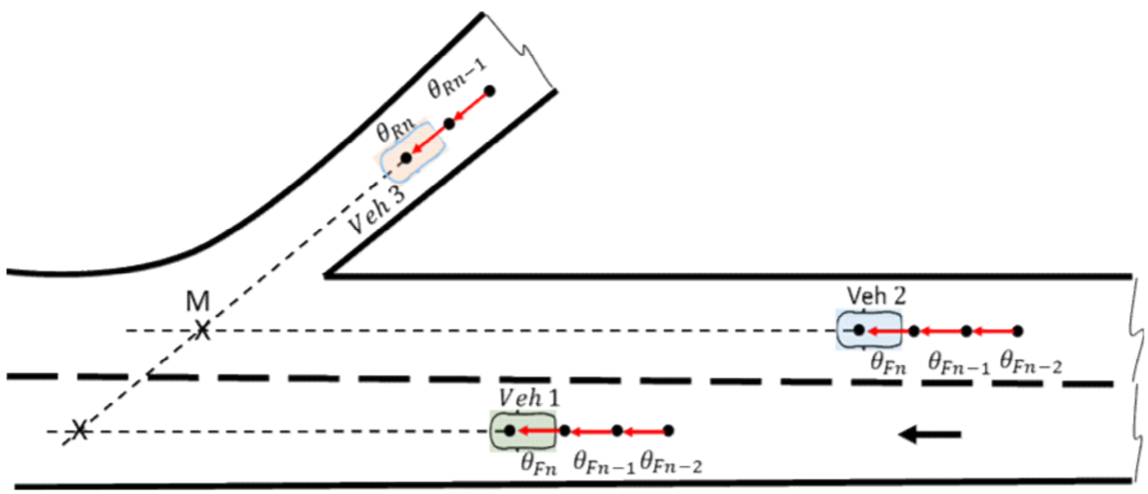

Figure 3.1: Graphical representation of merge time cushion calculation, where the ramp vehicle merges into the freeway in a straight path. 'M' is the common merging point of vehicle 2 and vehicle 3.

Case 1:

Calculating merging point '$M(P_x, P_y)$': As the two vehicles are travelling in a relatively straight path, their merging point can be estimated by calculating where the two straight lines intersect. This can be done by using Line-Line intersection equation (10).

$$P_x = \frac{(x_1y_2 - x_2y_1)(x_3 - x_4) - (x_3y_4 - x_4y_3)(x_1 - x_2)}{(x_1 - x_2)(y_3 - y_4) - (x_3 - x_4)(y_1 - y_2)}$$

$$P_y = \frac{(x_1y_2 - x_2y_1)(y_3 - y_4) - (x_3y_4 - x_4y_3)(y_1 - y_2)}{(x_1 - x_2)(y_3 - y_4) - (x_3 - x_4)(y_1 - y_2)}$$

Merge time cushion or Time to M (TTM): Once 'M' is calculated we can calculate the merge time cushion or TTM by calculating the distance between the vehicle traveling on the freeway and the common merging point M (DTM) and divide it by its speed.

$$Merge\ time\ cushion\ or\ TTM = DTM/Speed$$

Case 2:

As the vehicle travelling on the ramp is not travelling in a straight path (Figure 3.9), its trajectory cannot be extended to accurately estimate 'M'. However, most looped ramps have a straight section at the end of the ramp for the merging vehicles to accelerate and merge into the freeway. More research needs to be done to study and test the geometry of wide range of ramps. For now, we have noticed that most looped ramps start transitioning into a relatively straight road when $\theta' = \theta_F - \theta_R < 90$. Therefore, the same method used in case 1 can be applied but with some added adjustments. For example, in the case of figure 3.2, after θ' is < 90 the ramp starts transitioning into a relatively straight path. However, Distance to 'M' (DTM) of the freeway vehicle is estimated less than the actual DTM. As illustrated in figure 3.2, after each point the estimated DTM gets closer and closer to the actual distance. Therefore, by gathering enough data, θ' and the difference between estimated DTM and actual DTM can be used to form a trendline which can be used to adjust the estimated DTM. Once DTM is adjusted, it can be used to calculate the merge time cushion.

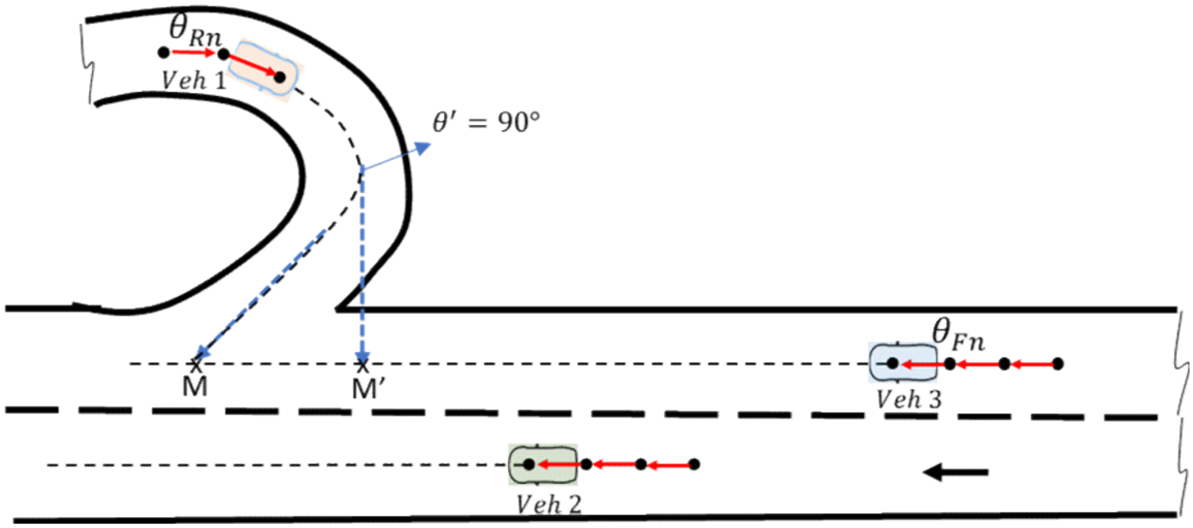

Figure 3.2: Graphical representation of case 2, where the ramp geometry is loop-shaped.

CHAPTER 4: CONCLUSION AND FUTURE WORK

In this report, a methodology is presented to estimate the merge time cushion using standard GPS and DSRC based vehicle to vehicle communication. The merge time cushion can potentially be used by the driver of the ramp vehicle to safely merge into the freeway. A methodology to accurately identify the relative lane and position of surrounding vehicles in real time using standard GPS receivers and DSRC based V2V communication is also presented. The identification of relative lane and position benefits not only a merge assist system, but could also be used in many other ADAS functions such as; Blind Spot Detection, Overtake Warning System etc. Field tests were performed on a freeway with a variety of curved road sections to evaluate the proposed lane identification methodology. The results of field tests show that the relative position of the surrounding vehicles in terms of which vehicle is trailing ahead or behind can be identified without any errors as long as the relative distance between them remains at least a few meters. On the other hand, the accuracy of relative lane identification was not 100% in all cases, especially when the relative distance between the two vehicles was large on curved road sections. Most of the errors occurred where the road segment had sharp curves and the relative distance between the two vehicles was >80 m and, no errors were observed when the distance between the two vehicles was <50 m, regardless of the degree of curvature of the road.

To estimate the merge time cushion, two distinct merging scenarios and its solution are presented based on the geometry of the road. However, more tests need to be conducted to test the performance of the proposed methodology. For future work, Field tests should be conducted to estimate the merge time cushion in real time, where one vehicle will be travelling on the freeway entrance ramp and (at least) two more vehicles will be travelling on the main freeway. The two vehicles on the main freeway will travel towards the merging point, and the ramp vehicle will follow to merge into the freeway at the same time. Once the DSRC communication is established between the vehicles on the main freeway and the vehicle on the freeway ramp, and relative positions of the vehicles are calculated in the DSRC device of the vehicle on the merge junction, it will be determined which vehicle is on the right most lane of the freeway which could interfere with the merging of the vehicle on the merge junction. Once lane determination is confirmed, using the speed of the vehicle on the right most lane, a merge time cushion will be estimated which will be shown to the driver of the ramp vehicle on the tablet screen in the form of how much time is needed for the right most vehicle to reach to the common merging point. The merge time cushion will be updated continuously in real time and it may slightly change depending upon the speed of the vehicle on the rightmost lane of the freeway and/or the geometry of the merging ramp. Please note that if there is only one vehicle traveling towards the merging junction on the freeway, it will be considered to be in the right most lane. Furthermore, the vehicle leading ahead in the right most lane towards the merging junction will be chosen for merge time cushion calculation.

References

1) ITS Strategic Research Plan 2015-2019. Please see at http://www.its.dot.gov/strategicplan.pdf.
2) A.T. McCartt et al., "Types and characteristics of ramp-related motor vehicle crashes on urban interstate roadways in Northern Virginia", Journal of Safety Research, vol.35, 2004, pp. 107- 114.
3) Bruce N. Janson, Wael Awad, Juan Robles, Jake Kononov, Brian Pinkerton, "Truck Accidents at Freeway Ramps: Data Analysis and High-Risk Site Identification", Journal of Transportation and Statistics, January 1998, p 75 – 92.
4) Chris Lee, Bruce Hulinga and Kaan Ozbay, "Quantifying Effects of Ramp Metering on Freeway Safety" in the proceeding of annual meeting of Transportation Research Board, Washington DC., Jan. 9 – 13, 2005, Paper No. 05-0889.
5) Katrin Bilstrup, et al., "Report on Collaboration between CVIS and CERES in the Project vehicle Alert System (VAS)", Technical Report IDE09120, December 2009.
6) Jean Marie Vianney Hakizimana, "Investigation of Services and Application Scenarios for Inter-Vehicle Communication", Technical report, IDE0751, June 2007.
7) A white paper by Univ. of Urbana-Champaign and Microsoft titled "Vehicle-to-Vehicle Communication Protocol for Cooperative Collision Warning" available at http://research.microsoft.com/en-us/um/people/zhao/pubs/yang_x_v2v.pdf
8) S. Rezaei, R. Sengupta, and H. Krishnan, "Reducing the communication required by DSRC-based vehicle safety systems," IEEE's Intelligent Transportation Systems Conference, 2007, pp. 361-366, Sept. 30 2007-Oct. 3 2007.
9) N. Kawanishi, R. Furukawa, S. Tang, A. Hasegawa, R. Miura and Y. Takeuchi "Simulation evaluation of cooperative relative positioning around intersections", ITS Telecommunications (ITST), 2013 13th International Conference, Nov 2013, pp. 372 – 377.
10) S. Tang, N. Kubo and M. Ohashi, "Cooperative Relative Positioning for Intelligent Transportation System," in Proc. 12-th International Conference on ITS Telecommunications, pp. 506-511, 2012
11) N. Alam, A. T. Balaei, and A. G. Dempster, "Relative positioning enhancement in vanets: A tight integration approach," IEEE Trans. Intell. Transp. Syst, vol. 14, no. 1, pp. 47–55, 2013 (cit. on pp. 2, 13).

12) J. Farrell and T. Givargis, “Differential gps reference station algorithm-design and analysis,” IEEE Transactions on Control Systems Technology, vol. 8, no. 3, pp. 519–531, 2000 (cit. on pp. 2, 9).
13) “High accuracy-nationwide differential global positioning system program fact sheet,” FHWA-RD-03-039, 2003. [Online]. Available: http:// www. fhwa. dot. gov/publications/research/operations/03039/ (cit. on pp. 2, 9).
14) Z. Peng, S. Hussain, M.I. Hayee, M. Donath. Acquisition of relative trajectories of surrounding vehicles using GPS and DSRC based V2V communication with lane level resolution. Proceedings of 3rd International Conference on Vehicle Technology and Intelligent Transport Systems, 2017, page 242-251.
15) Albert S. Huang. Lane Estimation for Autonomous Vehicles using Vision and LIDAR. 2010, http://rvsn.csail.mit.edu/Pubs/phd_ashuang_2010feb_laneestimation.pdf. Accessed Jul. 30, 2017.
16) Selloum, A., D. Betaille, E. L. Carpentier, and F. Peyret. Lane level positioning using particle filtering. 2009 12th International IEEE Conference on Intelligent Transportation Systems, 2009.
17) Lee, S., S.-W. Kim, and S.-W. Seo. Accurate ego-lane recognition utilizing multiple road characteristics in a Bayesian network framework. 2015 IEEE Intelligent Vehicles Symposium (IV), 2015.
18) Casapietra, E., T. H. Weisswange, C. Goerick, F. Kummert, and J. Fritsch. Building a probabilistic grid-based road representation from direct and indirect visual cues. 2015 IEEE Intelligent Vehicles Symposium (IV), 2015.
19) N. Alam, A. T. Balaei and A. G. Dempster, Relative positioning enhancement in VANETs: A tight integration approach", IEEE Trans. Intell. Transp. Syst., vol. 14, no. 1, pp. 47-55, 2013.
20) D Chun.; K, Stol. Vehicle motion estimation using low-cost optical flow and sensor fusion, Mechatronics and Machine Vision in Practice (M2VIP), 2012 19th International Conference, pp. 507 - 512, Nov. 2012.
21) Abdelfatah, W.F., et al., "2D Mobile multi-sensor navigation system realization using FPGA-based embedded processors," Canadian Conference on Electrical and Computer Engineering (CCECE), 2011, pp. 1218-1221.
22) Qingquan Li; Long Chen; Ming Li; Shih-Lung Shaw; Nuchter, A. A Sensor-Fusion Drivable-Region and Lane-Detection System for Autonomous Vehicle Navigation in Challenging Road Scenarios, Vehicular Technology, IEEE Transactions on, Volume: 63, Issue: 2, pp. 540 – 555, Feb. 2014.
23) H. Zhao, M. Chiba, R. Shibasaki, X. Shao, J. Cui and H. Zha, A laser-scanner-based approach toward driving safety and traffic data collection, IEEE Trans. Intell. Transp. Syst., vol. 10, no. 3, pp. 534-546, 2009.

24) A. Bansal, H. Badino and D. Huber, Understanding how camera configuration and environmental conditions affect appearance-based localization, Intelligent Vehicles Symposium Proceedings (IV), 2014 IEEE, pp. 800-807.
25) Guizhen Yu, Zhangyu Wang, Yalong Ma, Xinkai Wu. Improved Real-Time Lane Detection Using Advanced Lane Extraction Method. Transportation Research Board, Washington, DC. 2017.
26) Sakjiraphong, S., A. Pinho, and M. N. Dailey. Real-time road lane detection with commodity hardware. 2014 International Electrical Engineering Congress (iEECON), 2014.
27) Assidiq, A., O. O. Khalifa, M. R. Islam, and S. Khan. Real time lane detection for autonomous vehicles. 2008 International Conference on Computer and Communication Engineering, 2008.
28) R. Toledo-Moreo, M. A. Zamora-Izquierdo, B. Ubeda-Minarro, and A. F. Gomez-Skarmeta, High-integrity IMM-EKF-based road vehicle navigation with low-cost GPS/SBAS/INS, IEEE Trans. Intell. Transp.Syst., vol. 8, no. 3, pp. 491-511, Sep. 2007.
29) N. Mattern, R. Schubert, and G. Wanielik, High-accurate vehicle localization using digital maps and coherency images, in Proc. IEEE Intell. Vehicles Symp., La Jolla, CA, 2010, pp. 462–469.
30) R. G. García-García, M. A. Sotelo, I. Parra, D. Fernández, andM. Gavilán, 3D visual odometry for GPS navigation assistance, in Proc. IEEE Intell. Vehicles Symp., Istanbul, Turkey, 2007, pp. 444–449.
31) J. Juang; C. Lin. A Sensor Fusion Scheme for the Estimation of Vehicular Speed and Heading Angle, Vehicular Technology, IEEE Transactions on, pp. 2773 - 2782 Volume: 64, Issue: 7, July 2015.
32) S. Rezaei and R. Sengupta, "Kalman filter-based integration of DGPS and vehicle sensors for localization," IEEE Trans. Control Syst. Technol., vol. 15, no. 6, pp. 1080–1088, Nov. 2007.
33) A. Vu, A. Ramanandan, A. Chen, J. A. Farrell, and M. Barth, "Real-Time Computer Vision/DGPS-Aided Inertial Navigation System for Lane-Level Vehicle Navigation", IEEE Transactions on Intelligent Transportation Systems, vol. 13, no. 2, pp. 899-913, 2012.
34) J. Du and M. Barth, "Lane-level positioning for in-vehicle navigation and automated vehicle location (AVL) systems", Proc. Int. IEEE 7th ITSC, pp. 35-40, 2004.
35) C. Guo, J. Meguro, K. Yamaguchi, K. Kidono and Y. Kojima, "Improved lane detection based on past vehicle trajectories", Intelligent Transportation Systems (ITSC), 2014 17th International IEEE Conference, pp. 1956-1963

36) Converting UTM to Latitude and Longitude (Or Vice Versa). https://www.uwgb.edu/dutchs/UsefulData/UTMFormulas.HTM. Accessed Jul. 30, 2017.
37) Michele L. Timmons. Department of Transportation State Aid for Local Transportation Division, chapter 8820. 2013. http://www.dot.state.mn.us/stateaid/programlibrary/stateaidrules.pdf. Accessed Jul. 30, 2017.
38) A.S. MIHAITA, Paul Tyler, Aditya Menon. An investigation of position accuracy transmitted by connected heavy vehicles using DSRC. Transportation Research Board, Washington, DC. 2017.