Advanced Curve Speed Warning System using Standard GPS Technology and Road-level Mapping Information

Shahnewaz Chowdhury, Muhammad Faizan and M. I. Hayee
Department of Electrical Engineering, University of Minnesota Duluth, Duluth, MN 55812, U.S.A.

Keywords: Advance Curve Warning System, Super-elevation, Friction Factor, Advisory Speed Limit.

Abstract: Lane departure and advance curve warning are critical among several Advanced Driver-Assistance Systems (ADAS) functions, which have significant potential to reduce crashes. Generally, lane departure and advance curve speed warning systems either use different image processing techniques or GPS technology with digital maps of lane-level resolution. However, these systems are expensive to implement as well as have some limitations such as harsh weather or irregular lane markings can negatively influence their performance. Previously we proposed a lane departure detection which uses a standard GPS receiver without any lane-level resolution maps. Now, we have added another feature in this algorithm to detect an upcoming curve in advance and warn the driver about its advisory speed at a safe distance so that driver can adjust vehicle speed accordingly before reaching the curve. We have implemented our algorithm in a prototype system and demonstrated in the field. We have performed extensive field tests and the test results show that each time vehicle approaches a curve, our algorithm issues a warning and correctly determines the advisory speed for the curve to warn the driver at a safe distance before the curve starts.

1 INTRODUCTION

An increasing number of modern vehicles include different Advanced Driver-Assistance Systems (ADAS) to assist in driver's safety (C. Maag et al. 2012). Lane departure detection and advanced curve speed warning are two important ADAS features which can prevent high-speed accidents on highways and freeways when a vehicle is about to unintentionally drift away from its lane on a straight or a curve road. 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 (AASHTO: Driving down lane-departure crashes: A national priority, 2008). Similarly, in a Minnesota crash study, it was reported that 25 to 50 percent of the severe road departure crashes in Minnesota occur on curves, even though curves account for only 10 percent of the total system mileage (Preston, H., and T. Schoenecker, 1999). Systems which predict the driver's attentive state and intent of lane change (D. D. Salvucci, 2004, N. Kuge et al. 1998, J. McCall et al. 2004) and provide map-based route guidance and/or warning about unintentional lane departure (F. Heimes et al. 2002, W. Kwon et al. 2002) are all useful to reduce major road crashes. Majority of these crashes involve crossing of an edge line, center line, or otherwise leaving the intended lane or trajectory (FHA: Roadway Departure Strategic Plan, 2013). According to a recent study which compared crashes with and without a lane departure warning system, it was found that such a warning system was helpful in reducing crashes of all severities by 18%, with injuries by 24%, and with fatalities by 86% without considering for driver demographics (J Cicchino, 2018).

Most available lane departure warning systems typically use a single camera and a processor to identify the imminent lane departure (Xiangjing An et al. 2006, Pei-Yung Hsiao et al. 2006, B. Yu et al. 2008, Y. C. Leng et al. 2010), while other modern systems use optical scanning and Light Detection and Ranging (LIDAR) sensors (P. Lindner et al. 2009). Similarly, majority of the curve speed warning systems use a standard GPS receiver, a speed sensor, and access to the digital maps of lane-level resolution to detect the curve ahead (S. Glaser et al. 2007, R. Yoneda et al. 2013, S. Rogers et al. 2003). Some curve speed warning systems are also equipped with Bluetooth Low Energy (BLE) technology along with

Chowdhury, S., Faizan, M. and Hayee, M.
Advanced Curve Speed Warning System using Standard GPS Technology and Road-level Mapping Information.
DOI: 10.5220/0009396804640472
In *Proceedings of the 6th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2020)*, pages 464-472
ISBN: 978-989-758-419-0

the GPS receiver to transmit the curve information to the onboard unit (Qin Xiao et al. 2015).

In advance curve speed warning systems, once a curve ahead is detected and its degree of curvature is estimated, a safe distance and an advisory speed is calculated. The safe distance for a given curve is defined as the distance required for a vehicle to reduce its current speed to the advisory speed of a curve. Some available systems also impose the speed control mechanism to the vehicle in order to achieve a safe speed in case the driver could not achieve it (S. Glaser et al. 2007). If a vehicle is moving on a straight section with speed higher than the advisory speed of a curve, it is beneficial to warn the driver well in advance so that the driver can adjust the speed according to the advisory speed of the curve ahead. Based upon the advisory speed and the current speed of the vehicle, the proposed method will warn the driver about advisory speed of a given curve at a safe distance before the curve starts.

Although, useful, majority of the existing commercial systems with lane departure or advanced curve speed warning features require GPS technology, inertial navigation sensor, and access to digital maps of lane-level resolution (Daimler Chrysler AG, 2018) making such systems more complex and expensive to implement in most common vehicles.

We have proposed a novel algorithm for lane departure detection and advanced curve speed warning which uses only standard GPS receiver without any lane-level maps. Although absolute position accuracy of a standard GPS receiver is larger than the lane width (LW), its relative accuracy is much better (< LW), providing an opportunity to potentially detect lateral lane drift of a vehicle (J. M. Clanton et al. 2009, S. Glaser et al. 2007). Previously, the authors developed a methodology to accurately identify the relative lanes of the surrounding vehicles on a road by utilizing the relative accuracy of a standard GPS receiver (S. Hussain et al. 2018). Using that concept, the authors also proposed an algorithm to detect an unintentional lane drift of a vehicle (Muhammad Faizan et al. 2019). The proposed algorithm compares vehicle's trajectory to the reference direction of a given road to determine the lateral shift of a vehicle for potential lane departure detection. The reference direction of a given road is obtained from a standard digital mapping database containing only road level maps without lane-level resolution, which are commonly available in any navigational system.

The authors now propose an added feature for advanced curve speed warning system using the same road level resolution maps which were used for lane departure warning system. Based upon this feature, the prototype system was updated, and field tested. In this system, both lane departure and advanced curve speed warning system work simultaneously and warn the driver accordingly. The advanced curve speed warning system detects a curve ahead and calculates the degree of curvature and a safe distance using road geometry for a possible curve ahead warning. If a vehicle is moving on a straight section with speed higher than the advisory speed of a curve, it will warn the driver well in advance so that the driver can adjust the speed according to the advisory speed of the curve ahead. Based upon the advisory speed and the current speed of the vehicle, the proposed method will warn the driver about advisory speed of a given curve at a safe distance before the curve starts.

The rest of the paper is organized as follows. Section 2 describes the detail of the proposed algorithm and methodology for the advanced curve speed warning system. Section 3 summarizes the field tests and results followed by conclusions in Section 4.

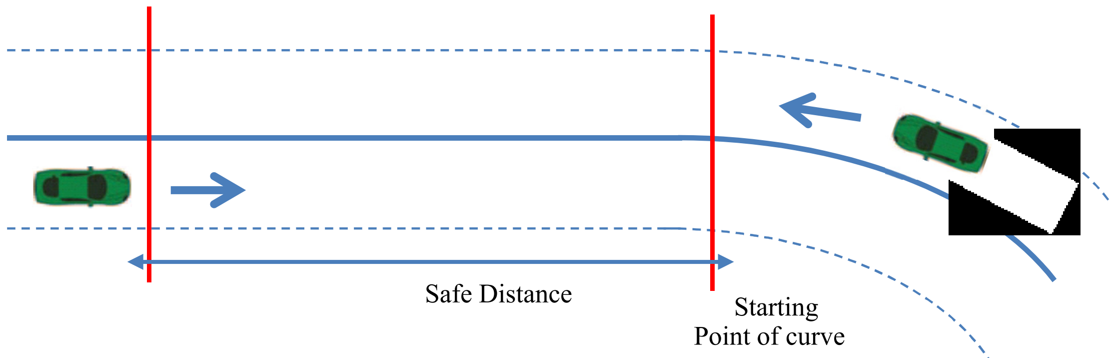

Figure 1: Conceptual diagram showing advance curve speed warning system.

2 ADVANCE CURVE DETECTION ALGORITHM

Our proposed advance curve detection algorithm utilizes reference road direction to detect a possible curve ahead and warn the driver about the advisory speed for a given curve at a safe distance before the curve starts as shown in Figure 1. The safe distance is assumed to be the distance needed to reduce a vehicle's speed from its current speed to the advisory speed of the curve by applying normal braking with safe deceleration rate. Usually, before applying brakes, a driver needs a buffer time called reaction time to adjust to the warning. Therefore, driver's reaction time will also be included in determining safe distance. There are three crucial parts of advanced curve speed algorithm. First to determine the advisory speed of a given curve and second to determine safe distance using vehicle's current speed and advisory speed for the curve, and a safe deceleration rate. The third element is the constituents of the advisory speed warning itself which is issued if the vehicle's current speed is higher than the advisory speed. In the following these three aspects of the proposed algorithm are explained in detail.

2.1 Advisory Speed for the Curve

We have explored two methods for determining advisory speed for a given curve. Although, various vehicles have different capacity to handle speed on curves, we have assumed just one advisory speed for all vehicles. To estimate the advisory speed, both methods obtain specific information from the same digital map database as we previously used for the lane departure warning system. In the first method, an advisory speed is determined using the shape points for a given curve which we previously used to determine the reference road direction. However, in the second method an advisory speed value for a given curve is directly acquired from the same mapping database. These two methods are further described below.

2.1.1 Calculated Advisory Speed

Our proposed algorithm uses reference road direction to determine the degree of curvature for any given curved section of the road segment. The degree of curvature is then used to calculate the advisory speed for that curved section. Our proposed methodology to determine the degree of curvature needed to calculate advisory speed for our proposed system is schematically shown in Figure 2 where the heading between two consecutive shape points for a given road is shown versus distance. The beginning and ending points of the curved section of the road are also shown along with the safe distance.

Our previously developed lane departure detection algorithm can detect the beginning and ending points of a curve ahead. By determining the beginning and ending points of a curve, we can calculate the total length of the curve *(L)* as well as the differential heading which is the difference of initial heading *(h1)* at the beginning of the curve and

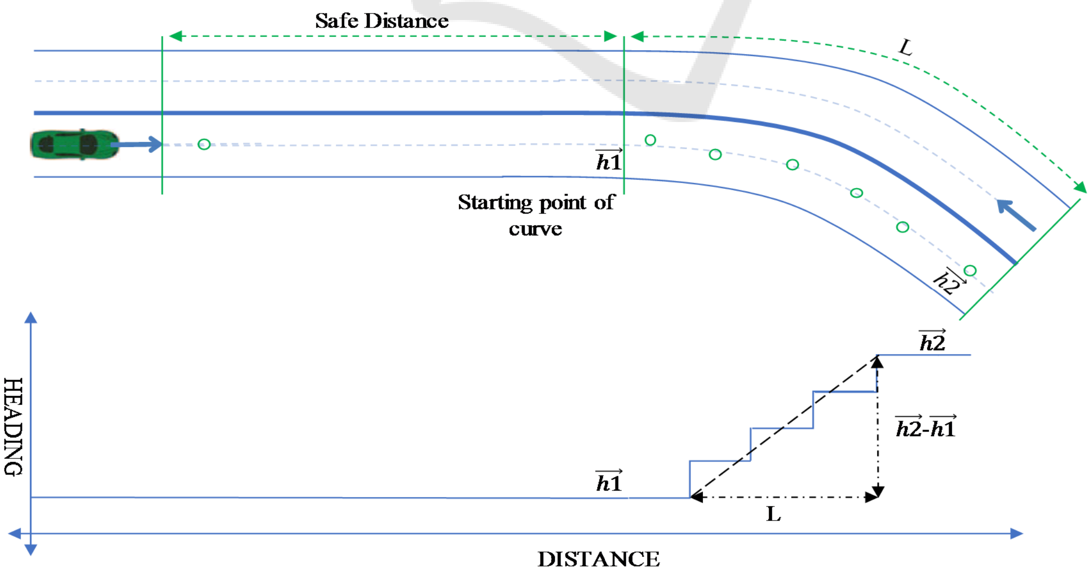

Figure 2: Schematic diagram showing methodology to determine beginning and ending points of a curve ahead. This will be needed to determine advisory speed.

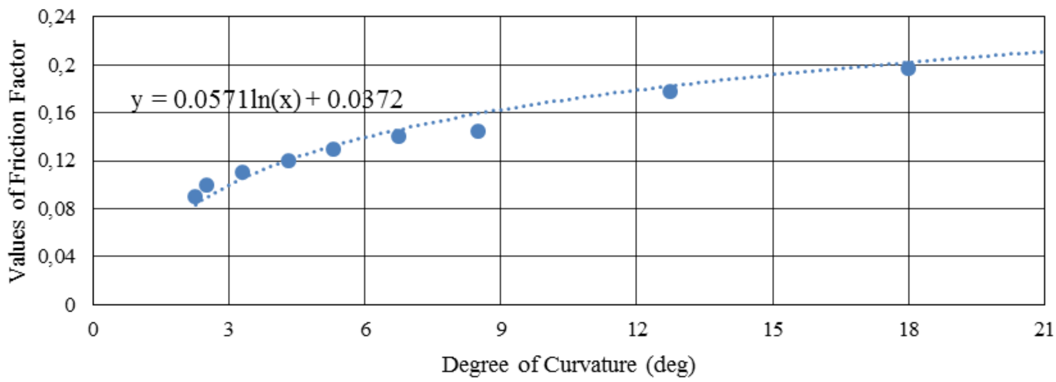

Figure 3: The friction factor vs. degree of curvature.

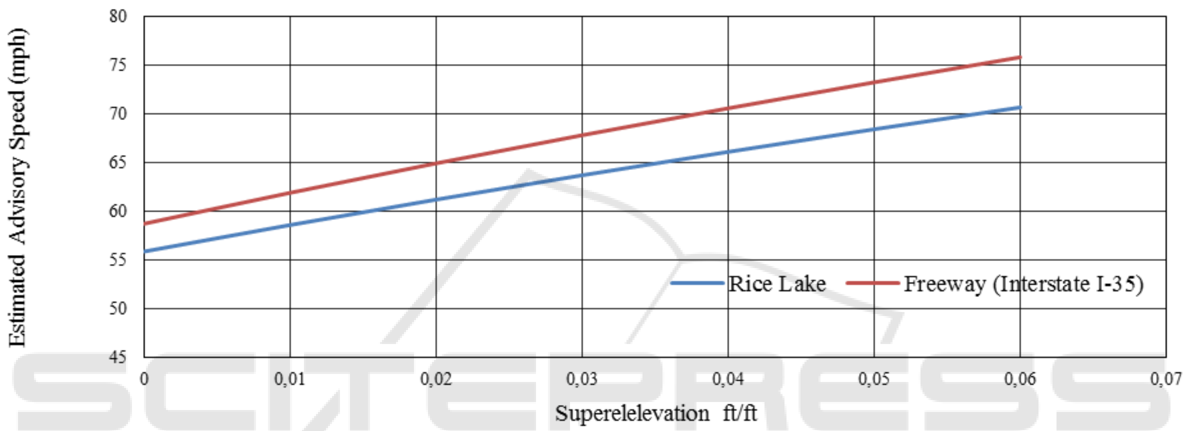

Figure 4: An Estimated advisory speed vs. Super-elevation values.

final heading *(h2)* at the end of the curve. Finally, the degree of curvature *(D)* which is defined as the change of heading (in degrees) over 100 ft, is calculated using equation 1 (AASHTO: A Policy on Geometric Design of Highways and Streets), where *L* is the curve length in feet.

$$D = \frac{100|h2-h1|}{L} \quad (1)$$

Once the degree of curvature is calculated, it is used to determine the advisory speed *(V)* which not only depends on degree of curvature but also rely on other factors including super-elevation *(e)* and road friction factor *(f)*, and can be calculated using equation 2 (AASHTO: A Policy on Geometric Design of Highways and Streets).

$$V = \sqrt{\frac{(5729.578)\,(15)\,(e+f)}{D}} \quad (2)$$

Both super-elevation and friction values can be estimated empirically. According to MnDOT road design manual, the specific degree of curvature corresponds to a specific limiting friction factor value for a given road (S. Glaser et al. 2007). It contains specific friction factor values for a few discrete values of degree of curvature ranging from 2 to 21 degrees (S. Glaser et al. 2007). We have curved fitted the specified friction factor values to generate a generic formula to determine friction factor value for a given degree of curvature as shown in Figure 3 where friction factor values are plotted versus degree of curvature.

Although friction factor value is fixed for a given degree of curvature, the super-elevation value for a given road can vary between 0 to 6 percent for the same degree of curvature. There is a possibility that roads with the same degree of curvature can have different super-elevation values or vice versa. Most of the highways and freeways in Minnesota use 6 percent of super-elevation value (maximum recommended) but a few highways especially the old ones use a smaller super-elevation value. Figure 4 shows calculated advisory speed versus super-elevation values for two curved road segments (Rice Lake Road and Interstate I-35 near Duluth, Minnesota). The calculated advisory speed of Rice Lake road ranges from 56 to 71 mph. However, the actual posted advisory speed for that curved section is 55 mph. This indicates that a super-elevation value of 0% is used to calculate the posted advisory speed for the Rice Lake Road. On the other hand, for the Interstate section I-35, the actual posted speed is 70 mph while the calculated advisory speed ranges from 58 to 76 mph. Which implies that the 4% super-elevation value was used to calculate the posted advisory speed for that segment. Without having the super-elevation information in advance, we cannot reliably calculate an advisory speed for a given road. Although the safest value of super-elevation is 0% resulting in the least or safest advisory speed for any given curve. Therefore, we used a super-elevation value of 0% to calculate advisory speed in our prototype system. In the cases of two roads (Rice Lake and I-35), the calculated advisory speed for the Rice Lake Road was close to the posted speed but much less for the I-35 curved section which was actually designed for a higher speed. An advisory speed using one fixed value of super-elevation i.e., 0% could vary from the actual posted advisory speed for any given road. To mitigate this factor and to warn the driver appropriately, it is best to obtain the actual posted advisory speed from the digital map database as explained below.

2.1.2 Acquired Advisory Speed

This method directly extracts posted advisory speed from the digital mapping database which also has road level information including advisory speed. After extracting the advisory speed directly from the mapping database, our algorithm compares it with the calculated advisory speed. To be on the safe side, we used the lower advisory speed whether it is from the mapping database or from the calculation method for issuing the warning. After determining the advisory speed, next step is to find the safe distance before issuing the warning.

2.2 Safe Distance

Safe distance is calculated using vehicle's current speed, the advisory speed of the given curve, and a safe deceleration rate. The current speed of the vehicle is calculated from the GPS coordinates and advisory speed is determined as explained above. As for as the safe deceleration rate is concerned, according to AASHTO, approximately 90% of motorists brake with the deceleration rate of more than 3.4 m/s^2 (S. Glaser et al. 2007). This rate enables drivers to reduce their speed safely without losing control. Therefore, 3.4 m/s^2 is used as a safe deceleration rate to calculate safe distance for our algorithm. Using current speed, advisory speed, and safe deceleration rate *(a)*, the safe distance is calculated by using Equation 3.

$$\frac{V_c^2 - V^2}{2a} \tag{3}$$

However, Equation 3 does not accommodate driver's reaction time. Therefore, an adjustment is made to include the driver's reaction time in calculating safe distance using Equation 4, where T is the reaction time for the driver. According to AASHTO, a person can take 0.9 to 2.5 seconds to react to a warning sign. To be on a safe side, we are using the longest reaction time (2.5 s) for safe distance calculations for our system.

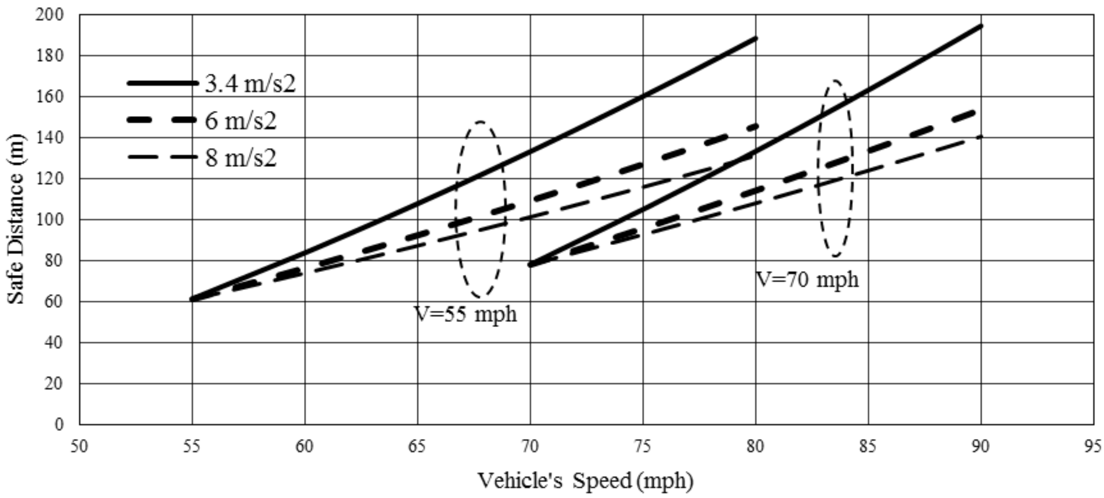

Figure 5: Calculated safe distance vs. vehicle's current speed for two different advisory speeds.

$$\frac{V_c^2 - V^2}{2a} + V_c \times T \quad (4)$$

Figure 5 shows the safe distance vs. vehicle's current speed for three different values of deceleration rate (3.4, 6 and 8 m/s^2) for each of the two advisory speeds (55 and 70 mph). Although system uses 3.4m/s^2 as deceleration rate, the higher declaration rates (6 and 8 m/s^2) have been incorporated for reference only. It is to be noted that the higher deceleration rates show the usage of emergency brakes while reducing speed. When the vehicle is driving at the same speed as the advisory speed *($V=V_C$)*, safe distance only accounts for driver's reaction time and will have some non-zero value.

2.3 System Warning Generation

Based on safe distance analysis, our algorithm scans a curve ahead at least half a mile in advance to ensure that advanced curve warning can be issued in time. Half a mile criterion gives 30 seconds buffer time at the speed of 60 mph. Once the advisory speed is determined and a safe distance is calculated, the following two possible scenarios are evaluated prior to issuing the warning.

- Vehicle's current speed is higher than the advisory speed.
- Vehicle's current speed is less than or equal to the advisory speed.

Curve Ahead
Advisory Speed: **XX mph**

In both scenarios, our algorithm recommends the same warning, however, the safe distance where the warning will be issued will be different in both scenarios. Once vehicle approaches at the safe distance to the curve, the above warning will be issued.

The warning message comprises of two important pieces of information, first about the existence of curve ahead and second about the advisory speed for that curve. By giving the warning within the safe distance, our algorithm ensures that the driver has enough time to adjust vehicle's speed comfortably. Our prototype system displays a written warning on the console for demonstration purposes.

3 FIELD TESTS AND RESULTS

The functional flow diagram for both lane departure detection and advanced curve speed warning

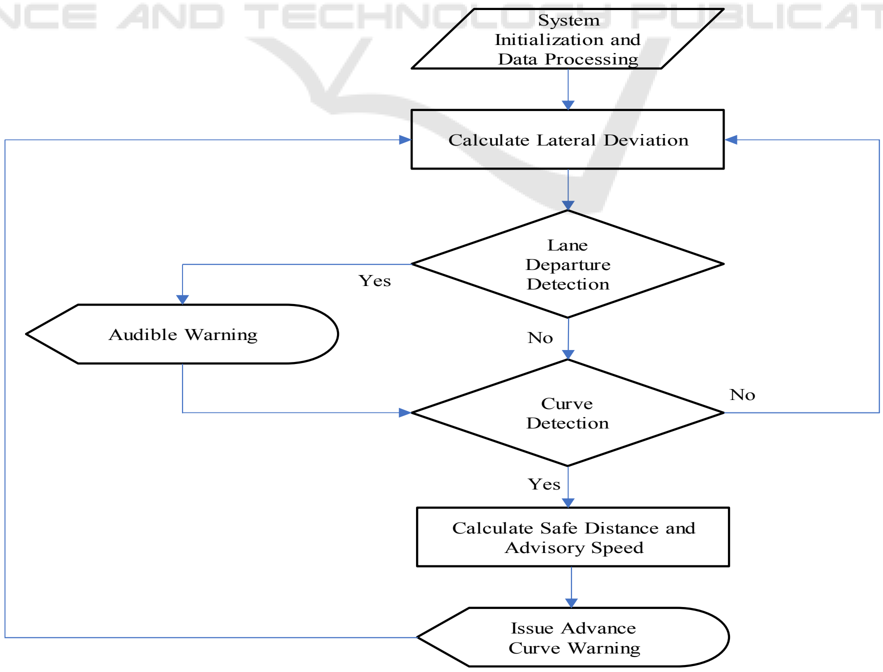

Figure 6: Flow diagram showing the complete functionality of lane departure warning and advance curve speed warning systems.

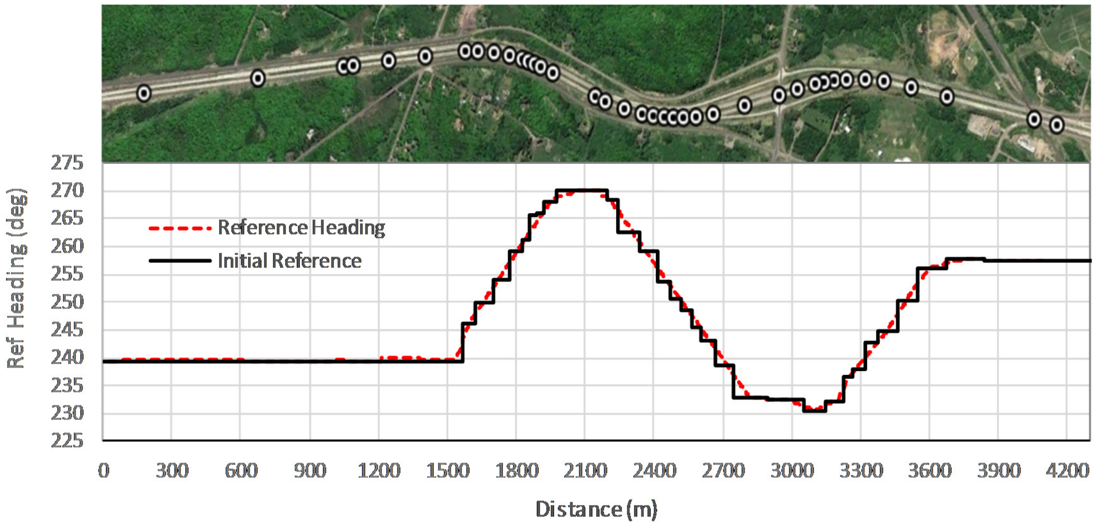

Figure 7: Database heading between consecutive shape points (black) and calculated reference heading (red dashed line) versus road distance for a 4 km segment of Interstate I-35. The Google Earth view of the corresponding road segments with shape points are also shown for reference.

algorithms are shown in Figure 6. We used a Savari MobiWAVE unit to implement our algorithm and evaluate its performance in the field. The Savari unit has a built in GPS receiver and processing power to implement our algorithm. The built-in GPS receiver had a UBlox LEA-6 chipset which is a common chipset in many GPS receivers. Please note that the proposed algorithm can be implemented in any navigational device having a standard GPS receiver and necessary processing power.

The prototype system periodically (every 100 ms) calculates instantaneous lateral distance and accumulates it over time. If the accumulated lateral distance crosses certain threshold, the system will issue an audible warning to alert the driver of unintentional lane drifting. Simultaneously, the prototype system also checks if there is any curve ahead. The system has the capability to differentiate between curve and straight sections of the road in real time. If a curve is detected, first its advisory speed is determined and then a safe distance is calculated based on vehicle's current speed and the advisory speed for the curve. The safe distance calculation determines when to issue the advance curve speed warning. In our prototype system, the warning is issued as soon as the vehicle approaches within the safe distance from the curve so the driver will have enough time to reduce the vehicle's speed. This whole cycle of calculation is repeated every 100 msec and appropriate warnings are given when warranted. In this way, both lane departure and advanced curve speed warning algorithms works simultaneously.

We tested our prototype system on two different road segments, a 3 km long segment of Rice Lake Road in Duluth, MN, and a 4 km long segment of Interstate I-35 near Duluth, MN. Figure 7 shows the reference heading for I-35 vs travelled distance as extracted from the mapping database. The Google Earth picture of the corresponding section of Interstate I-35 is also shown on the top of the figure. The I-35 test segment has three curves in 4 km segment as can be seen in Figure 7.

The lane width for both road segments was 3.6 m and the speed limit were 55 MPH for Rice Lake Road and 70 MPH for Interstate I-35. The vehicle was driven at about speed limit on both road segments and many back-and-forth driving runs were made. During these test runs, whenever, the vehicle was approaching to a curve, the driver was warned about the presence of the curve ahead along with its advisory speed before the curve starts.

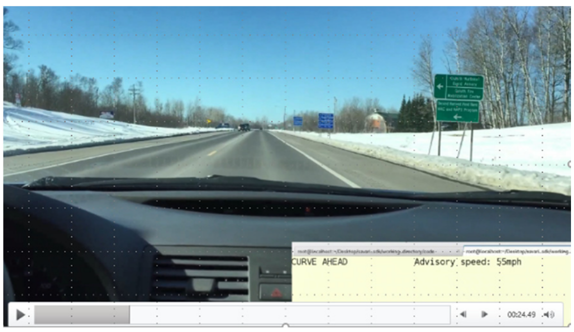

Figure 8: Snapshot from field demonstration showing advanced curve speed warning while approaching a curve.

Figure 8 shows a snapshot of the console during one of our field tests while approaching one of the three curve sections in the test segment. We evaluated the accuracy of the algorithm by marking down the distance where the warning was issued while driving at different speeds. Each time, the curve was successfully detected and the warning was shown at the appropriate safe distance. We also evaluated the system for lane departure warning by intentionally making many back and forth lane changes on both straight and curved sections of the test segment. Those results have already been published elsewhere (Muhammad Faizan et al. 2019).

4 CONCLUSIONS

Previously we proposed and demonstrated a novel algorithm to detect an unintentional lane departure and warn the driver in time. Now we have added another feature in this algorithm which can detect an upcoming curve and determines its advisory speed. We designed the algorithm for this added feature and demonstrated in the field by developing a prototype system. Extensive field tests were performed to evaluate the efficiency of the newly developed algorithm on two different road segments. The advance curve detection algorithm can detect the upcoming curve and correctly determines its advisory speed before issuing the appropriate warning at a safe distance before the curve starts. We have performed error analysis for the lane departure detection part of this work but both the temporal and spatial scale involved in an upcoming curve detection are large enough to be ignored. An error in an upcoming curve detection, can be up to ± 25 m in location which translates to ± 1 second in time, is insignificant for this feature.

ACKNOWLEDGEMENTS

The authors wish to acknowledge those who made this research possible. The study was funded by the Minnesota Department of Transportation (MnDOT) and Minnesota Local Research Board (LRRB).

REFERENCES

C. Maag, D. Muhlbacher, C. Mark and H. P. Kruger, Studying Effects of Advanced Driver Assistance Systems (ADAS) on Individual and Group Level Using Multi-Driver Simulation, IEEE Intelligent Transportation Systems magazine, vol. 4, no. 3, pp. 45-54, Fall 2012.

Driving down lane-departure crashes: A national priority. (2008). Washington, DC: American Association of State Highway and Transportation Officials.

Preston, H., and T. Schoenecker, Potential Safety Effects of Dynamic Signing at Rural Horizontal Curves, Minnesota Local Road Research Board. St. Paul, MN, December 1999.

D. D. Salvucci, Inferring driver intent: A case study in lane-change detection, Proc. Human Factors Ergonomics Society 48th Annu. Meeting, New Orleans, LA, 2004, pp. 2228–2231.

N. Kuge, T. Yamamura, and O. Shimoyama, A Driver Behavior Recognition Method Based on a Driver Model Framework. Warrendale, PA: Soc. Automot. Eng., 1998.

J. McCall and M. M. Trivedi, Visual context capture and analysis for driver attention monitoring, Proc. IEEE Conf. Intelligent Transportation Systems, Washington, DC, Oct. 2004, pp. 332–337.

F. Heimes and H.-H. Nagel, Towards active machine-vision-based driver assistance for urban areas, Int. J. Comput. Vis., vol. 50, no. 1, pp. 5–34, Oct. 2002.

W. Kwon and S. Lee, Performance evaluation of decision-making strategies for an embedded lane departure warning system, J. Robot. Syst., vol. 19, no. 10, pp. 499–509, Sep. 2002.

Federal Highway Administration, FHWA Roadway Departure Strategic Plan. Washington, DC: March 2013.

Cicchino, J. (2018). Effects of lane departure warning on police-reported crash rates. Journal of Safety Research, 66, pp.61-7.

Xiangjing An, Mo Wu and Hangen He, A Novel Approach to Provide Lane Departure Warning Using Only One Forward-Looking Camera, International Symposium on Collaborative Technologies and Systems (CTS'06), 2006, pp. 356-362.

Pei-Yung Hsiao and Chun-Wei Yeh, A Portable Real-Time Lane Departure Warning System based on Embedded Calculating Technique, 2006 IEEE 63rd Vehicular Technology Conference, Melbourne, Vic., 2006, pp. 2982-2986.

B. Yu, W. Zhang and Y. Cai, A Lane Departure Warning System Based on Machine Vision, 2008 IEEE Pacific-asia Workshop On Computational Intelligence and Industrial Application, Wuhan, 2008, pp. 197-201.

Y. C. Leng and C. L. Chen, Vision-based lane departure detection system in urban traffic scenes, 2010 11th International Conference On Control Automation Robotics & Vision, Singapore, 2010, pp. 1875-1880.

P. Lindner, E. Richter, G. Wanielik, K. Takagi and A. Isogai, Multi-channel lidar processing for lane detection and estimation, 2009 12th International IEEE Conference On Intelligent Transportation Systems, St. Louis, MO, 2009, pp. 1-6.

S. Glaser, L. Nouveliere and B. Lusetti, Speed Limitation Based on an Advanced Curve Warning System, 2007

IEEE Intelligent Vehicles Symposium, Istanbul, 2007, pp. 686-691.

R. Yoneda, K. Okuda and W. Uemura, A tight curve warning system using FSK visible light and road-to-vehicle communication, 2013 IEEE Third International Conference on Consumer Electronics, Berlin (ICCE-Berlin), Berlin, 2013, pp. 1-3.

S. Rogers and Wenbing Zhang, Development and evaluation of a curve rollover warning system for trucks, IEEE IV2003 Intelligent Vehicles Symposium. Proceedings (Cat. No.03TH8683), Columbus, OH, USA, 2003, pp. 294-297.

Qin, Xiao & Zhang, Shaohu & Wang, Wei. (2015). Advanced Curve-speed Warning System Using an In-Vehicle Head-Up Display.

S. Glaser, L. Nouveliere and B. Lusetti, Speed Limitation Based on an Advanced Curve Warning System, 2007 IEEE Intelligent Vehicles Symposium, Istanbul, 2007, pp. 686-691.

DaimlerChrysler AG (2018). Vehicle With Optical Scanning Device For A Lateral Road Area. US006038496A.

J. M. Clanton, D. M. Bevly and A. S. Hodel, A Low-Cost Solution for an Integrated Multisensor Lane Departure Warning System, IEEE Transactions On Intelligent Transportation Systems, vol. 10, no. 1, pp. 47-59, March 2009.

S. Glaser, L. Nouveliere and B. Lusetti, Speed Limitation Based on an Advanced Curve Warning System, 2007 IEEE Intelligent Vehicles Symposium, Istanbul, 2007, pp. 686-691.

S. Hussain, M. Faizan and M.I. Hayee. Real-time relative lane and position identification of surrounding vehicles using GPS and DSRC based vehicle-to-vehicle communication. Presented at the proceedings of IEEE Conference on Communications, Kansas City, MO., May 2018.

Muhammad Faizan, S. Hussain and M.I. Hayee, Design And Development Of In-vehicle Lane Departure Warning System Using Standard GPS Receiver. Transportation Research Record, Journal of Transportation Research Board, I-9, 2019.

A Policy on Geometric Design of Highways and Streets, 2018, 7th Edition: American Association of State Highway and Transportation Officials.