Development of a Smartphone App for Lane Departure Warning

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Keywords: Smartphone App, Database, GPS, Reference Road Heading, Lane Departure Detection, Algorithms.

Abstract: Unintentional Lane departure is a significant safety risk. Currently, available commercial lane departure warning systems use vision-based or GPS technology with lane-level resolution. These techniques have their own performance limitations and are complex and expensive to implement, inhibiting their widespread market penetration. We have previously developed a lane departure detection (LDD) algorithm using standard GPS technology. Our algorithm acquires the trajectory of a moving vehicle in real-time from a standard GPS receiver and compares it with a road reference heading (RRH) to detect any potential lane departure. The necessary RRH is obtained from one or more past trajectories on that road using our previously developed RRH generation algorithm. Our previous field tests have shown that our lane departure detection and warning technique is robust enough to detect unintentional lane departures successfully. Due to its robustness and simplicity, we have now developed a smartphone app for this technique incorporating our previously developed LDD and RRH generation algorithms to detect a lane departure and issue a warning to the driver in real-time using an audible alarm. We have developed the app database structure and have completed programming the algorithms for the app. We are currently in the testing phase. The smartphone app is being prepared for both iOS and Android phones, however, the Android app will be available before the iOS app.

1 INTRODUCTION

Modern vehicles include Advanced Driver Assistance Systems (ADASs) because they play a vital role in safe driving (Maag et al., 2012). Lane departure warning is one of the primary ADAS features to prevent accidents on highways and freeways if a vehicle unintentionally departs from its lane. According to the American Association of State Highway and Transportation Officials (AASHTO), almost 60% of fatal accidents happen due to an unintentional lane departure of a vehicle on crucial roads (Officials, 2008). A recent study that compared crashes with and without a lane departure warning system (LDWS) revealed that an in-vehicle LDWS helped reduce crashes of all severities by 18%, injuries by 24%, and fatalities by 86% without considering driver demographics (Cicchino, 2018).

Most lane departure warning systems either use a single camera and a processor (Hsiao & Yeh, 2006) (An et al., 2006) (Yu et al., 2008) (Leng & Chen, 2010) or optical scanning and Light Detection and Ranging (LIDAR) sensors (Lindner et al., 2009) to identify the impending lane departure. The camera-based systems employ different image processing techniques like the linear parabolic lane model (Jung & Kleber, 2004) or the extended edge-linking algorithm (Lin et al., 2010) to extract the lane markings from successive picture frames to calculate the lateral shift of the vehicle. Camera-based systems need favorable lighting conditions to recognize the lane markings at night. However, recent advancements in image processing techniques during the past couple of decades conquered the limitation of diminished lighting conditions to successfully detect lane departure even in low lighting or night-time (Hsiao et al., 2008). A Video-Based Lane Estimation and Tracking (VioLET) system with steerable filters can detect solid-line and segmented-line markings under different lighting and road conditions leading to robust and accurate lane-marking detection (McCall & Trivedi, 2006). Likewise, optical scanning systems consisting of a linear array of infrared transmitting devices can scan the lateral area of the highway for lane markings even in varying lighting conditions (Dobler et al., 2000). The performance of the camera and optical sensor-based systems in detecting lane departure deteriorates when the road conditions are unfavorable due to an irregular, broken, or absence of lane markings or harsh weather

Tasnim, N., Zaman, A. and Hayee, M.
Development of a Smartphone App for Lane Departure Warning.
DOI: 10.5220/0011836000003479
In *Proceedings of the 9th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2023)*, pages 223-231
ISBN: 978-989-758-652-1; ISSN: 2184-495X

conditions such as fog, rain, and snow. Moreover, some systems 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, an inertial navigation sensor, and access to digital maps of lane-level resolution to correctly identify the GPS position (Clanton et al., 2009), making such systems more complex and expensive to implement.

We previously developed an LDWS using a standard GPS receiver without any image processing or optical scanning devices. Our previously developed LDWS used two algorithms to detect an unintentional lane departure. The first algorithm used standard GPS technology to obtain a Road Reference Heading (RRH) from a vehicle's past trajectories to generate an RRH for that road (Chowdhury et al., 2021). The second algorithm calculated the instantaneous lateral shift by comparing the RRH of a given road with a vehicle's current trajectory on that road using a standard GPS receiver. The change in the lateral shift was accumulated over time for unintentional Lane Departure Detection (LDD) (Faizan et al., 2019).

In this work, we have incorporated the previously developed RRH generation and LDD algorithms to develop a smartphone app that can detect an unintentional lane departure and warn the driver in real-time using an audible warning.

The rest of the paper is organized as follows. Section 2 describes the overall architecture of the smartphone app, followed by section 3, which describes the app database structure. Section 4 highlights the app's user interface and functionality, followed by conclusions in section 5.

2 ARCHITECTURE OF THE SMARTPHONE APP

The architecture of the smartphone app combining the previously developed RRH generation and lane departure detection algorithms is shown in Figure 1a. The GPS receiver acquires longitude and latitude from the position of a moving vehicle in real-time to be later used by both algorithms. RRH generation algorithm extracts the RRH of a given road from a vehicle's past trajectories on that road. Please note

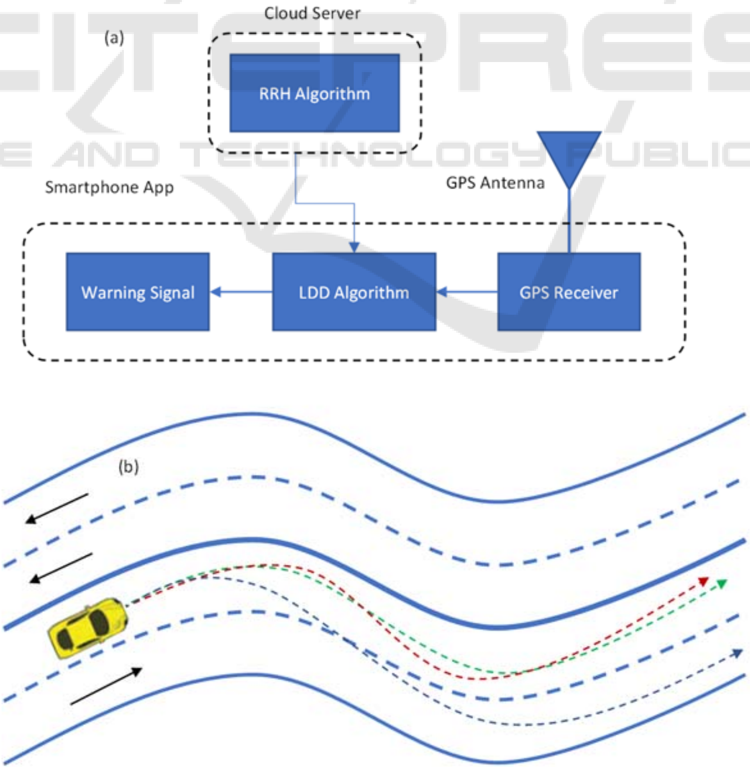


Figure 1: (a) The system architecture of the smartphone app using previously developed RRH and LDD algorithms. (b) Conceptual diagram showing how past trajectories (red and green dashed line) of a given vehicle can be used to generate RRH to detect a future lane departure (blue dashed line).

that the RRH algorithm runs on a cloud server which will be explained later. This algorithm uses an adequate length of the GPS trajectory on a given road to generate an RRH for that road. The RRH generated is then used to detect any future unintentional lane departure of the vehicle using the previously developed LDD and RRH generation algorithms (Figure 1a). The unintentional lane departure detection using these two algorithms is illustrated in Figure 1b, where the red and green dashed lines represent a vehicle's past trajectories, and the blue dashed line represents unintentional lane departure.

Our proposed app will only be able to provide a warning for those roads where the vehicle has traveled in the past at least once because the necessary RRH of travel for any given road requires at least one past vehicle trajectory on that road. From the very first trajectory, the necessary RRH is extracted and saved for future use in the cloud database. During a future trip on the same route, the app will retrieve the RRH of that road and, using the LDD algorithm, will detect a potential lane departure to warn the driver.

In addition to the two algorithms, the smartphone app must establish a secure connection with the cloud server to manage the extraction and retrieval of RRH for multiple roads. We have selected Google Cloud Platform (GCP) as our cloud server, which contains two databases, one for trajectory upload and one for RRH storage. Figure 2 describes the architecture of GCP containing the two databases and its interconnection with the smartphone app to manage the secure connection and RRH extraction and retrieval. While both databases will be described in the following section, the secure connection and RRH extraction and retrieval management are described below.

2.1 Secure Connection

The first step for any smartphone running the app is to securely connect to GCP to successfully share the road trajectory and obtain the RRH of any road from the cloud database. In order to do that, the smartphone must exchange authentication credentials with the GCP each time it connects to it.

While launching the app on a smartphone for the first time, the app requires the user to create a username, which can be anonymous for privacy concerns. The authentication credentials are associated with the username so that it can use those credentials to establish a connection with GCP for future use. The block showing “Firebase Auth” in Figure 2 is responsible for the authentication process between the smartphone app and GCP.

2.2 RRH Extraction and Retrieval Management

For any given road, an RRH is generated using the previously developed RRH generation algorithm as soon as a new trajectory gets uploaded to the Firestore database. The actual code for the RRH extraction algorithm runs inside GCP using the Google cloud function (Figure 2), a computation service provided

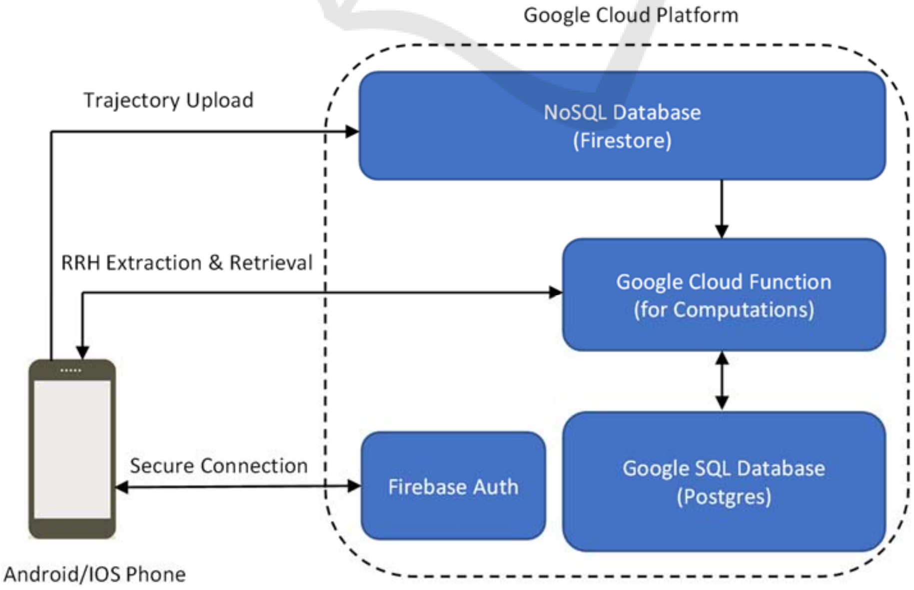


Figure 2: Schematic architecture of the smartphone app and its interconnection with GCP containing app database.

by GCP. Google cloud function retrieves raw trajectory data from the Firestore database and converts it into a functional RRH. It also saves the RRH in a structured database called “Postgres” (lower right block in Figure 2). Whenever a smartphone needs an RRH for any given road, it requests the required RRH from the Google cloud function by sending its current location. If the relevant RRH exists in the Postgres database, the cloud function retrieves it and forwards it to the smartphone to detect lane departure using the previously developed LDD algorithm. The smartphone app database structure is discussed in detail in the following section.

3 APP DATABASE STRUCTURE

The app database structure development is the most crucial milestone toward the successful development of the smartphone app. The app needs to retrieve the corresponding RRH for any given road from the app database using the vehicle’s current position to detect and warn the driver of any unintentional lane departure. This situation is analogous to the initial locking mechanism of a GPS receiver in which a vehicle (with a GPS receiver) is pinpointed at its current location on the map from an extensive mapping database. Similarly, for a vehicle traveling on a particular road for the very first time, our database structure has the ability to expand itself to accommodate the new RRH as well as to keep the provision for updating each existing RRH if and when more future trajectories are available for any given road which are already part of the database. Furthermore, the algorithm to extract RRH from past trajectories applies to large tracts of vehicle trajectories. However, sometimes trajectories include unnecessary portions of data like turns on highways and entrances/exits on freeways which require exclusion from the RRH before making it a part of the database. This process demands developing a structured app database to format and store RRH for multiple roads in one place.

Although the app database can reside in the memory of a smartphone, we opted for a cloud service, i.e., GCP, to accommodate the app database structure to allow multiple users to have access to the RRH generated by any participating user. Please note that the RRH generation algorithm will run on the cloud server, and the LDD algorithm will run on the smartphone. Therefore, multiple vehicles traveling on the same or different roads can upload their trajectories for the GCP to extract RRH for all those roads. Resultingly, an RRH generated by one vehicle can be potentially used by another vehicle for lane departure detection.

The app database is structured into two separate databases, one for trajectory upload and one for RRH storage, both of which are described below.

3.1 Trajectory Upload

Once a smartphone establishes a secure connection with GCP, it can upload its trajectory to GCP, which will reside in a “NoSQL” database called “Firestore” provided by the GCP.

A NoSQL database is appropriate for accommodating a large amount of data without much structure. Such a database is mainly used to house a large amount of raw data, especially if the data are temporary in nature. In our case, any road trajectory from even a short trip can contain a large volume of data which is only temporarily needed for RRH extraction and can be discarded later after successful extraction of each RRH. The nature of the data can be a good estimation tool for the amount of data present in a raw trajectory. Any trajectory data consists of a collection of GPS data points where each point is represented as a snippet of data, as shown in Figure 3. This snippet of data is stored in Google Firestore (NoSQL database). The GPS device can generate up to 10 such points every second while the smartphone travels along a road producing a large amount of data.

```
{
  // Provided by GPS chip on phone.
  “accuracy”: 3,
  “heading”: 347,
  “latitude”: 38.74422308172889,
  “longitude”: -77.19622757445973,
  // Provided by Google Roads API
  “googleLatitude”:
38.74421031329726,
  “googleLongitude”: -
77.19629289235164,
  // Generated by our app.
  “isManipulated”: true,
  “timeStamp”: “2021-06-19
00:03:42.022Z”
}
```

Figure 3: Snippet of data stored in JSON format.

3.2 RRH Database

The RRH database is the most crucial element of the app database structure because it accommodates the RRH for all the roads. As stated before, the location of the RRH database is chosen in the GCP instead of the smartphone's memory to allow multiple app users to upload their trajectories for RRH extraction so that it is available for any app user. This feature will be efficient when multiple users will use and test the app during the beta testing phase. Additionally, this provides a platform for commercial apps like Google Maps to integrate the app feature within their environment. The structure also allows the database to expand itself to accommodate the new RRH (when a vehicle with a smartphone travels on a given road for the first time) as well as to keep the provision for updating each existing RRH when more future trajectories are available for any given road that are already part of the database.

Due to its highly structured nature, a SQL database called Postgres (bottom right block in Figure 2) is used, which is accessible within the GCP. This database contains RRH for all road sections, along with the road name and other relevant parameters. The relevant parameters of each section of the road are the start and end points (longitude and latitude), path average heading (PAH) for the straight sections, and initial heading (IH), and path average heading slope (PAHS) for the curve or transition sections. Whenever a vehicle needs to retrieve an RRH for a given road, it sends a query to the Postgres database to retrieve the required RRH using the road name and the position of the two end points of various sections of any road present in the database. The RRH of each section of the road also contains a parameter called "degree of confidence," or DoC, which has an integer value indicating the number of times a particular RRH has been previously updated. For example, a DoC value of "1" implies that only one trip generated the RRH for that road. A DoC value of 2 or 3 means that two or three past trajectories have been used for that RRH. Multiple trajectories can be either from the same vehicle traveling on that road at different times or by different vehicles traveling on the same road either at the same time or at different times.

A typical road structure containing two freeways (FW1 and FW2) is shown in Figure 4 to explain the RRH database (SQL database). Four different trajectories are also shown in the Figure using colored dashed lines. After a trajectory is uploaded in the NoSQL database (Firestore), it is processed by the Google cloud function to generate RRH using the RRH generation algorithm for that road segment. After generating an RRH, the Google cloud function stores all sections of RRH in the SQL database (Postgress). The structure of this database is shown in Table 1, with a grey highlighted area. The first three columns of the table (not highlighted) are not part of the database but have been included to explain the process of updating the RRH resulting from various trajectories.

After the first trajectory (dashed blue line in Figure 4) is uploaded and converted to RRH, all the relevant parameters of each section of the RRH are stored in the database along with the road name and DoC value. In this case, the road name is FW1, and DoC is 1 for all sections. After the RRH resulting from this trajectory is saved in the database, a total of 7 entries are made corresponding to 7 sections, as can as can be seen in Table 1.

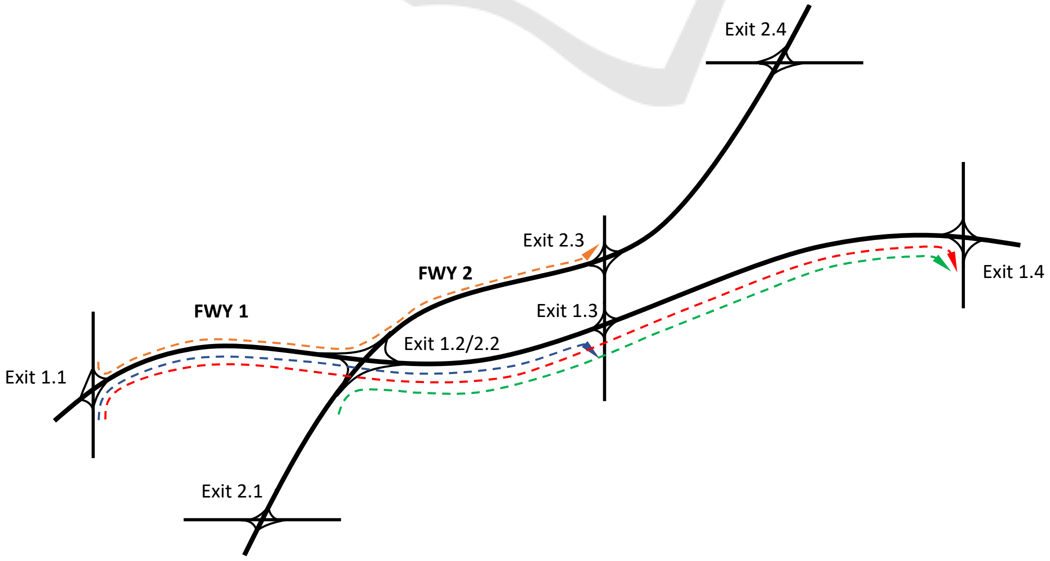


Figure 4: A typical road infrastructure containing two freeways to illustrate RRH database structure. The colored dashed lines are trajectories on that road obtained at different times.

When the second trajectory (red dashed line in Figure 4) is available and converted to an RRH, the database entries are updated (Table 1). As seen in Figure 4, the new trajectory (red dashed line) is simply the extension of the first trajectory (blue dashed line). Therefore, the new RRH contains some of the old sections for the part of the road from the first trajectory as well as some new sections for the new part of the road. In this case, the first seven sections (already present) are updated, and two more new sections are added, as shown in Table 1 (Trajectory #2). If a section is updated, its DoC value is increased by one and remains 1 for the new sections. Please note that the last section or section #7 resulting from the first trajectory may get modified when RRH sections are generated from the second trajectory because the last section (either curve or straight) may get extended and the endpoint may differ from the previous point. For that purpose, this section will be either updated or remain the same depending upon how long the extension is. As a rule of thumb, if it is not extended by more than 20% in

Table 1: RRH database showing updated database after every new trajetory.

Reference Itenerary	Count	Comment	Road	DoC	Start	Start	End	End	PAH	IH	PAHS
Trajectory #1 (blue dashed line) from Exit 1.1. to 1.3	1	new	FW1	1	x	x	x	x		x	x
	2	new	FW1	1	x	x	x	x		x	x
	3	new	FW1	1	x	x	x	x	x		
	4	new	FW1	1	x	x	x	x		x	x
	5	new	FW1	1	x	x	x	x		x	x
	6	new	FW1	1	x	x	x	x	x	x	x
	7	new	FW1	1	x	x	x	x	x		
Trajectory #2 (red dashed line) from Exit 1.1 to Exit 1.4	1	update	FW1	2	x	x	x	x		x	x
	2	update	FW1	2	x	x	x	x		x	x
	3	update	FW1	2	x	x	x	x	x		
	4	update	FW1	2	x	x	x	x		x	x
	5	update	FW1	2	x	x	x	x		x	x
	6	update	FW1	2	x	x	x	x	x	x	x
	7	update*	FW1	1 or 2	x	x	x	x	x		
	8	new	FW1	1	x	x	x	x		x	x
	9	new	FW1	1	x	x	x	x		x	x
Trajectory #3 (green dashed line) from Exit 1.2 to 1.4	1		FW1	2	x	x	x	x		x	x
	2		FW1	2	x	x	x	x		x	x
	3	update*	FW1	2 or 3	x	x	x	x	x		
	4	update	FW1	3	x	x	x	x		x	x
	5	update	FW1	3	x	x	x	x		x	x
	6	update	FW1	3	x	x	x	x	x	x	x
	7	update	FW1	2	x	x	x	x	x		
	8	update	FW1	2	x	x	x	x		x	x
	9	update	FW1	2	x	x	x	x		x	x
Trajectory #4 (orange dashed line) from Exit 1.1 to 2.3	1	update	FW1	3	x	x	x	x		x	x
	2	update	FW1	3	x	x	x	x		x	x
	3	update*	FW1	3 or 4	x	x	x	x	x		
	4		FW1	3	x	x	x	x		x	x
	5		FW1	3	x	x	x	x		x	x
	6		FW1	3	x	x	x	x	x	x	x
	7		FW1	2	x	x	x	x	x		
	8		FW1	2	x	x	x	x		x	x
	9		FW1	2	x	x	x	x		x	x
	10	new	FW2	1	x	x	x	x	x		
	11	new	FW2	1	x	x	x	x	x		
	12	new	FW1	1	x	x	x	x		x	x

length, we will not consider this as a different section and increase the DoC value by one. However, if it gets extended by more than 20%, we will call it a different section and keep the Doc value to 1. In the future, we will also consider setting some margins for other parameters (PAH or IH and PAHS) of a given section of the RRH to decide on updating the existing section.

4 APP USER INTERFACE AND FUNCTIONALITY

After establishing the RRH database and the RRH generation algorithm in GCP, the LDD algorithm is programmed in the smartphone memory using the smartphone processor and its GPS receiver. Our developed smartphone app's user interface and functionality are described below. Please note that currently, the app works for Android-based phones only. In the future, we intend to develop a similar app for iOS-based smartphones.

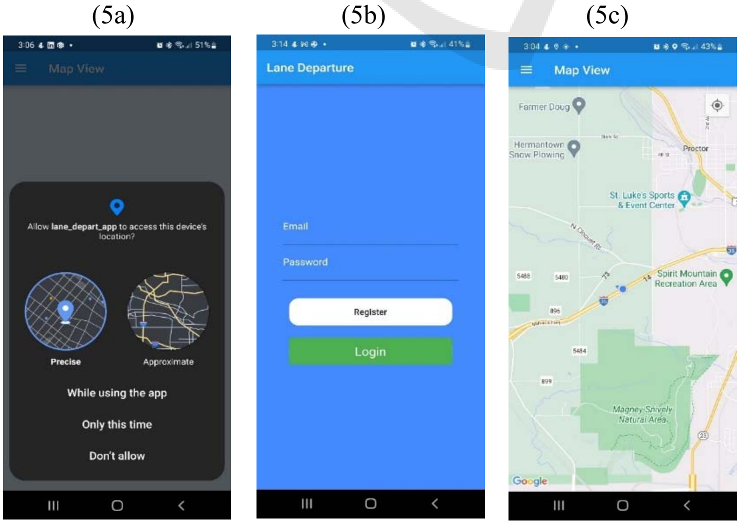
4.1 App User Interface

Once our app is installed on a smartphone and started, a pop-up screen will appear asking for permission whether the app can access the device's location using the device's GPS receiver. Figure 5a shows a screenshot where our app asks the user to choose if the user wants to share a precise or approximate location with the app. The user will have three options to choose from: "While using the app," "Only this time," or"Don't allow." The user's preferences will be saved once and will not be shown to the user again, although a user can change these settings anytime using the settings menu.

After saving the location preferences, signing in will be required to establish a secure connection to upload the trajectories and extract the RRH for a given road from GCP. The sign-in page is shown in Figure 5b, where users can register using a valid email and a password of their choice. These credentials will be required to log in to the app for every use. The app must be active in the foreground to take the GPS data and for the lane departure detection algorithm to work. However, if the app runs in the background, it will not collect any GPS points, and neither the LDD algorithm will work. Once the user logs in to the app, and it is running in the foreground, the vehicle's current position will appear on the map of the smartphone app screen as a blue dot, as shown in Figure 5c. Typically, a comfortable view of about ± 100m around the vehicle's position is shown on the map of the app screen. Users can zoom in or zoom out according to their comfort level.

4.2 Functionality

While traveling on the road with the app running in the foreground, the LDD algorithm will be active and be able to detect any lane departure and issue an audible warning. In the future, when the app gets integrated into a vehicle's navigation system, the app will be able to differentiate between intentional and unintentional lane departures using the turn signal indicator. For now, our app will issue an audible warning for all lane departures, including intentional lane changes.


(5a) (5b) (5c)

Allow **lane_depart_app** to access this device's location?

Figure 5: (a) Screenshot of the app seeking user permission to access the device's location. (b) Screenshot of the registration page of the app. (c) Screenshot of the app showing the device location on the map.

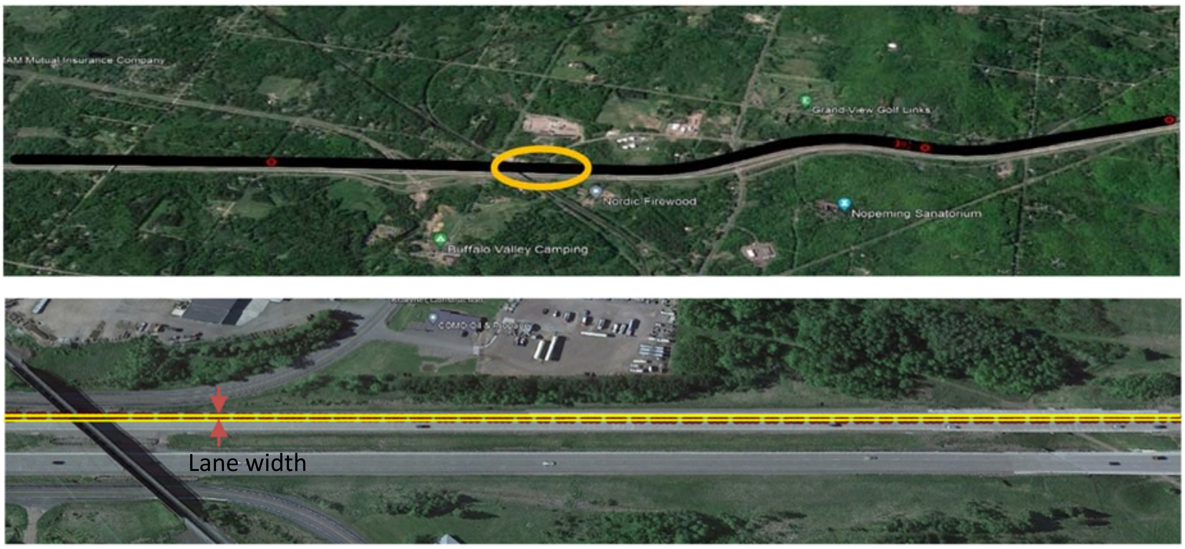


Figure 6: (6a) Picture from the Google Map of the 7 km route on Interstate I-35 with one lane departure highlighted with a yellow circle. (6b) A zoomed in picture of the lane departure portion circled in yellow in (6a) indicating the lane width with yellow lines. The lane change inside the yellow circle was made from left to right.

To demonstrate the app's functionality in the field, we drove the smartphone running our app in a vehicle on a 7 km segment of Interstate I-35 near Duluth, MN, for which an RRH was already generated from a previous trip. The test vehicle was driven within the speed limit (70 MPH) on the 4-lane freeway (2 lanes each way), and many back-and-forth lane changes were made intentionally in each test run. For safety reasons, intentional lane changes were made to test the accuracy of lane departure detection using the LDD algorithm. The app successfully identified the lane changes made during the test run and issued an audible warning. The detection is completed within a few GPS cycles, where each GPS cycle is 100 msecs. Normally, the lane departure is detected for a little less than a second. The accuracy of our lane departure on any given road depends upon the accuracy of the RRH of that road. On curved portions, the accuracy may not be as much as on straight portions. However, unintentional lane departures occur mainly on long stretches of straight road portions as opposed to curved road sections where the driver must be attentive anyway. Figure 6a depicts a picture from Google Maps, showing a typical trajectory of the test run with a lane change circled in yellow. The zoomed-in portion of this part of the trajectory with a lane change (from left to right) is shown in Figure 6b. Please note that the trajectory with GPS points is shown as a continuum of small circles laterally shifting from left to right for a lane change. The lateral shift is approximately one lane width, as illustrated in Figure 6b, with two yellow lines. The app development is a work in progress. Once the app is completely developed, we plan to do more elaborate field testing and characterize the accuracy of lane departure detection, which will be reported in a future publication.

5 CONCLUSIONS

We have developed a smartphone app incorporating two of our previously developed algorithms to detect lane departure and warn the driver in real-time. Our app is appropriate for use on longer stretches of freeways or rural highways as opposed to urban areas where the GPS signal is not as strong. Currently, the app works for Android-based smartphones only, but we plan to develop a similar app for iOS-based smartphones as well. Our Android-based app is almost ready for extensive field testing, and we are in the middle of doing those tests. After thoroughly testing our app, we will launch it for public use.

ACKNOWLEDGEMENTS

The authors wish to acknowledge those who made this research possible. This work was made possible by Minnesota cities and counties by the Local Road Research Board with support from MnDOT's Office of Research & Innovation.

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