Development of an Interactive Lane Keeping Control System for Vehicle

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***Abstract*-The objective of this study is to develop a vision-based driver assistance system for lane detection and active keeping control based on the design of cooperative driving. This lane keeping system (LKS) can alert the driver beforehand to the danger of unintentional departure from the lane and then actively control the vehicle steering to help the driver keep the car within the lane more easily. A charge-coupled-device (CCD) camera is used as the front-end sensing for this system to detect the lane marks and instantaneously calculate the lateral deviation. In order to enhance the image recognition precision, an adaptive lane detection algorithm with dynamic calibration was developed. The lane keeping control strategy was designed in accordance with the vehicle dynamics to figure out the appropriate assisted steering torque and further control the column-type electric power steering (EPS) of vehicle. In this work, the electronic control unit (ECU) of LKS has been implemented with an embedded hardware for the consideration of access to flexible adjustment and volume production.**

I. INTRODUCTION

With the enhancement of people's living level and rapid development of auto-electronics technology, vehicle safety has attracted more and more attention in recent years. The automotive industry worldwide is enthusiastic about developing advanced driver assistance systems, such as lane departure warning (LDW), lane keeping (LK) and forward collision warning (FCW), etc., to make a substantial improvement in driving safety. Previous studies [1,2] indicated that over 90% of traffic accidents resulted from human errors and nearly 60% of road fatalities were in relation to unintended lane departures. These accidents represent a considerable amount of social costs, over billions Euros, for a country. Hence, over the years, many investigations have been done on the lane departure warning system with the common goal of reducing a number of traffic accidents. However, only little work [3,4] on the lane keeping assistance has been reported so far, and the control method in those studies mainly used the steering wheel angle as the control input that was difficult to permit driver intervention in the steering control loop .

Therefore, the aim of this work is to develop an interactive lane keeping assistance system based on the steering torque control. This LK system can issue an audio warning when the driver drifts out of his lane unintentionally and further control the electric power steering motor to apply assist torque to the steering column according to the extent of departure. Moreover, the steering torque control method proposed in this study can make the flat road like a cambered surface to keep the host vehicle around the center of the lane readily, and always give highest priority to the driver's conscious operations.

II. SYSTEM OVERVIEW

Figure 1 shows the overall configuration of the LK system. This LK system mainly comprises two parts, i.e., lane departure detection and lane keeping control. The module for lane departure detection can extract the lane information, including lane position and road curvature, by image recognition technology and then send these data to the LK ECU to calculate the EPS assist torque that is needed to help the driver keep the vehicle in the current lane.

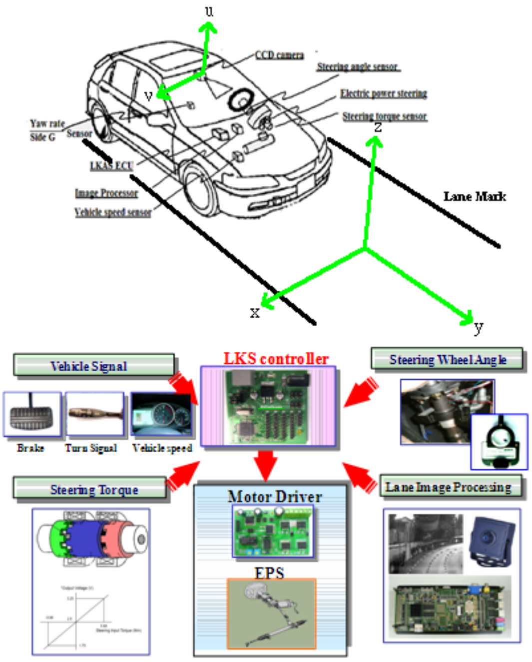

Fig. 1 Configuration of the lane keeping system.

Lane Departure Detection

The lane detection module of the LK system uses a CCD camera mounted on the windscreen behind the rearview mirror to take images of the road surface ahead of the car. And then these images are processed by the pattern recognition hardware to extract the road information such as lateral displacement, road slope and curvature. The whole process for lane departure detection basically consists of four steps, namely, lane recognition, coordinates conversion, road parameter estimation and viewpoint calibration, and its flowchart is shown in Fig. 2.

Since the lane recognition is performed on the image plane, the relationship between the world and image coordinates is built for calculating the road parameters and given by the following equation.

$$u = \frac{ke_u e_v H}{e_v m_\theta - v} + me_u + \frac{be_u}{He_v}(e_v m_\theta - v) \tag{1}$$

Where (u, v) is the point in the image coordinates, e_u is the ratio of focus length to horizontal sensor pixel size, e_v is the ratio of focus length to vertical sensor pixel size, H is the installation height of the camera, m_θ is the slop of the road, and k, m and b are the parameters of the road model. Please note that the road model used in this work is a quadratic equation: $y = k \cdot x^2 + m \cdot x + b$. Therefore, this module can be operated not only on straight but also on highly curved road sections. The lateral displacement (y_d), road slope (ε_d) and curvature (ρ_d) can be calculated with the following expressions, respectively.

$$y_d = k \cdot x^2 + m \cdot x + b \tag{2}$$

$$\varepsilon_d = 2 \cdot k \cdot x + m \tag{3}$$

$$\rho_d = \frac{2 \cdot k}{\left(1 + (2 \cdot k \cdot x + m)^2\right)^{3/2}} \tag{4}$$

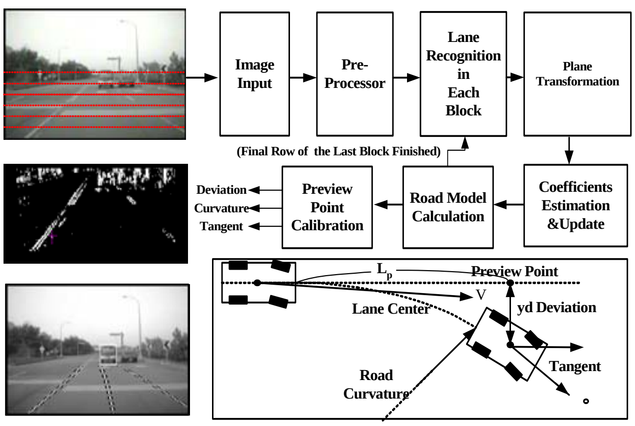

Fig. 2 The flowchart of the lane recognition process.

Lane Keeping Control

Based on the recognition results, the LK control method proposed in this study uses three parameters, i.e., deviation, road curvature and vehicle speed, as major control inputs to figure out the assist torque. In contrast to the lane keeping system proposed by a previous study [5] where an extra actuator is used to produce the assist torque, here an electric power steering system is directly integrated to output an addition torque for staying in the lane by its motor. Moreover, the proposed control method can make the drive feel like driving on a cambered road surface and keep the host vehicle within the lane more easily. The block diagram of lane keeping control is shown in Fig. 3. Note that this LK system is just to assist the driver to keep the vehicle staying in the lane easily, not to auto-pilot. In order to prevent the driver from being dependent on the system excessively and misusing as an auto-pilot as mentioned in the Ref. [6], in the region around the lane center, the LK system designed by this work would not take action to intervene in the steering control. Only if the explicit departure approaching to the lane border is observed, the LK ECU will immediately send a torque command of T_a to the EPS motor to assist the driver in returning the vehicle to the approximate center of the lane. Furthermore, the steering torque assisted by the LK system will be adjusted depending on the applied torque and direction of the driver. However, in order to keep the driver in the control loop, the maximum assist torque is set at about 90% of the total torque needed for steering the vehicle back to the approximate lane center. Additionally, as the road curvature is smaller than 1/250 or the vehicle lateral acceleration is greater than 0.2 G, the LK system will not be activated to avoid causing the violent sway of the vehicle.

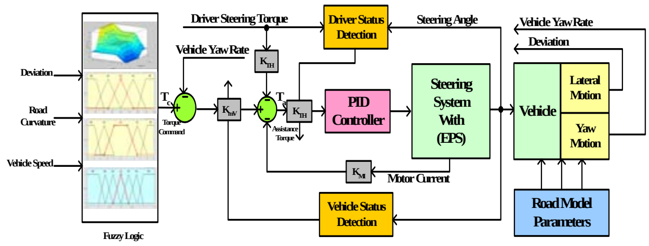

Fig. 3 The block diagram of lane keeping control.

The vehicle model used in this work is a simplified two-wheel bicycle model as shown in Fig. 4. Figure 4 shows the schematic relationship between the steering angle of the front wheel and the corresponding vehicle lateral acceleration as well as the yaw moment. The vehicle motion equations for designing the keeping control algorithm are expressed as the following Eq. (5) and Eq. (6). In addition, the vehicle steering model is shown in Fig. 5. This steering model is used to work out the assist torque (current) supplied by the EPS motor according to the inputs of vehicle lateral deviation, speed, road curvature and driver's torque. The block diagram for computing the assist torque command is shown in Fig. 6.

$$M\ddot{y} = C_f(\delta - \beta - \frac{l_f \gamma}{V}) - C_r(\beta - \frac{l_f \gamma}{V}) \tag{5}$$

$$I\dot{\gamma} = l_f C_f(\delta - \beta - \frac{l_f \gamma}{V}) + l_r C_r(\beta - \frac{l_f \gamma}{V}) \tag{6}$$

Where M is the vehicle mass, $\ddot{y}$ is the lateral acceleration, C_f and C_r are respectively the cornering stiffness of the front and rear wheels, δ is the steering angle of the front wheel, β is the slip angle of the vehicle center of gravity, V is the vehicle speed, γ is the yaw rate, and l_f and l_r are the distances from the vehicle center of gravity to the front and rear wheels, respectively.

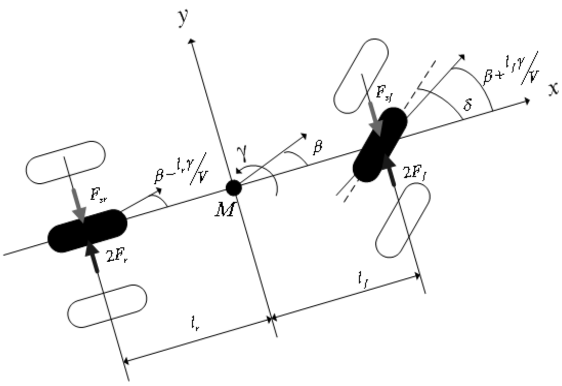

Fig. 4 The simplified vehicle motion model (bicycle model).

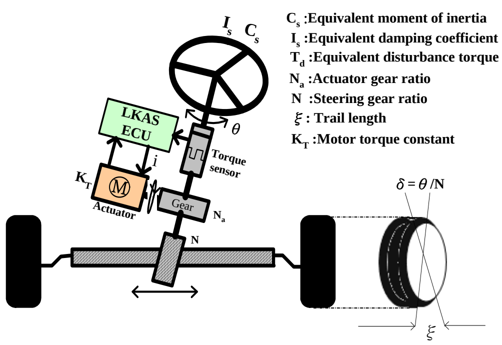

Fig. 5 The configuration of the vehicle steering model.

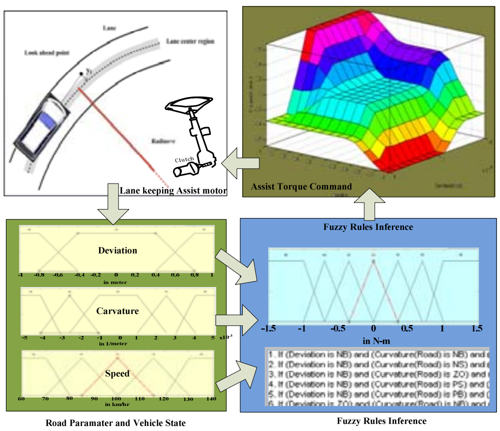

Fig. 6 The block diagram for computing the assist torque command.

In order to avoid the conflict between the driver and system, the LK system can detect the driver's operations, such as braking and lane changing, to determine whether the system shall be deactivated or not. Moreover, the assist torque generated by the LK system is set at a threshold that can be overridden by the driver readily. In other words, the driver's operation is the top priority for controlling the vehicle. In this study, the signals of the blinker (turning switch), brake pedal steering angle, torque and G (lateral acceleration) sensors are used to judge the timing for LK system deactivation, as listed in Table 1.

Table 1 LK system deactivated conditions

Condition	Detection
Emergency Braking	Brake signal
Lane Change	L/R Turning signal
Forced Steering	Steering torque
Hands On	Steering torque/angle frequency distribution
Over Turning	Lateral G

Simulation Results

In this work, the Matlab/Simulink software was used to build the LK control model and carry out the preliminary function simulation. The simulation results for hand-free driving with and without LKS activation are shown in Fig. 7 and Fig. 8, respectively. Apparently, it can be seen in Figs. 7 and 8 that, under the hand-free driving with the LKS activation the vehicle can be effectively kept within the lane. On the contrary, the vehicle without the LKS activation gradually drifted out of the lane until the driver took over the control. Figure 9 shows the vehicle responses of wheel steering angle, yaw rate and lateral acceleration during the LKS operation. It can be observed from Fig. 9 that the reaction frequency of the steering wheel is quite low, about 0.05 Hz, meaning the vehicle is not frequently steered by the LK system, and thus the vehicle motion would be more stable.

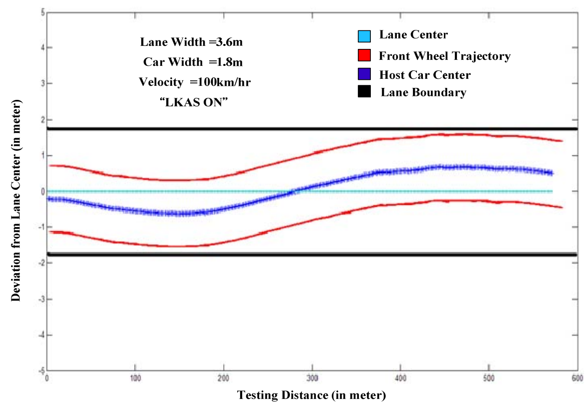

Fig. 7 Hands free driving with LKS

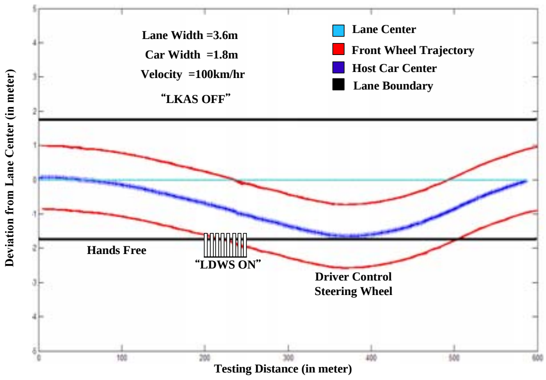

Fig. 8 Hands free driving without LKS

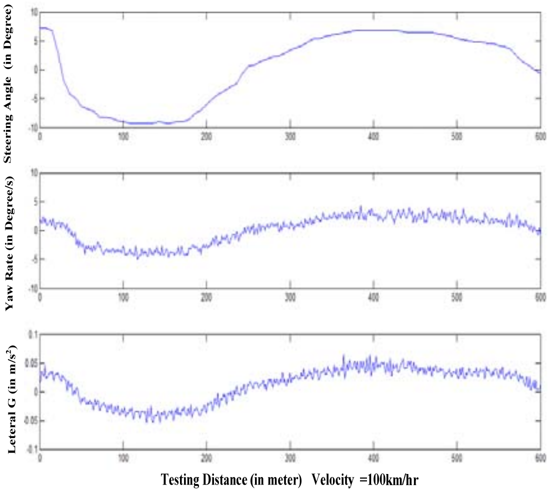

Fig. 9 Vehicle response simulation results as LKS is acting

Proving ground testing results

The LK system incorporating with the function of lane departure warning established in this study is shown in Fig. 10. The LK system was tested on the test tracks of the ARTC proving ground to validate its performance. Figure 11 shows the testing results of the LK system performed on the straight test track for 3.5 km with a vehicle speed of 100 km/h. It can be seen in Fig. 11 that the vehicle can be kept within the lane by the LK system similar to that of the aforementioned simulation result, and the frequency of the pendulum motion and the lateral acceleration are, respectively, below 0.02 Hz and 0.05 G indicating stable keeping control.

Fig. 10 The developed lane keeping system with lane departure warning function.

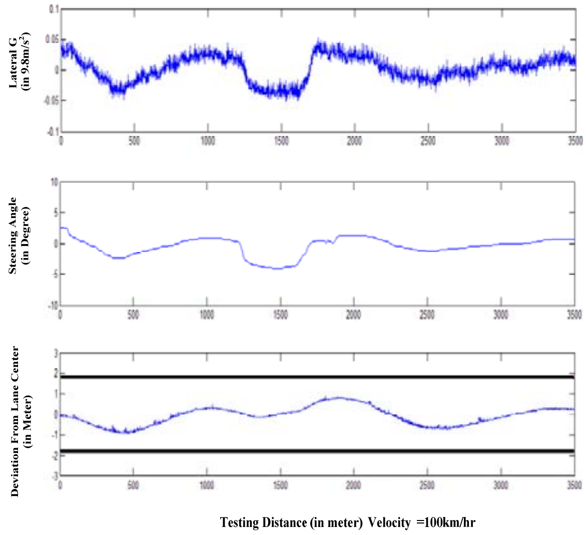

Fig. 11 LKS performance testing on a straight track.

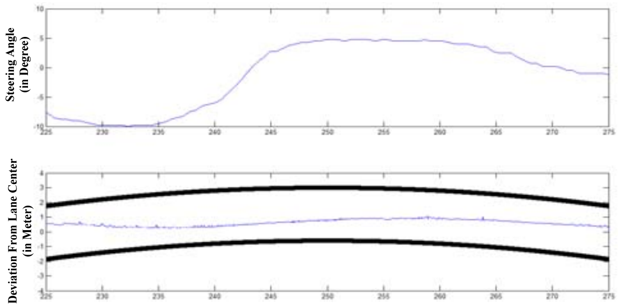

Fig. 12 LKS performance testing on a curve track (road curvature=1/250)

Figure 12 shows the testing results of the LK system performed on the curved track of a curvature of 1/250 m^{-1} with a vehicle speed of 100 km/h. From Fig. 12, it can be seen that the vehicle can still be controlled to stay within the lane. However the frequency of the pendulum motion and the lateral acceleration are obviously increased. In order to avoid the instability of vehicle motion, the lateral acceleration is limited to a maximum of 0.2 G for deactivating the LKS operation as shown in Fig. 13.

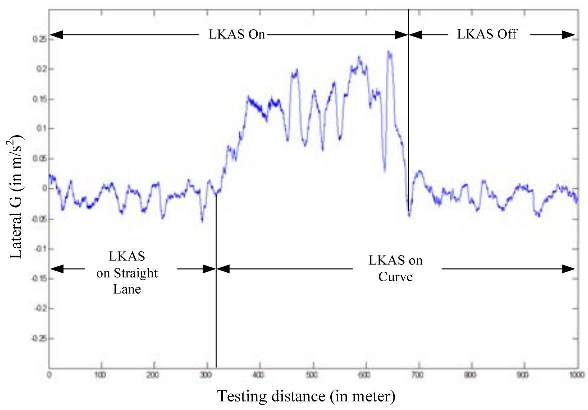

Fig. 13 Threshold of lateral acceleration for activating LKS.

IV. SUMMARY

In this paper, an interactive lane keeping system incorporating with the function of lane departure warning has been developed. This LK system can issue an audio warning while the driver departs from the lane unintentionally based on the use of a CCD camera and then calculate the EPS torque to assist the driver in keeping the vehicle within lane boundary. Here a CCD camera mounted on the windscreen behind the rearview mirror was used to recognize the lane marks and compute the lateral deviation.

In order to avoid the conflict between the driver and system, the signals of the turning switch, brake pedal steering angle, torque and G (lateral acceleration) sensors are used to determine whether the system shall be deactivated or not. Moreover, the assist torque generated by the LK system is set at a threshold that can be overridden by the driver readily, i.e., the driver's operation is the top priority for controlling the vehicle.

The performance results conducted on the test tracks of the ARTC proving ground with an actual vehicle indicated that this LKS system developed in this work can effectively assist the driver to keep the vehicle within the lane with a road curvature below 1/250 m^{-1}.

ACKNOWLEDGMENT

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REFERENCES

[1] Consumer Products, Mobileye's Advance Warning System (AWS), http://mobileye-vision.com/default.asp?PageID=6.

[2] J. pohl and J. Ekmark, "Development of a Haptic Intervention System for Unintended Lane Departure," SAE Technical Paper, 2003-01-0282, Society of Automotive Engineers.

[3] H. Mouri and H. Furusho, "Automatic Path Tracking Control Using Quadratic Control Theroy," IEE Conference on Intelligent Transportation Systems, 1997.

[4] H. Furusho and H. Mouri, "Research on Automated Lane Tracking Using Linear Quadratic Control: Control Procedure for a Curved Path," JSAE Review, Vol. 20, pp. 325-329, 1999.

[5] K. Naab and G. Reichart, "Driver Assistance Systems for Lateral and Longitudinal Vehicle Guidance - Heading Control and Active Cruise Support", Paper No 78, AVEC 94, 1994.

[6] D. Balzer, "Safety Enhancement by Lane Observation of Advanced Driver Assistance Systems (ADAS), VDA, Technical Congress 2002, Germany, 2002.