Lane Departure Warning System using Standard GPS Technology and V2V Communication

Md Touhid Hossain, Shahnewaz Chowdhury and M. I. Hayee
Department of Electrical Engineering, University of Minnesota Duluth, Duluth, Minnesota, U.S.A.

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Abstract: Lane departure warning system (LDWS) has significant potential to reduce crashes. Generally, an LDWS uses various image processing techniques or global positioning system (GPS) technology with lane-level resolution maps. However, these are expensive to implement and have performance limitations, such as harsh weather or irregular lane markings can drastically reduce their performances. Previously, we developed an LDWS which generated road reference heading (RRH) from a vehicle's past travel trajectories acquired by GPS to detect unintentional lane departure. However, when a vehicle travels for the first time on a given road, it does not have any past trajectory to generate the RRH needed to detect unintentional lane departure. To overcome this limitation, we have augmented our previously developed LDWS by adding a vehicle to vehicle (V2V) communication feature to it, which can acquire the required RRH from a nearby vehicle via V2V communication. We have extensively tested the V2V communication feature of our current LDWS in the field to evaluate its performance in real-time. Test results show that the RRH of a given road can be successfully transferred from one vehicle to another on demand, and the LDWS can detect each unintentional lane departure accurately in a timely manner.

1 INTRODUCTION

All modern vehicles are equipped with different Advanced Driver Assistance Systems (ADAS) to improve safe driving (Maag et al., 2012). Lane departure warning is one of the most important ADAS features which can prevent accidents on highways and freeways when a vehicle is about to unintentionally drift away from its lane. According to American Association of State Highway and Transportation Officials (AASHTO) almost 60% of the fatal accidents are caused by an unintentional lane drifting of a vehicle on major roads (Officials, 2008). In a recent study which compared crashes with and without a lane departure warning system (LDWS), it was found that an in-vehicle LDWS was helpful in reducing crashes of all severities by 18%, with injuries by 24%, and with fatalities by 86% without considering for driver demographics (Cicchino, 2018).

Most available lane departure warning systems typically use a single camera and a processor to identify the imminent lane departure (Hsiao & Yeh, 2006) (An et al., 2006) (Yu et al., 2008) (Leng & Chen, 2010) while other modern systems use optical scanning and Light Detection and Ranging (LIDAR) sensors (Lindner et al., 2009). A careful view of camera-based systems reveals that the calibration of a camera is an important element. However, there are systems available that can detect the lateral offset of a vehicle even with an uncalibrated camera (Jung & Kelber, 2005). Most of these camera-based systems use different image processing techniques such as linear parabolic lane model (Jung & Kelber, 2004) or the extended edge-linking algorithm (Lin et al., 2010), which extract the lane markings from consecutive picture frames to calculate lateral shift of a vehicle. Earlier camera-based systems were vulnerable to lighting conditions, hence not capable to accurately recognize the lane markings at nighttime. However, image processing techniques have advanced over the past couple of decades overcoming the limitation of diminished lighting conditions to successfully detect lane drifting even in the low lighting or night-time (Hsiao et al., 2008). For example, a Video-Based Lane Estimation and Tracking (VioLET) system, which uses steerable filters, is an efficient method for detecting solid-line and segmented-line markings under varying lighting and road conditions for robust and accurate lane-marking detection (McCall & Trivedi, 2006).

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Similarly, optical scanning systems which comprise of a linear array of infrared transmitting devices to scan the lateral area of the highway for lane markings, are inherently independent of the varying lighting conditions (Dobler et al., 2000). Although camera and optical sensor-based systems work well in favorable weather and road conditions in day or night light, their performance deteriorates when the road conditions are not favorable such as an absent or irregular/broken lane marking or harsh weather conditions such as fog, rain, and snow resulting in inaccurate lane departure detection. Moreover, there are also some systems which integrate Global Positioning System (GPS) data with a camera based LDWS to increase the reliability of lane departure detection in adverse road and weather conditions. However, such systems require GPS technology, inertial navigation sensor, and access to digital maps of lane-level resolution to correct the GPS position (Clanton et al., 2009), making such systems more complex and expensive to implement.

In our previously developed LDWS, we used standard GPS technology and developed a road reference heading (RRH) generation algorithm which uses a vehicle's past trajectories on a road to generate an RRH for that road (Shahnewaz Chowdhury et al., 2021). By comparing the RRH of a given road with a vehicle's current travel trajectory on that road obtained from a standard GPS receiver, our developed LDWS calculates the instantaneous lateral shift which is accumulated over time to detect any unintentional lane departure (Faizan et al., 2019). However, our previously developed LDWS had a drawback in case of a vehicle traveling on a given road for the first time, as it would not have the any past trajectories to generate the RRH needed to detect unintentional lane departure. In this work, we have augmented our previously developed LDWS by adding the feature of vehicle to vehicle (V2V) communication. The provision of V2V communication enables the transfer of RRH from one vehicle to the other; provided both the vehicles are equipped with V2V communication device. Our field test results show that by using the RRH received from another vehicle, our newly proposed LDWS can detect any lane departure on a given road and issue timely warning even if the vehicle is traveling for the first time on that road.

The rest of the paper is organized as follows. Section 2 describes the system architecture of the newly developed LDWS enabled with V2V communication feature to transfer RRH generated from a vehicle's past trajectories. Section 3 provides the details about the V2V communication process, and section 4 discusses the field test results. Finally, section 5 states the conclusions.

2 SYSTEM ARCHITECTURE

The newly developed lane departure warning system has both an RRH generator as well as it is equipped with V2V communication feature to transfer RRH from one vehicle to another on need basis. The RRH generator can generate RRH for any given road using

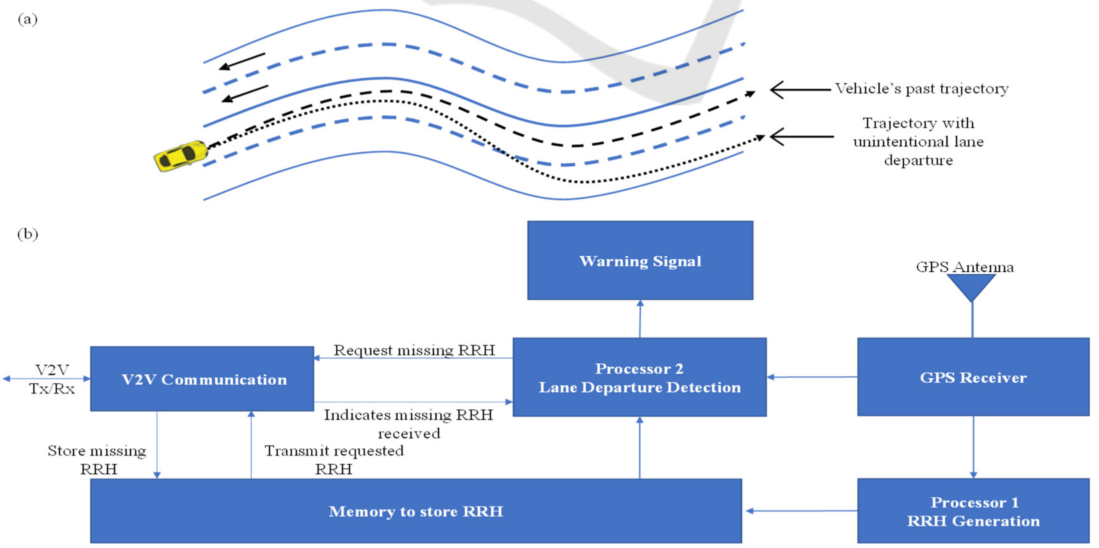


Figure 1: (a) Conceptual diagram showing how a past trajectory (black dashed line) of a given vehicle can serve to generate RRH to detect its unintentional lane departure in future (black dotted line), and (b) the system architecture of LDWS enabled with V2V communication to transmit or receive RRH from a nearby vehicle.

a vehicle's one or more past trajectories on that road acquired by a standard GPS receiver as shown in schematic diagram of Figure 1a. The dashed line in Figure 1a represents a vehicle's past trajectory which can be used to generate RRH for the road to detect any unintentional lane departure as represented by the dotted line in Figure 1a. In case if a vehicle is traveling on a given road for the first time, it would lack any past trajectory to generate RRH. However, if any nearby vehicle equipped with V2V communication has the RRH for that road, our current LDWS enables the vehicle in need to obtain the RRH from the nearby vehicle via V2V communication. Once an RRH for a given road is generated or an RRH is received from a nearby vehicle, it can be used to detect any future unintentional lane departure on that road.

Figure 1b shows the architectural diagram of the proposed system combining the previously developed LDWS, and the newly added V2V communication feature; the GPS receiver acquires longitude and latitude of a moving vehicle's position in real-time to be used by both processors 1 and 2. The processor 1 uses a sufficient length of a past trajectory on a given road whenever that is available to generate an RRH for that road. On the other hand, processor 2 works in real-time to detect unintentional lane departure by using either the RRH generated by processor 1 or RRH received from a nearby vehicle via V2V communication. Once an RRH is generated or received from another vehicle, it is stored in the memory of LDWS for future lane departure detection. This prevents processor 2 from reproducing RRH if already available and thus improves the LDWS's efficiency. The V2V communication module added in this augmented LDWS can transmit an already generated RRH to a nearby vehicle when requested as well as request and receive a missing RRH from a nearby vehicle when needed.

3 V2V COMMUNICATION FOR LDWS

The V2V communication feature added to our proposed LDWS has overcome the drawback of not having past trajectories to generate necessary RRH for a first-time traveling vehicle on any given road. To establish proper communication between two vehicles, we have developed a V2V handshake protocol and RRH data transfer software. This section will highlight the design and development of V2V communication protocol needed to exchange RRH between two vehicles upon need.

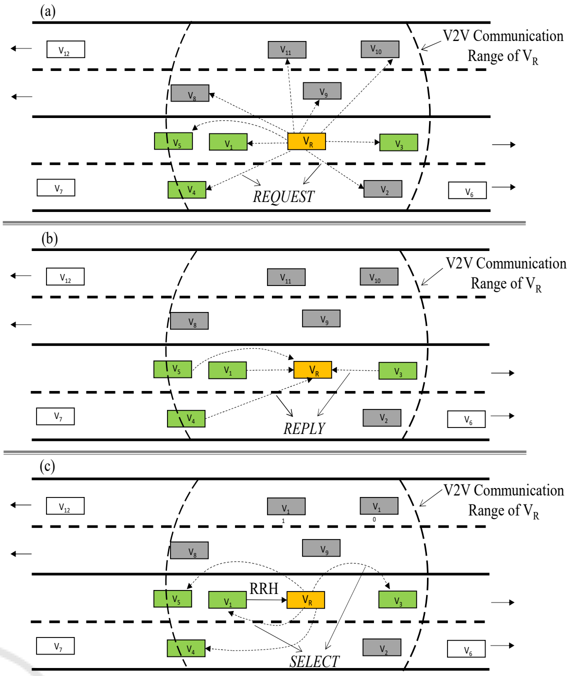


Figure 2: A scenario illustrating V2V handshake protocol where (a) a vehicle VR in need of road reference heading (RRH) broadcasts a *REQUEST* to all neighboring vehicles within its V2V communication range, (b) all potential candidate vehicles (colored in green) send a *REPLY* message back to the requesting vehicle and (c) the requesting vehicle VR sends a *SELECT* message to receive RRH from the most suitable potential candidate vehicle (V1).

3.1 V2V Handshake Protocol

For successful transfer of an RRH from one vehicle to another upon request, proper V2V handshake protocol is required to identify the most suitable neighboring vehicle to transfer RRH to the vehicle in need. A vehicle will request an RRH from neighboring vehicles only when it is traveling on a road for the very first time or does not have the RRH for that road. One such scenario showing a vehicle V_R traveling on a 4-lane road for the first time while not having the RRH for that road is illustrated in Figure 2. A total of 12 neighboring vehicles (V_1 to V_{12}) are also traveling on the same road (Figure 2). The vehicle V_R will need the RRH for that road to detect any unintentional lane departure. Therefore, it broadcasts a request for the RRH by transmitting a message called *REQUEST*. The *REQUEST* reaches all nearby vehicles within its communication range as shown by dashed arrows in Figure 2a. The data of *REQUEST* includes the direction of travel of the requesting vehicle (V_R) and its location coordinates. The direction of travel is needed to eliminate those vehicles which are traveling in the opposite direction of the requesting vehicle (V_R) because those vehicles will not stay within the communication range of the requesting vehicle long enough to complete the handshake protocol to transfer RRH.

All neighboring vehicles receiving the *REQUEST* will assess if they are traveling in the direction of the requesting vehicle and if they have the requested RRH to pass on. Any vehicle not having the requested RRH or traveling in the opposite direction of the requesting vehicle will ignore the *REQUEST*. Any vehicle having the requested RRH and traveling in the same direction as the requesting vehicle becomes a potential candidate vehicle to transfer RRH to the requesting vehicle (V_R). There are 4 such potential candidate vehicles (V_1, V_3, V_4, and V_5) shown in green color in the scenario of Figure 2. The rest of the vehicles (shown in grey color) are either traveling in the opposite direction or do not have the requested RRH. There is always a possibility to have more than one potential candidate vehicles to transmit RRH as in the scenario of Figure 2. In case of more than one potential candidate vehicles having the needed RRH, it is important that only one of those vehicles is selected to transfer RRH to avoid broadcast congestion. Usually, a vehicle which is the nearest to the requesting vehicle should transfer the requested RRH for most reliable communication. To accomplish this, each potential candidate vehicle calculates its distance from the requesting vehicle (V_R) and transmits a message called *REPLY* back to the requesting vehicle as shown by dashed arrows in Figure 2b where the same scenario of Figure 2a is repeated showing communication paths of *REPLY* messages from all potential candidate vehicles. The data of each *REPLY* message from a potential candidate vehicle includes its distance from the requesting vehicle as well as a unique identifier (ID) so that the requesting vehicle can distinguish among all potential candidate vehicles.

After receiving the *REPLY* messages from all potential candidate vehicles, the requesting vehicle, V_R selects one potential candidate vehicle at the shortest distance. Please note that if two or more vehicles are at the same distance, then the requesting vehicle can randomly select any one of them. After selecting one of the potential candidate vehicles, the requesting vehicle (V_R) sends a message called *SELECT* back to all potential candidate vehicles as shown in Figure 2c where the same scenario is repeated showing the multiple communication paths of the SELECT message to all potential candidate vehicles. The data of the *SELECT* message includes the unique ID of only one potential candidate vehicle which is at the shortest distance from the requesting vehicle so that all other potential candidate vehicles can ignore this message except the one whose unique ID is carried in this message. This will complete the V2V handshake protocol by successfully selecting the most suitable vehicle to transfer RRH to the requesting vehicle. The potential candidate vehicle with matched unique ID (V_1 in case of the given scenario of Figure 2c) can now start transferring the requested RRH to the requesting vehicle (VR) as shown by a solid arrow from V_1 to V_R in Figure 2c. The implementation details of the V2V handshake protocol and transfer of RRH are given in the rest of this section.

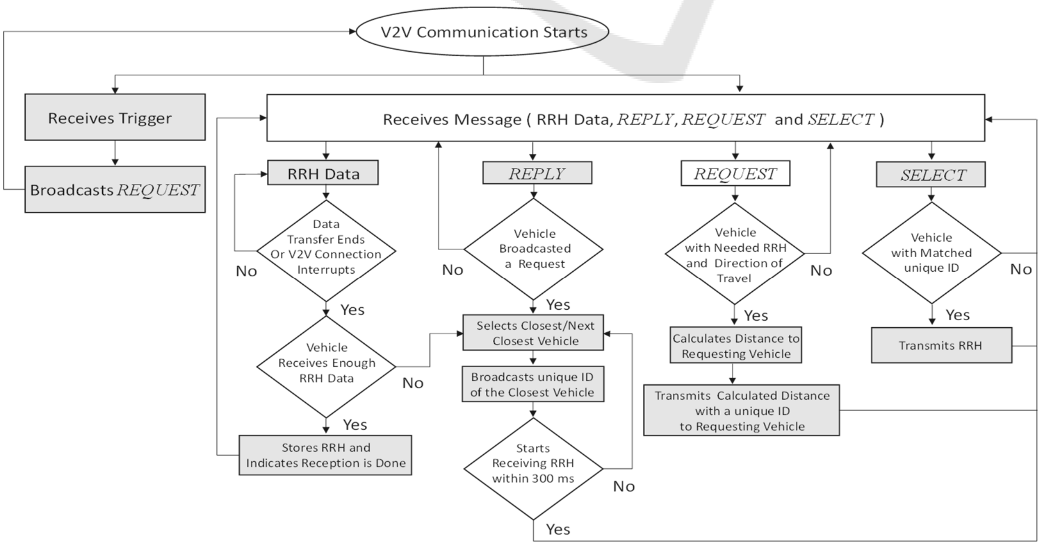
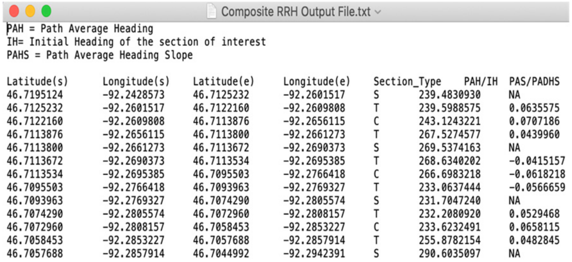


Figure 3: A flow chart of the V2V handshake protocol for a vehicle in need to receive RRH data of a given road from the most suitable neighboring vehicle on that road.


Composite RRH Output File.txt

PAH = Path Average Heading
IH= Initial Heading of the section of interest
PAHS = Path Average Heading Slope

Latitude(s)	Longitude(s)	Latitude(e)	Longitude(e)	Section_Type	PAH/IH	PAS/PADHS
46.7195124	-92.2428573	46.7125232	-92.2601517	S	239.4830930	NA
46.7125232	-92.2601517	46.7122160	-92.2609808	T	239.5988575	0.0635575
46.7122160	-92.2609808	46.7113876	-92.2656115	C	243.1243221	0.0707186
46.7113876	-92.2656115	46.7113800	-92.2661273	T	267.5274577	0.0439960
46.7113800	-92.2661273	46.7113672	-92.2690373	S	269.5374163	NA
46.7113672	-92.2690373	46.7113534	-92.2695385	T	268.6340202	-0.0415157
46.7113534	-92.2695385	46.7095503	-92.2766418	C	266.6983218	-0.0618218
46.7095503	-92.2766418	46.7093963	-92.2769327	T	233.0637444	-0.0566659
46.7093963	-92.2769327	46.7074290	-92.2805574	S	231.7047240	NA
46.7074290	-92.2805574	46.7072960	-92.2808157	T	232.2080920	0.0529468
46.7072960	-92.2808157	46.7058453	-92.2853227	C	233.6232491	0.0658115
46.7058453	-92.2853227	46.7057688	-92.2857914	T	255.8782154	0.0482845
46.7057688	-92.2857914	46.7044992	-92.2942391	S	290.6035097	NA

Figure 4: Screenshot of an RRH file of a given road with all optimized parameters.

After developing the V2V handshake protocol to identify the most suitable vehicle to transfer RRH to a vehicle in need, we implemented this protocol in our LDWS and did the necessary programming to successfully demonstrate its functionality. The flow-chart of the software to implement the newly designed V2V handshake protocol is shown in Figure 3. Please note that the software of flowchart given in Figure 3 will be running in each vehicle in addition to two other previously developed software i.e., RRH generation software and the lane departure detection software.

3.2 V2V Transfer of RRH

The handshake protocol to select the most suitable vehicle to transfer RRH to the vehicle in need is described above. The actual data transfer is implemented using a dedicated short-range communication (DSRC) based device for the demonstration purposes. The DSRC device used has a built in GPS receiver and necessary processing power to run the V2V communication software as well as software for RRH generation and LDWS algorithms. As an alternative to DSRC based V2V communication, cellular V2V (C-V2V) communication could be used as well.

After the most suitable vehicle is identified and selected, the process to transfer RRH takes place slowly over next several cycles of DSRC communication depending upon the amount of RRH data. The data of RRH generated from past vehicle trajectories using our previously developed algorithm is included in a text file as shown in Figure 4 where a screenshot of a typical RRH data file for a 4.2 km road segment of the Interstate I-35 is shown. Each row describes an individual section (straight, curve or transition) of the road and there are 13 sections (rows) in the given text file. Each section is defined by its beginning and ending points (in terms of latitude and longitude), the optimized values of relevant parameters, and the section type. Please note that an "N" indicates that the corresponding parameter is not applicable to that section. This text file has the necessary information to completely define the road reference heading at any point along the road and can be used by LDWS to detect any unintentional lane departure in real-time. Although each section of the road in RRH data file contains seven parameters to fully characterize the given section, one of the 7 parameters (the section type shown in Figure 4) is not necessarily needed as it can be deduced from the other parameters. Therefore, in our developed system, each section can be transmitted using only six parameters.

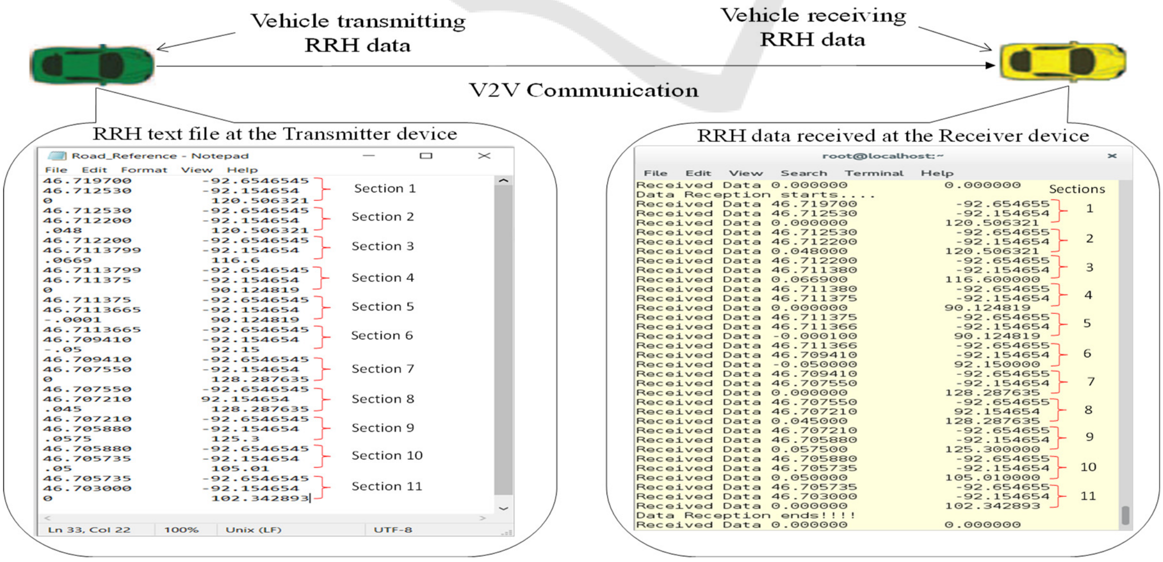


Figure 5: Screenshot of the console of the DSRC device in the transmitter vehicle (left bubble box) showing a text file of RRH data stored in the device and screenshot of the console of the DSRC device in the receiving vehicle (right bubble box) when the RRH data is received via DSRC based V2V communication.

In DSRC based V2V communication, each data transfer cycle is 100 ms and any data transfer can take place during this cycle. We have implemented RRH data transfer process section by section but in such a way that only two parameters can be transferred in one communication cycle (100 ms). As there are six useful parameters in each section of RRH data for any given road, we need three cycles (300 ms or 0.3 s) to completely transfer one section. Depending upon the number of sections of the road in an RRH text file, it can take up to a few seconds to complete the RRH transfer process. For example, there are 13 sections in the RRH text file of Figure 4, therefore, it will take 3.9 seconds (13 x 0.3 s) to completely transfer all the sections of this RRH. After successfully completing the transfer of all the sections present in the RRH data file, a final message is sent to the receiving vehicle to indicate that all the data has been sent. Please note that an additional communication cycle (0.1 s) will be needed for the final message indicating the data transfer completion. For some reason, if the connection is lost before the transfer of RRH data is completed or before enough RRH data is transferred, our developed software can manage the situation by restarting the process as described above in the V2V handshake protocol.

After developing the software for V2V handshake protocol and RRH data transfer, we evaluated this in the lab by using two DSRC devices to simulate two vehicles, one vehicle without the RRH and the other with the RRH. One such lab evaluation scenario is illustrated in Figure 5 where the vehicle shown as yellow needs an RRH for a given road and the vehicle shown as green has that RRH. Once the V2V handshake protocol establishes the connection between the two vehicles (transmitting and receiving), the transfer of RRH data takes place section by section. The transfer of the RRH data is also illustrated in Figure 5 where the screenshots of the consoles of the two DSRC devices of the two corresponding vehicles are also shown. The left-side console is for the transmitting vehicle's device and shows the actual RRH data which is being transmitted to the other vehicle. The right-side console is for the device of the receiving vehicle and shows the actual received RRH data by the receiving vehicle's device. There are 11 sections in the RRH of the text file used in this lab evaluation which was successfully transmitted in a total of 3.4 seconds. The transmission of each of the 11 sections in the RRH data file took 0.3 seconds so all 11 sections were successfully transmitted in 3.3 seconds (11 x 0.3 s). The final message (in the form of two consecutive zeros) took another 0.1 second indicating that the transfer was complete.

4 FIELD TESTS AND RESULTS

After successfully developing and testing V2V handshake and data transfer software in the lab, we wanted to evaluate both in the field to detect unintentional lane departures. We have been using a

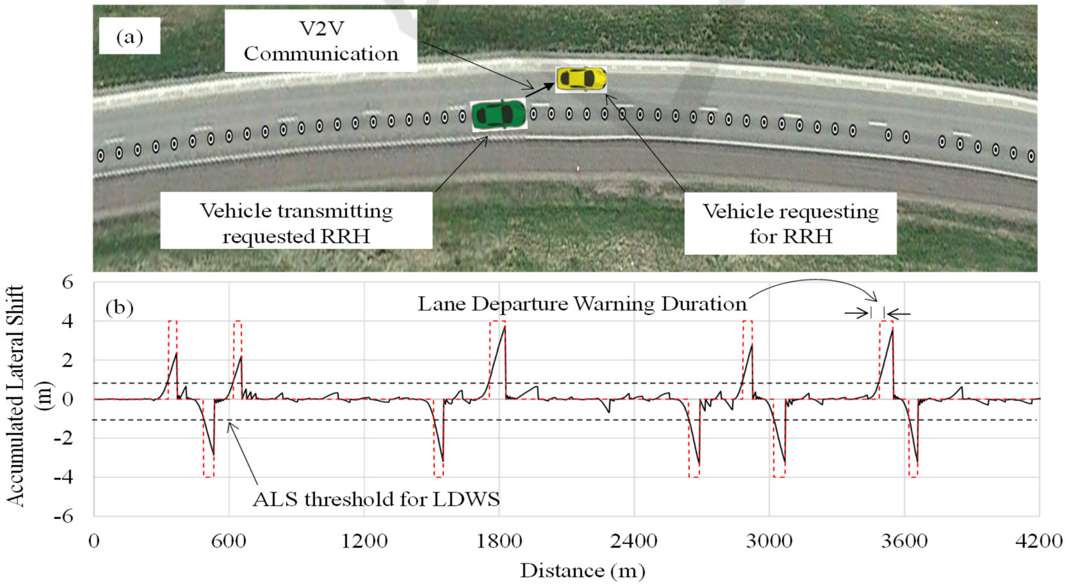


Figure 6: (a) A typical V2V communication scenario for transferring RRH data, and (b) ALS vs. traveled distance for a test run on the 4.2 km road segment of interstate I-35 with 10 lane changes. The red dashed line in (b) represents a digital mask for the duration of audible warning and the two black dashed lines in (b) represent ALS threshold for LDWS.

4.2 km long road segment of the Interstate I-35 for our previous field tests for which we have already generated an RRH. We used the same road segment to test the V2V handshake protocol and RRH data transfer software. The complete field test involves driving at least two test vehicles, one of these two vehicles without having the RRH data file in its DSRC device and running only lane departure warning software while the other vehicle having the required RRH data file in its DSRC device. The two vehicles should be driven within the DSRC communication range of each other on the same road.

We wanted to drive two test vehicles in close proximity on our test road segment as shown in Figure 6a. However, because of the Covid-19, we were not able to go to the field as it required at least two people in each of the two vehicles for a prolonged period. Instead, we used an innovative method to test the full operation of all the pieces of our developed software including V2V handshake protocol, RRH data transfer, and lane departure detection. We had previously acquired and stored multiple GPS trajectories of a test vehicle on our test road segment. We used two such separate trajectories of two vehicles driven in proximity of each other on the test road segment and stored them in two separate DSRC devices. The two DSRC devices represented two test vehicles traveling on the actual road. Each of the two DSRC devices was operated normally in the lab except that every new GPS point acquired by the GPS receiver of the corresponding DSRC device was replaced with one of the GPS points in stored trajectory. By doing this, each DSRC device appeared to be as it was being driven on the actual road. The DSRC device of one of the two vehicles (shown as yellow in Figure 6a) was running the lane departure detection software but did not have the corresponding RRH of that road segment so it needed to request RRH from a neighboring vehicle to detect lane departure and issue an audible warning. The other vehicle (shown as green in Figure 6a) acted as a neighboring vehicle having the necessary RRH data file in its DSRC device. In this test, only one of the two vehicles (yellow) without the needed RRH data file was tested for lane departure detection algorithm after successfully receiving the RRH data file from the neighboring vehicle (green).

Our lane departure detection algorithm calculates lateral shift of the test vehicle by comparing its calculated heading with the RRH of that road in real-time. The instantaneous lateral shift is accumulated over time and when the accumulated lateral shift (ALS) crosses 1 m threshold, an audible warning is issued. When a vehicle intentionally changes its lane, the increase in lateral distance saturates upon completion of its lane change because the vehicle starts to travel again in parallel to the RRH of the road. This phenomenon is used to reset the ALS to zero after every lane change to detect a future lane change or unintentional lane departure.

We used two test vehicles' trajectories on the same road segment with the trajectory of one vehicle having many lane changes present in it to test lane departure detection and warning. Please note that in all our field tests, we used lane change to test unintentional lane departure warning for safety reasons. One of the two test vehicles or the DSRC devices did not have the necessary RRH while the other vehicle or the DSRC device had the necessary RRH data file, and both were always driven in proximity of each other to ensure DSRC connection. In each new test drive, the vehicle running the lane departure software successfully obtained the required RRH from the neighboring vehicle using our developed V2V handshake protocol and RRH data transfer software. After obtaining the required RRH, a lane departure warning was issued upon each lane change.

Although, we have tested our LDWS on a freeway with two lanes each direction, our algorithm design is not restricted to number of lanes of the road. Furthermore, roadside units (RSU) if available can be used to transfer RRH when traffic density is too low or V2V communication equipped vehicles are absent within the range of communication.

For one such test run, the calculated ALS versus traveled distance is shown in Figure 6b. Our lane departure warning software issued audible warning upon each of the 10 lane changes whenever ALS crossed the 1 m threshold as shown by dashed black line in Figure 6b. A digital mask for audible lane departure warning signal is also superimposed in Figure 6b with dashed red line showing the start and end of the lane departure warning signal for each of the 10 lane changes. Lane departure audible warning signal becomes active when ALS crosses the threshold (1m) and is deactivated when the vehicle heading becomes parallel to the RRH of the road. In each of the 10 lane changes, our algorithm accurately detected all lane departures (or lane changes) in a timely manner and nowhere else along the trajectory, ALS crossed the threshold showing no false alarms.

5 CONCLUSIONS

In this work, we have successfully augmented our previously developed LDWS by adding a V2V communication feature to transfer RRH from one vehicle to another. We have designed a V2V handshake protocol and developed the corresponding software to facilitate proper communication among neighboring vehicles to select and transfer RRH from one vehicle to another upon request. We have used two DSRC devices simulating the two vehicles in the lab to test our developed V2V handshake protocol and RRH data transfer software. Please note that instead of DSRC based V2V communication, C-V2V communication can also be used to test our software. After developing and extensively testing our software, we have performed field tests to successfully detect lane departures using the RRH received via V2V communication. The V2V communication based LDWS can be successfully implemented in large scale if the market penetration of V2V communication enabled vehicles reaches a critical level which is not there as of now. As an alternative to V2V communication, the developed LDWS can also be integrated into popular smartphone apps e.g., Waze, Google Maps or Apple Maps to take advantage of the vast database of multiple GPS trajectories which can be used to generate RRH for almost all roads making it available for a vehicle to detect its unintentional lane departure on any road even if the vehicle is driven on that road for the first time.

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