VIRTUAL EXPERIMENTAL ENVIRONMENT DESIGN of CAMERA-SENSOR-BASED LANE DETECTION SYSTEM

Ziyi, Peng
Chinesisch-Deutsches Hochschulkolleg, Tongji University
China

Junyi, Chen
Hongyan, Wang
Lulong, Cai
School of Automotive Studies, Tongji University
China

Yutong, He
Shanghai United Road Traffic Safety Scientific Research Center
China

Paper Number 15-0125

ABSTRACT

Based on the application of software model building, virtual experiment can be conducted with vehicle model, road environment model and sensor model building to develop camera-sensor-based lane detection system in PreScan. These three types of models are connected and the virtual experimental environment is built. Sensor-extracted data are processed by Matlab/Simulink to acquire the accurate ground truth. Meanwhile, images from camera sensor are processed with standard size for further application. The virtual experimental environment design is the foundation for the analysis and comparison of ground true and camera-detected data, as well as for accuracy evaluation in system pre-development. In conclusion, the virtual experimental environment design can be used in camera-sensor-based lane detection system development and is a supplement to traditional system development.

INTRODUCTION

In recent years, with rapid development and comprehensive application of computer vision and image processing technology, more and more products about pilotless automobiles and Advanced Driver Assistance Systems (ADAS) are coming to the market.

Camera-sensor-based vision and image processing technology are suitable for application of trajectory recognition and tracking. A lot of scientific achievements have been already applied in the real world. For example, a six-wheeled autonomous off-road vehicle (called an Argo vehicle) was equipped with various sensors at the University of Waterloo. 3D objects on the road can be dectected by the sensor on the Argo vehicle [1]. In Highway Lane Change Assistant (HLCA) system which was designed by M.Ruder from BMBF in Germany, vision and radar sensors were combined to detect dangerous objects in the neighboring lanes [2]. The system which was applied to Lane Departure Warning was connected to computers with Controller Area Network (CAN) and controlled by CAN. AutoVue System from Iteris Inc was also applied to Lane Departure Warning. The system was controlled by an integrated unit which consisted of camera and computer [3]. Currently most research focuses on application and optimization of lane detection algorithm in ADAS and pilotless automobiles [4]. There are basically two major research focuses in algorithm development. One is trajectory recognition and tracking with Hough Transform and other related algorithm. The other is based on the existing lane marker models. Parameters of the lane markers are detected by camera and matched with models [5]. The suitable lane marker model will be selected, if the information of lane markers and the model is similar or identical.

With deeper and more intensive research in development and evaluation of camera-sensor-based driver assistance system, a new method is expected to ensure the effectiveness and efficiency of system development process [6]. Meanwhile, due to high cost and long term of field experiment, virtual experiment is suggested as a good support and supplement of traditional field experiment by R&D engineers. Thus, design and development of virtual experiment is a new research focus of camera-sensor-based driver assistance system development.

1 BACKGROUND

This paper focuses on virtual experimental environment of camera-sensor-based driver assistance system, especially lane detection systems, for instance, Lane Departure Warning (LDW), Lane Keeping Assist (LKA), Lane Centering Assist (LCA) etc. Camera-sensor-based driver assistance system aims to identify various types of lanes on different roads and help cars drive in the right lane [7].

Traditional evaluation method of camera-sensor-based driver assistance system development is to apply advanced data process technology such as VBOX or TRC to extract ground truth [8]. Taking VBOX for instance, it is a GPS based data acquisition system, which can extract the real-time location and dynamic parameters of the vehicle. Extracted data will be transmitted to computers without delay [9]. Meanwhile, VBOX can process image data of lanes from the camera and output the distance between the lane markers and the vehicle. By comparing this information with data from lane detection algorithm, the accuracy of the algorithm can be evaluated.

In the course of research and development in real life, a major problem of field experiment is that the system cannot be tested and evaluated exhaustively under every operating condition. Besides, the cost of traditional field experiment is relatively high. Thus, it is quite difficult to achieve the effectiveness of experiment. Under this circumstance, virtual experiment by software is regarded as a good supplement of traditional experiment. A vehicle dynamic model is needed to calculate dynamic parameters in camera-sensor-based driver assistance system virtual experiment. A standard road environment model along with weather and traffic condition is designed in the experiment. A camera sensor and a lane marker sensor should be also included to extract real-time image data and ground truth. In total, the vehicle model, road environment model and sensor models are mutually dependent and interacting.

The PreScan Software developed by TNO provides the possibility of design of the above three kinds of models under request of different parameters and conditions. PreScan is a physics-based simulation platform that is used for development of ADAS that are based on sensor technologies such as camera and GPS [10]. Meanwhile, PreScan can be connected with Matlab/Simulink for further data processing and calculation.

2 VIRTUAL EXPERIMENT MODELS

In order to design the virtual experimental environment of camera-sensor-based lane detection system, a vehicle model, a road environment model and sensor models should be set up in the related simulation software separately. The three types of models should work together so that the model can calculate vehicle dynamic data and the sensor can receive the signal of the road environment model at the same time. The vehicle dynamic model is primarily used to simulate the vehicle motion in reality, meanwhile the sensor is equipped on the vehicle, so the motion state of the vehicles can directly influence the signal received by the sensor. The road environment model, as one of the most important parts in this virtual experiment, is the source of the information collected by the sensor. This model should contain not only the information of national standards of roads, but also the driving route and the velocity of the vehicle.

2.1 Vehicle Model

In the test experiment of lane detection system vehicle model is basically focused on vehicle dimensions and dynamic model. Vehicle dimensions can affect the location of camera, while dynamic model is to calculate dynamic parameters. Audi A8, the software built-in dimension model, is chosen for the experiment as a dimension model in this paper. A suitable vehicle dynamic model can calculate real-time dynamic parameters for development and test of lane detection system. The Two-wheeled vehicle dynamic model is selected as a dynamic model, because there is no specific requirement for more sophisticated dynamic in the lane detection system experiment. The Two-wheeled vehicle dynamic model will calculate longitudinal and lateral velocity and acceleration, as well as yaw angle and pitch angle etc. For instance, pitch angle of the vehicle is different at different accelerations. As figure 1 shows below, the right image is in the course of acceleration, while the left one shows vehicle without acceleration. It is obvious that the horizon in the right image is higher because of the different pitch angle under conditions of different accelerations.

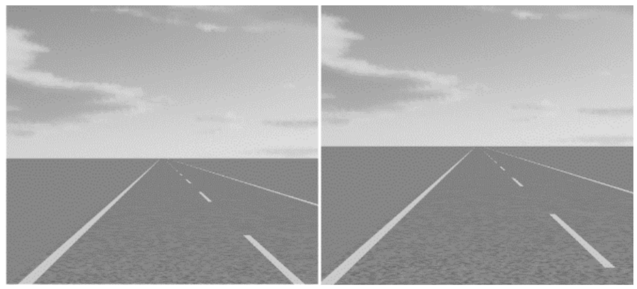

Figure1. Comparison of output images at different accelerations

It should be noted that, a customized, more sophisticated vehicle dynamic model can be called into PreScan if there is higher requirement for the virtual experimental environment.

2.2 Road Environment Model

2.2.1 Road model Lane detection systems are usually designed for expressways or other well-structured roads. Thus, the chosen road model in this paper is based on expressway model.

There are rigorous rules and regulations in Standard of Chinese Highway Route Design [11]. Direction of roads, as well as numbers and width of lanes are considered in the virtual experiment. Length, width and interval of lane markers and other related information is also important to the reality of the virtual road model.

According to the Standard of Chinese Highway Route Design, the radius of curves ranges from 250m to 1500m, and a total of 6 groups of bend road are designed. In order to test the fault tolerance of misstatement and omission of lane detection systems, missing lane markers are designed in the virtual experiment. In this paper the length of missing lane markers is 5m, 10m, 20m and 50m respectively. In addition, the color of lane markers, the luminance of lane markers, dashed/solid lane markers and bumpy/flat roads etc. can be defined as well.

2.2.2 Trajectory In the virtual experiment, the trajectory of the vehicle can be identified under specific request. However, due to the Two-wheeled vehicle dynamic model, the actual trajectories of the vehicle might be slightly different with the identified ones when vehicles change lanes or make a turn in the virtual experiment.

2.2.3 Vehicle velocity Vehicle velocity is essential to the result of virtual experiment. Since lane detection systems are mainly applied on expressways, the velocity is set at the range over 80km/h in the experiment. The performance of lane detection system is tested under different driving scenarios, including acceleration, deceleration, uniform motion and constant acceleration motion, etc.

2.3 Sensor Models

2.3.1 Camera sensor **A** camera sensor is one of the most important sensors in lane detection systems. All the extracted data are from the video images that captured by the camera sensor.

Parameters of the camera sensor can be set according to the specific sensor applied in traditional experiments, including location coordinates, range of sight, focal length, resolution of the output images, the video frames and the bit rate and so on. In this paper the frequency of the camera sensor is set as 25 Hz, that is, the video frame of the output images is 25.

2.3.2 Lane marker sensor Besides camera sensor, a lane marker sensor is quite necessary to extract accurate and real-time ground truth in the virtual experiment. The lane marker sensor is a built-in virtual sensor. It can provide the accurate information of the lane markers. The specific form of the lane marker information is the absolute coordinates of intersection between the center line of the lane marker and the sensor scanning line, as well as the distance from the intersection to the sensor. The accuracy of the data is 0.01m. According to the sensor settings, it can detect and record 3 points of the intersections at most each time. The frequency of the lane marker sensor is identical to the camera sensor, which is 25 Hz. In order to facilitate data processing and calculation afterwards, the lane marker sensor is located at the center position of the rear axle.

2.4 Build of Virtual Experiment Models

After setting the parameters of the above three types of models, different models can be connected and built in the Matlab/Simulink and the parameters of connections which are shown in Figure 2 can be further set according to specific requirements.

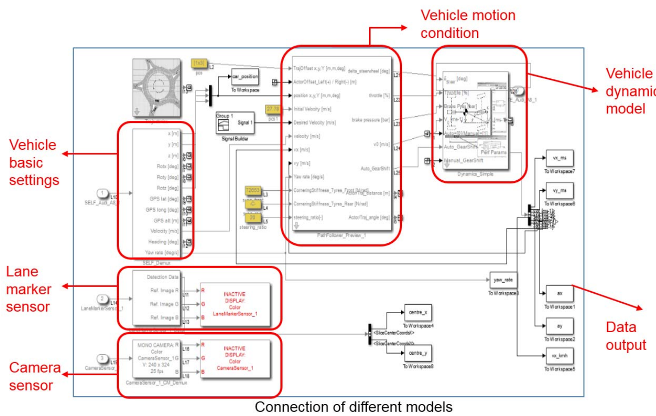

Figure2. Connections and control strategy diagram of lane detection system

3 DATA PROCESSING

In order to facilitate simulation data processing for the subsequent Software or Hardware in the Loop (SiL or HiL), the output data should be real-time data of ground truth and vehicle dynamic based on every video frame. These data can be regarded as the accurate vehicle dynamic and ground truth in the experimental environment. The results come from camera video image processing can be validated by comparing with the accurate data mentioned above.

3.1 Lane Marker Model

This paper only introduces two-dimensional lane marker models. Two-dimensional lane marker models can be divided into straight lane marker model, curve lane marker model and combined model, etc. A combined model of lane marker is chosen in this paper. At certain time, the lane marker model function below can describe the lane marker ahead [12].

$$y(x) = y_0 + \tan(\varepsilon)\, x + \frac{C_0}{2} x^2 + \frac{C_1}{6} x^3 \quad \textbf{(1)}$$

Where,

y_0 : the distance from the center line of lane marker to the center of the rear axle

ε : the angle between travel direction of vehicle and the lane marker

C_0, C_1 : coefficients

The origin of the coordinate system is the center of the rear axle as shown in Figure 3.

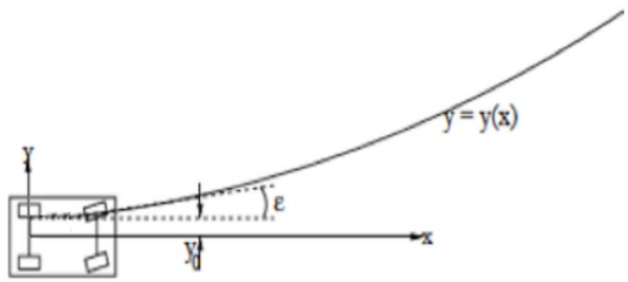

Figure3. Sketch of the lane marker model and vehicle-rear-axle-based coordinate system

3.2 Ground Truth Data Processing

In order to determine the coefficients of the lane marker model, points on the lane marker should be recorded for data fitting as many as possible at every moment. However, the lane marker sensor can detect and record only 3 points of the intersections at most each time and data are based on absolute coordinate system.

Under this circumstance, two tasks should be completed to determine the coefficients of function (1). The first task is to extract as many points as possible. The lane marker sensor is required to cover 100m lane marker ahead and extract about 1000 points in total each time, which means the points are extracted about every 0.1m on average. As a result, the vehicle should run two times in the virtual experiment.

For the first time the vehicle runs at the velocity of 2.5m/s (about 9 km/h) from the beginning of the lane to the end, by which the points on the lane marker can be extracted. The extracted data are in the absolute coordinate system. Because the frequency of the lane marker sensor is 25Hz and the velocity of the vehicle is 2.5m/s, the points can be extracted every 0.1m on the road. It can meet the requirements of data density which mentioned above.

For the second time the vehicle runs at the previous set velocity and follows the set trajectory on the road. The real-time vehicle-rear-axle-GPS data, as well as the vehicle dynamic data such as velocity, yaw rate, pitch, etc. can be extracted by PreScan. As the frequency of camera video is 25Hz, the absolute coordinate of the vehicle rear axle on each image can be known by reading the GPS data.

The second task is to transform the absolute coordinates to vehicle-rear-axle-based coordinates and determine the coefficients of function (1). The following data processing procedure is used to complete the second task:

Step 1. Coordinate transformation. The data of points on the lane marker should be transformed into the real-time vehicle-rear-axle-based coordinate system by applying the two-dimensional coordinate transformation formula.

Step 2. Data selection. All the points on the lane marker are extracted at the first time of the vehicle motion. In order to extract the points within about 100m ahead, the distance from the vehicle rear axle to the farthest points should be a little more than 100m.

Step 3. Determination of the coefficients. All the selected data should be stored by cell function. With the help of Polyfit function in data fitting tool box in Matlab, the coefficients of function (1) can be fitted. In this way, the accurate real-time ground truth can be acquired based on every frame of the camera video images.

Taking one of the lane markers on the curve road as an instance, the fitting results of these 1021 points are in the following.

$$\begin{cases} y_0 = 5.6356 \\ \varepsilon = 0.0015 \\ C_0 = -0.0044 \\ C_1 = -2.128E-05 \end{cases}$$

The fitted curve whose standard deviation is 0.0117 is shown in Figure 4.

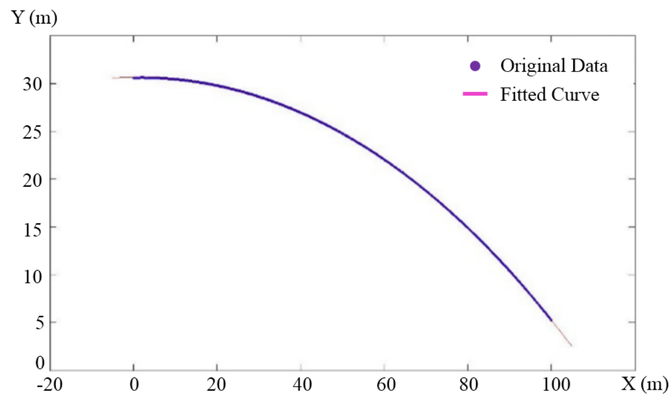

Figure4. Scatter and fitted curve of the curved lane (t=48.25s)

3.3 Video Images Output

Besides the data extracting and data processing, the video images from camera sensor should also be output and processed. In order to prepare for application of algorithm verification, the output images should be scale and processed to fitting size by batch processing in Matlab. The suitable image recognition algorithm, such as Hough Transform, is applied to extract the information of the lane markers on the image. By comparing the coefficients of function (1) determined by the image recognition algorithm with the above mentioned coefficients, the accuracy of the lane marker fitting algorithm in the virtual experimental environment can be identified.

CONCLUSIONS AND DISCUSSIONS

The design of virtual experiment for lane detection system can simulate the vehicle model, road environment and camera and lane marker sensors in PreScan. With the help of virtual experiment, vehicles, roads and sensors in different conditions can be designed and tested in short time. The cost can be much less than field experiment and the efficiency can be much higher. The accurate ground truth of the road and vehicle dynamic data can be acquired by running of the virtual experiment and the data processing.

In conclusion, the virtual experimental environment design and development can be used in camera-sensor-based lane detection system development and is a supplement to traditional system development.

However, this paper only introduces the design of basic road models of straight and curve road with a two-dimension combined lane marker model. More types of road models should be considered in further study, such as spiral road model and bumpy road model. Thus, a three-dimension lane marker model is required to acquire the accurate ground truth. In addition, complex traffic conditions, as well as different lighting conditions and weather conditions can also be added in the further study of virtual experiment design.

REFERENCES

[1] Javed, M.A., Spike, J., Waslander, S., Melek, W., Owen, W. 2001. "Argo Vehicle Simulation of Motion Driven 3D LIDAR Detection and Environment Awareness." Autonomous and Intelligent Systems, Volume 6752: 284-293

[2] Ruder, M., Enkelmann, W., Gamitz, R. 2002. "Highway Lane Change Assistant". In Proceedings of Intelligent Vehicle Symposium (Versaille, France, June 17-21). IEEE, 240-244

[3] Wang Rongben, Guo Lie, Jin Lisheng, et al. 2007. "Recent Research of Safety Driving Assistance Technology in Intelligent Car". Journal of Highway and Transportation Research and Development, 24(7): 107-111

[4] Qu Yang, Feng Huanqing, Ding Feng. 2013. "A Lane Detection Algorithm Based on Real-Time Video Process." Application Research of Computers, 30(3): 930-932

[5] Sun Yanbiao, Liu Wei, Wang Shaoping, et al. 2014. "Design and Implementation of Lane Detection System Based on DSP." Electronic Measurement Technology Press, April: 83-86

[6] Tideman, M., Versteegh, T., Bouts, R. 2012 "Developing Methodology for Design and Assessment of Active and Integrated Safety Systems for Automobiles." Journal of Automotive Safety and Energy, 3(2)

[7] Borkar A. 2011. "Multi-viewpoint lane detection with applications in driver safety systems." PhD thesis

[8] Preda, I., Covaciu, D., Ciolan, Gh., et al. 2008. "Vehicle Dynamic Behaviour Analysis Based on GPS Data." In Proceedings of "SMAT2008" International Conference (Craiova, Romania)

[9] Wang Liang. 2010. "Performance Test and Result Analysis of Abs Based On VBOX Equipment." Light Vehicles

[10] Tideman, M., Van Noort, M. 2013. "A Simulation Tool Suite for Developing Connected Vehicle Systems." In Proceedings of Intelligent Vehicles Symposium (IV), IEEE

[11] JTG D20—2006, "Standard of Chinese Highway Route Design."

[12] Southall, B., Taylor, C.J. 2001. "Stochastic road shape estimation." In Proceedings of Eighth International Conference on Computer Vision, IEEE