ADVANCED DEVELOPMENT DATA ACQUIRING TECHNIQUES FOR VEHICLE ROAD DEPARTURE PREVENTION SYSTEMS

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Abstract:

In recent years, road departure prevention systems (RDPSs) for mitigating/avoiding road departure crashes have been developed and equipped in some high-end production vehicles. This paper describes the test scenario development and the associated data acquisition and data post-processing systems in order to provide a standardized and objective performance evaluation of RDPSs,. Seven key factors are identified and analyzed. On both straight roads and curved roads, their possible values are used to describe the most representative road departure test scenarios. The overall structure and components of data collection and post-processing systems for RDPSs' evaluation are devised. They are presented here. The algorithms for computing vehicle dynamic information are developed. Experiments are performed on the test track under various scenarios. The results show that the sensing system (SS) and data post processing system (DPPS) can capture all necessary signals accurately and display the test vehicle motion profile effectively.

***Keywords:* Road Departure Prevention Systems (RDPSs), Sensing System (SS), Data Post Processing System (DPPS).**

1. INTRODUCTION

A leading cause of deaths on US roads [1] is vehicle crashes due to road departure. Each year approximately 12,000 drivers lost their lives due to road departure crashes [1]. About 35% of the deaths on US roads [2] is due to road side crashes. For addressing this issue Road Departure Warning (RDW) and Road Keeping Assistance (RKA) systems are active safety technologies. Based on the detection of lane markings are most of recently developed lane/road departure mitigation systems. However, many roads do not have lane markings or clear lane markings, especially in some rural and residential areas [3]. Therefore, on the detection and identification of various types of road edges and road boundary objects, rely road departure detection and avoidance technologies.

By developing modeling methods, perception algorithms, and control strategies for road departure warning/mitigation systems, safety professionals and automobile manufacturers have strived to overcome the road departure issue. [4] Discuses a simulated road departure prevention system that relies on roadside terrain geometry analysis and subsequent threat assessment. The viability of detecting vehicle runoff the road through the measurements of anomalies under scenarios that left and right tires experience force imbalance was investigated in [5]. Authors in [6] explored the effectiveness of a three-layer perceptron neural network to predict an unintentional road departure. [7] Presents a driving simulation study that evaluates the road-departure prevention system in an emergency. In [8], authors propose a system based on a closed-loop Driver Decision Estimator (DDE) that determines the risk of road departure. Traffic forecast using deep learning method [9], evaluation of Lane Departure Correction System (LDCS) based on the stochastic driver model [10], analysis of the LDCS utilizing naturalistic driving data [11] are the other related research works.

2. ROAD DEPARTURE TEST SCENARIOS

The main objective of developing RDPSs is to reduce the number of injuries and fatalities due to road departure crashes. Vehicle dynamics, road geometries, roadside objects, and safety features have a great influence on the crash frequency and severity of the crashes. To develop a road departure prevention system and determine its appropriateness, it is imperative and necessary to identify the pre-crash characteristics and scenarios regarding both vehicle dynamics and environmental conditions or other driver distracted or other driver related factors. There are two categories of road departure crashes [17]: (1) A common crash occurs when vehicles run off the road due to drivers distraction; (2) Motorist over-corrects steering angle to avoid the objects on the roads, which is an avoidance maneuver causing the vehicle to lose control. This paper is focused on type (1) road departure crashes, since all known RDPSs, to the best of authors knowledge, are not designed for avoiding type (2) crashes.

A. Identification of Road Departure Events

The development of active safety technologies for vehicle lateral support systems (LSS), such as RDW and RKA (that operate well in the conditions of poor lane markings or lack of lane markings) are still a challenging problem. Unlike Lane Keep Assistance (LKA) that uses lane markings to determine lane boundaries or road edge, the RDPS should be able to detect road edges without using lane marking information [3]. In this paper, we consider road departure events on both the roads with clear lane markings, un-clear lane markings and without lane markings.

Road departure accident is a cause of fatal crashes in the US and half of all the crashes are related to run-off-the-road according to the Fatality Analysis System Reporting (FARS) from the National Highway Traffic Safety Administration (NHTSA) [4], [18]. It is necessary to know the definitions of road departure events before defining road departure scenarios. As described in [19], road departure events are defined as the vehicle crosses the road edge, or leaves the roadway leading to striking roadside objects, or rolls over and head-on into objects moving from the opposite direction. A natural question from the road departure definition is how to determine the road edge. The success of RDP or RKA relies greatly on the ability to detect and identify the road edges and boundaries. The study in [3] showed that 33.4% of the US roads with grass edge do not have road marking or not clearly marked. Fig.1 demonstrates poor lane marking conditions where a lane marking detection system may not work well.

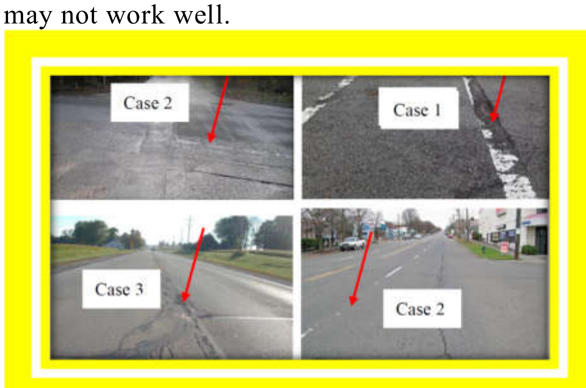

Figure 1. Poor lane markings that RKA might not work.

To be more specific, the un-clear lane markings can be described in three cases, (1) missing part of the solid lane marking; (2) missing part of the dashed lane marking leading to a large gap between dashes; and (3) road patch repair resulting in lane markings difficult to identify. When there is poor lane marking, RDPS needs to use ther methods to find the road edge. The overview of the nomenclature can be seen in Figure2.

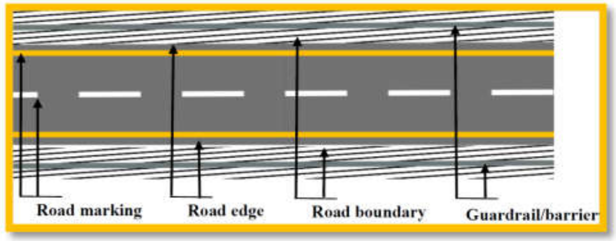

Figure. 2 Overview of nomenclature: Road markings, road edges, road boundaries, and road barriers like guardrails.

Road edge is defined as the closest sensor identifiable intersection between the road and non-road surfaces [18]. In other words, road edge is the intersection of the sealed homogeneous road surface (such as concrete and asphalt) and unsealed road surface (such as grass and gravel). Road edges can also be indicated by road boundaries such as curbs, concrete dividers, and metal guardrails. Road boundaries are vertical objects that are close to the road edges such as vehicles, fences, utility/lighting poles, and mailboxes. The successful three-stage working process of current RDPS on vehicle potential straying road that may cause crashes has been shown in Fig. 3. At stage 1, the warning signal is triggered when vehicle lateral deviation or potential lane/road departure was observed; Then the steering torque (and possibly braking) input will be applied to avoid straying road if driver fails to take actions at the second stage; Stage 3 can keep vehicle back onto the center-line of the road using autonomous steering.

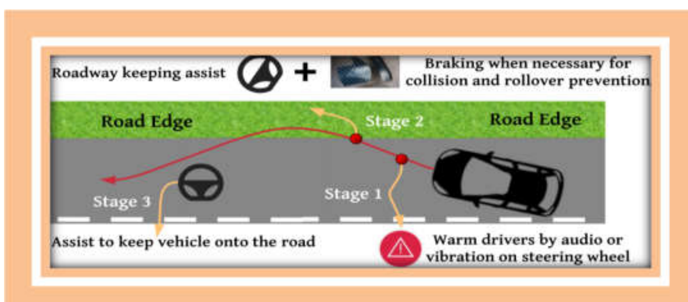

Figure. 3 Three-stages operating process of current RDP systems.

B. Overall Approach and Key Variables

All test methods and results rely on road departure test scenarios. The first step for the determination of representative road-departure test scenarios is the identification of key variables.

In this subsection, it is described how to determine the key variables for road-departure test scenarios and their most representative values. Fig 4. Proposes an overall approach for identifying key variables.

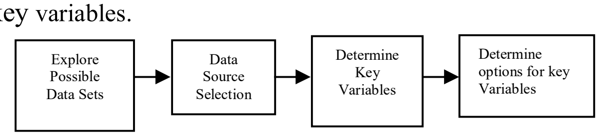

Figure. 4 Overall approach for determining key variables and their values of road departure test scenarios.

From the distribution of road departure conditions associated with road departure crashes, key parameters for road departure test scenarios can be obtained. These conditions contain variables. They are vehicle speed, road edge type, vehicle departure angle, and environmental factors. These conditions are used to generate key parameters for RDPS testing. In this work, the data sources containing conditions of road departure crashes are – (i).National Automotive Sampling System Crashworthiness Data System (NASS CDS), (ii) Fatality Analysis Reporting System (FARS), (iii) National Cooperative Highway Research Program (NCHRP) 17-43, (iv) National Motor Vehicle Crash Causation Survey (NMVCCS), (v) Google Street View images, (vi) Federal Highway Administration Rollover Study, and (vii) Texas Transportation Institute data.

Many factors and conditions are associated with the descriptions of road departure crashes in these data bases. These factors are (1) road conditions (road geometries, road surface, road slope, and radius of the road curvature) (2) roadside conditions (road edges and boundaries) (3)vehicle conditions (vehicle departure speed, vehicle road departure angle, vehicle lateral speed, and side of the road) (4) environmental conditions (weather, time, and lighting conditions) and (5) driver attentiveness (distraction and fatigue). Since we are interested in the effectiveness of road departure prevention/mitigation systems, factor (5) is not applicable. Therefore the following seven key factors for describing general road-departure test scenarios are selected:

1) Road type - the road geometries or alignment (straight road or curved road);
2) Radius of the road curvature - radius of the curved road;
3) Combination of road material and road edge types - different combinations of road materials and roadside edges, such as asphalt/grass, concrete/gravel, concrete/ curb, asphalt/metal guardrail, and so on;
4) Vehicle departure velocity - the vehicle velocity in vehicles0 actual moving direction;
5) Vehicle departure side - on which side of the road that road departure occurs;
6) Vehicle departure angle – Fig. 5 depicts the relationship between vehicle departure speed and vehicle departure angle, where vehicle CG (center of gravity) velocity is the same as vehicle departure speed;
7) Lighting conditions - time, weather condition, and street lighting.

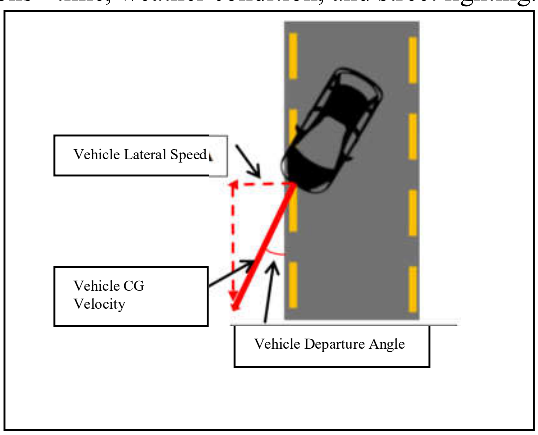

Figure.5 Relationship between vehicle departure speed, lateral speed, and departure angle.

Since we cannot find a comprehensive representative national data set to cover the combination of all seven key variables, these variables are analyzed separately according to their possible values. The variables, such as vehicle departure velocity, vehicle departure angle, and radius of road curvature, which are represented using numbers, are defined as continuous variables in our method. Variables, such as road type, a combination of road material and road edge types, vehicle departure side, and lighting condition, that are represented by discrete values are called discrete variables. The most representative values of three continuous variables can be obtained. All the discrete variables are considered in a group, and once the most common combinations are determined, the values of continuous variables will be inserted. Therefore, the complete road departure test scenarios can be generated.

3. Structure of Road Departure Test System

For the development of standardized performance evaluation of RDP systems, the coordinated test data collection and post processing systems were designed and implemented based on the outcomes of key variables and scenarios of road departure tests in Section II. In a RDPS performance test, the values of road-related variables are known. Only the values of variables with vehicle driving information need to be measured. These variables include vehicle departure speed and vehicle departure angle. Some vehicle reactions to the road departure with precise timing also need to be recorded, such as vehicle acceleration, time from warning to recovery and so on. Fig.6. depicts the proposed overall structure for road departure prevention system testing. The system includes: (1) Test vehicle with a data collection system, (2) Surrogate roadside objects, including grass, metal guardrail, curb, and concrete divider, (3) Central computer for data recording and system coordination and control. All components, except for the roadside surrogate objects, communicate with each other wirelessly through a ZigBee network with operation distance around one mile. RDPS testing consists of two stages: data collection and post-data processing. A data acquisition system was developed to measure and collect all the required data during testing. The data post-processing system decodes, analyzes, plots, and displays test results.

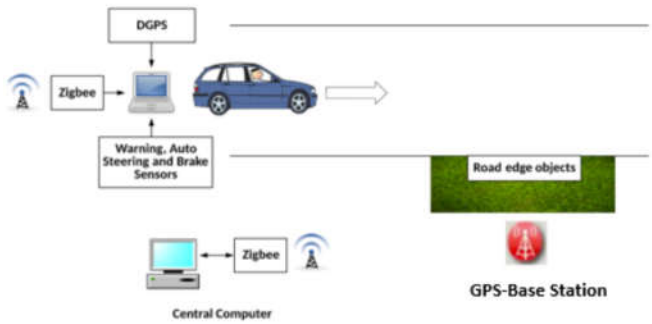

Figure. 6. Proposed structure of road departure test system.

A. Data Collection System

A vehicle road-departure prevention system may have three action levels. The RDP system first gives a visual and/or audible warning to alert the driver to take corrective actions when vehicle is about to cross the boundary of the road. If the driver fails to take any action, the RDP system will actively apply the appropriate steering torque to push the vehicle back onto the road. If the vehicle cannot be pushed back and vehicle is on roadside, then autonomous braking or steering assistance might be applied.

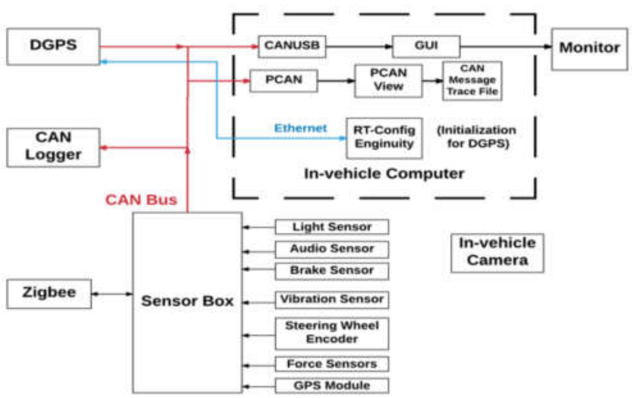

Figure. 7. Overall structure of the data collection system

For evaluating the performance of the road departure prevention system, a data collection system is designed to capture and record the motion trajectory of the test vehicle, the activation time of vehicles road departure prevention actions (warning, auto-steering, and auto-braking), and action by the driver (steering and/or braking). The proposed structure of the data collection system is shown in Fig. 7. The data collection system consists of six key components including sensor box, Differential GPS, in-vehicle computer, in-vehicle camera, CAN logger, and vehicle speed display monitor.

The design objective of the sensor box is to receive all necessary vehicle dynamic information during road departure testing, including visual/audible warning, assistive action signals generated by the vehicle and the driver. These signals include brake pedal movement signal, brake light signals, warning sound, vehicle vibrations caused by crossing different road surfaces, steering wheel motion, impact force from the bumper, and a time synchronized GPS module. The results are sent to both the CAN logger and in-vehicle computer through CAN bus. The ZigBee wireless communication module is also designed in the sensor box to exchange information with the central computer. The central computer is located outside of the test vehicle but close-by on the test track. The overall structure of the sensor box is shown in Fig. 8.

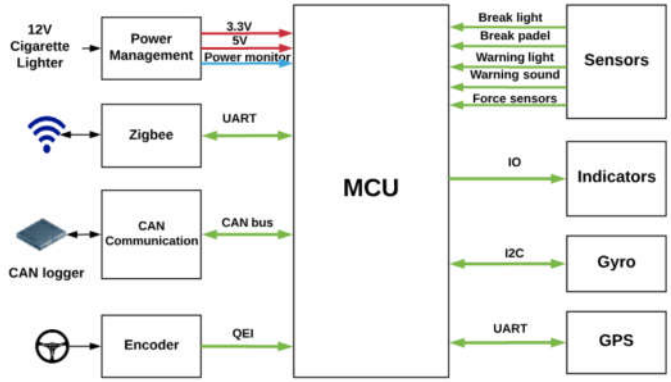

Figure. 8. Overall structure of the sensor box.

A foreground-background operating system is designed to allow the program in the sensor box to read the status of sensors, record data, synchronize GPS time, and communicate with laptop through CAN bus. It should be mentioned that the audible warning signal from the vehicle is in a narrow frequency range. Thus, fast Fourier transform is implemented on a Raspberry Pi for audio signal processing. The Raspberry Pi is included in the sensor box to record the vehicle road departure warning beep in real time.

The DGPS is for measuring the motion profile and position of the test vehicle. A Windows based laptop PC is utilized to initialize the DGPS and record CAN messages. As shown in Fig. 7, the CAN data from sensor box and DGPS are split into two channels. One channel goes through the PCAN dongle for raw data collection, the other channel goes through CAN-USB dongle for vehicle speed monitoring. PCAN and CAN-USB

B. Data Post-Processing

All captured raw data are transferred into the in-vehicle computer through CAN bus and saved as a trace file. To analyze the performance of the road-departure prevention system, a data post-processing system is proposed and implemented. Fig. 9 shows the basic structure of the software for the data post-processing method, which includes decoding all recorded trace data, time synchronization of all collected data, user interface design, data plotting, and data analysis.

4. ALGORITHM FOR COMPUTING VEHICLE MOTION PROFILE

From the knowledge of last section, in order to implement the road departure tests on the real test track, a speed monitor was developed to show the vehicle dynamic information

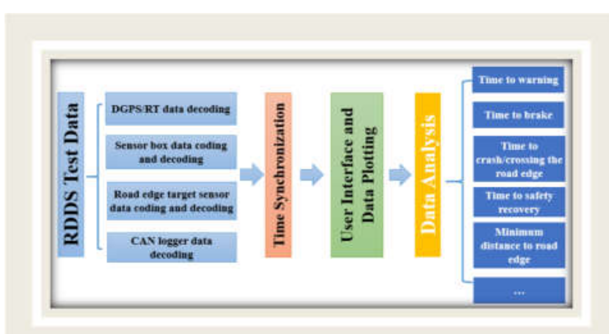

Figure. 9 Basic structure of the software for data post-processing.

for assisting drivers to compare the actual and desired vehicle velocities from test scenarios. Therefore, the designed algorithm for computing the vehicle forward speed, lateral speed, and departure angle on both straight roads and curved roads is presented in this section. The algorithm of straight road and curved road data processing will be discussed in the following sub-sections.

Straight Roads

For straight roads as depicted in Fig. 14, the key variables (vehicle speed, vehicle lateral speed and vehicle departure angle) listed can be directly decoded from the captured DGPS CAN messages based on local coordinate. The convention used for the Local coordinate system utilizes the right-handed set with the Z-axis up. For convenience of test result description and test data plotting, the origin of the coordinate system is set around the departure location on right road edge if the right road departure is tested, and the origin of the coordinate system is set around the departure location on left road edge if the left road departure is tested.

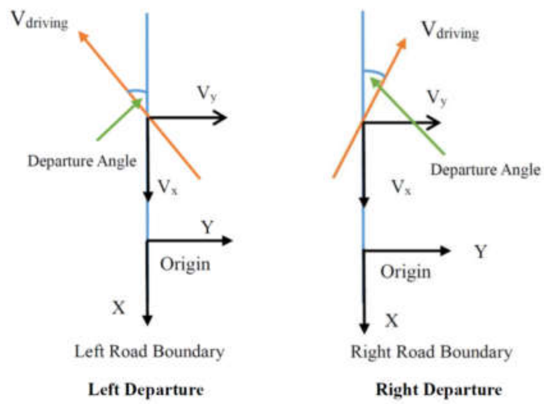

Figure. 10 Vehicle motion profile of the straight road.

- Vehicles longitudinal driving direction is along the negative direction of X-axis.
- The positive lateral motion direction is along the Y-axis.
- Vehicles driving direction is the component of the longitudinal driving direction and the lateral moving direction.
- Departure speed vehicle speed at the departure point
- The road departure angle is calculated

  Thus, for right road departure test, the departure angle is negative if the vehicle has right road departure, and the departure angle is positive if the vehicle is back from the roadside to the road; For left road departure test, the departure angle is positive if the vehicle has left road departure, and the departure angle is negative if the vehicle is back from the roadside to the road.

Curved Roads

For curved roads, we drive along the boundary of the curved roads and record a sequence of positions (Py; Px) representing the boundary of a curved road. A second order fitting function of these road boundary points can be generated to represent the road boundary. Then a two-step algorithm is designed to compute the vehicle departure speed, lateral speed, and departure angle according to a selected local coordinates system. The first step of the algorithm is to find the point D that has the closest distance between the vehicleand the curved road (shown in Fig. 11). The second step for computing vehicle motion profile is shown in Fig. 12. The local coordinate definition and setup are the same as that used on straight roads.

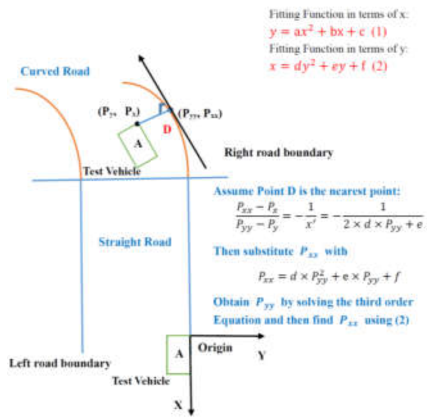

Figure. 11 Step 1: Obtain the closest point D to the moving vehicle A on curved road.

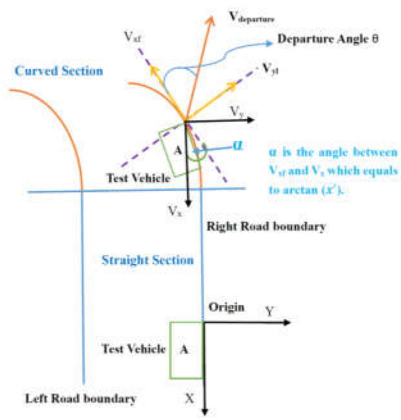

Figure. 12 Step 2: Obtain the closest point D to the moving vehicle A on curved road.

5. Experimental Results

The experimenters have conducted about 70 road departure tests on the real test track according to the recommended test scenarios. The test track is located in Columbus, Indiana, which is illustrated in Fig. 13. Mainly tests were conducted on the straight road (with both daylight and dark conditions). A few tests were conducted on the curved road. The experimenters list the signals that they can capture using the testing equipment in Table 1, along with their data accuracy. The quantities of interests that can be calculated based on these recorded signals are summarized in Table 2.

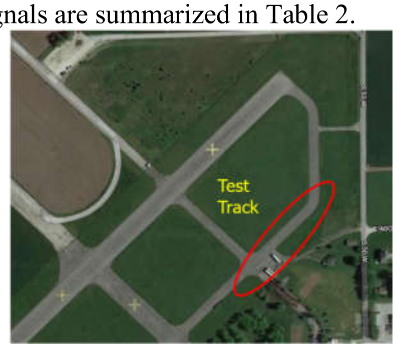

Figure. 13 Test track that operates vehicle road departure test experiments (ROC_67m).

SIGNALS TO BE MEASURED IN VEHICLE TESTING.

Name of Signals	Measurement Equipment	Data Accuracy
Vehicle longitudinal/lateral position	DGPS	0.02 m
Vehicle longitudinal/lateral velocity	DGPS	0.05 km/h
Vehicle acceleration	DGPS	0.01 m/s^2
Road departure warning signal	Sensor Box	N/A
Brake light signal	Sensor Box	N/A
Steering wheel angle signal	Sensor Box	N/A
Vehicle yaw angle	DGPS	N/A
Vehicle yaw rate	DGPS	0.01 deg/s

Table :1

SIGNALS TO BE CALCULATED IN VEHICLE TESTING.

Name of Signals
Vehicle Departure Velocity
Distance from vehicle to the Road Edge
Time to Road Edge Crossing
Time interval between warning and actual road departure

Table :2

6. Conclusion

This paper presents the development of a data collection system and data post-processing methods for evaluating vehicle RDPS on the real test track. The overall architecture of the vehicle road departure testing system is proposed. Seven key factors for describing road departure scenarios are defined according to the most representative national crash based or non-crash-based data sources. Road geometry, radius of road curvature, combination of road material and road edge types, vehicle departure velocity, vehicle departure angle, vehicle departure side, and lighting conditions are the seven factors. The complete road departure test scenarios are also analyzed and determined by separating all seven variables into continuous variables and discrete variables. The integrated structure and detailed components of the data collection and post-processing system are illustrated. For both straight roads and curved roads, the algorithm for computing vehicles lateral speed and vehicles departure angle is also developed. To decode and visualize test results, the data post-processing method is devised and implemented. The experimental results on both straight road and curved road depict that the sensing system, data collection system, and data post processing system could perfectly record all necessary signals and display all vehicle dynamic data under the various road departure scenarios.

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