Development of A Lane Departure Monitoring and Control System

Kunsoo Huh*
School of Mechanical Engineering, Hanyang University,
17 Haengdang-Dong, Sungdong-Ku, Seoul 133-791, Korea

Daegun Hong
Department of Precision Mechanical Engineering, Hanyang University,
17 Haengdang-Dong, Sungdong-Ku, Seoul 133-791, Korea

Jeffrey L. Stein
Department of Mechanical Engineering, University of Michigan,
Ann Arbor, Michigan

The lane departure avoidance systems have been considered promising to assist human drivers in AVCS (Advanced Vehicle Control System). In this paper, a lane departure monitoring and control system is developed and evaluated in the hardware-in-the-loop simulations. This system consists of lane sensing, lane departure monitoring and active steering control subsystems. The road image is obtained based on a vision sensor and the lane parameters are estimated using image processing and Kalman Filter technique. The active steering controller for avoiding the lane departure is designed based on the lane departure metric. The proposed lane departure avoidance system is realized in a steering HILS (hardware-in-the-loop simulation) tool and its performance is evaluated with a driver in the loop.

Key Words: Lane Departure Monitoring, Lane Departure Avoidance, Lane Sensing, Active Steering Control

Nomenclature

\( a \) : Distance to the front axle from CG
\( b \) : Distance to the rear axle from CG
\( C_{af} \) and \( C_{ar} \) : Cornering stiffness of the front and rear tires
\( F_{ff} \) and \( F_{fr} \) : Lateral tire force of the front and rear tires
\( h_{cg} \) : Height of center of gravity
\( I_z \) : Moment of inertia about the \( z \) axis
\( K \) : LQR control gain
\( (l, w, h) \) : Camera origin in vehicle coordinate
\( m \) : Vehicle mass

\( T \) : Lookahead time
\( q_y, q_r, q_i, \text{ and } q_p \) : Weighting factors
\( R_c \) : Camera rotation matrix considering the camera tile angle
\( R_v \) : Camera rotation matrix considering roll and pitch angle
\( \gamma \) : Yaw rate
\( (X_c, Y_c, Z_c) \) : Camera coordinate
\( (X_l, Y_l, Z_l) \) : Global coordinate
\( (X_v, Y_v, Z_v) \) : Vehicle coordinate
\( (y, z) \) : Image coordinate
\( u \) : Longitudinal vehicle velocity
\( v \) : Lateral vehicle speed
\( \alpha_f \) and \( \alpha_r \) : Tire slip angle of the front and rear tires
\( \delta_c \) : Steering control input
\( \delta_{c,fb} \) : Feedback steering control input
\( \delta_{c,ff} \) : Feedforward steering control input

* Corresponding Author,
E-mail: khu2@hanyang.ac.kr
TEL: +82-2-2220-0437; FAX: +82-2-2295-4584
School of Mechanical Engineering, Hanyang University, 17 Haengdang-Dong, Sungdong-Ku, Seoul 133-791, Korea. (Manuscript Received March 18, 2005; Revised September 18, 2005)
\( \delta_d \) : Driver’s steer angle \\
\( \delta_{kin} \) : Kinematically required steer angle to follow the lane curvature \\
\( \lambda \) : Focal length of camera

1. Introduction

Lane departure warning/avoidance system is one of the key technologies for the future active-safety passenger cars. It warns the driver of drifting off the lane due to sleeping or being inattentive in a monotone environment such as straight expressways. Besides, if necessary, this system with an active steering controller can be used to control the lateral position in an unintended road departure. The lane departure warning/avoidance systems require lane sensing, lane departure monitoring and active–steering control technologies.

Lane sensing technology based on vision sensors requires little infrastructure on the highway except clear lane markers. However, they require intelligent processing algorithms in vehicles to generate reliable previewed roadway from the vision images. In order to implement the lane-sensing techniques in passenger cars, the sensing reliability and robustness should be guaranteed for the harsh environment. Various lane sensing techniques using vision sensors have been developed and reported (Takahashi and Ninomiya, 1996; Goldbeck and Huertgen, 1999; Dickmanns and Mysliwetz, 1992; Lin and Ulsoy, 1995; Huh and Park, 2002).

The lane departure monitoring of a vehicle should be judged in real-time and on-line utilizing the lane sensing results and the motion status. The typical approach for monitoring the road departure is to build rumble strips into the road edge. The rumble strips can cause the vehicle tire to vibrate as a distinctive warning, but cannot monitor in advance before the road departure actually occurs. A predictive measure of monitoring the road departure is the TLC (Time-to-Lane-Crossing) (LeBlance et al., 1996) which is defined as the time until the vehicle center crosses either edge of the roadway. The TLC is usually calculated assuming constant vehicle speed and front wheel steering angle.

Regarding the active steering control system for the lane departure avoidance, the brake–steer method with braking only had been reported (Pilutti et al., 1995), but its responses are slow and cause the unnecessary deceleration. Recently, several active steering actuators are developed such as additional electric motor and planetary gear set to the conventional steering systems (Klier and Reinelt, 2004; Reinelt et al., 2004; Asai and Kuroyanagi, 2004). These actuators allow electronically controlled superposition to the driver’s steering angle and enable the advanced functions such as variable steering ratio and steering lead. In addition, they can provide interface for the vehicle dynamics and stability control systems. Moreover, the unmanned autonomous guided vehicle based on the steering controller and vision sensor is introduced (Lee et al., 2005).

In this paper, a lane departure avoidance system is developed and its performance is evaluated on a steering HILS (Hardware-in-the-loop simulations) tool. A lane sensing algorithm using vision sensors is constructed based on a lane geometry model. Its parameters such as road curvature are estimated by a Kalman filter technique and utilized to reconstruct the road geometry in the global coordinate. The FLOD (future lateral offset distance) index is proposed for the lane departure monitoring. The FLOD index is defined as the future lateral distance between the vehicle CG and the either lane of roadway after a certain look-ahead time. The well-known TLC index (LeBlance et al., 1996) and the proposed FLOD index are utilized for constructing the lane departure monitoring systems and for comparing the lane departure warning performances. The active steering control system is developed based on the LQR (Linear Quadratic Regulator) approach such that an optimal controller is designed by including lateral deviation, heading angle error, yaw rate and steering angle in the cost function. The key idea of the active–steering controller is that the driver remains in the loop and the control efforts only adjust the steering angle in addition to that given by the driver. The driver provides the primary steering commands, but only in the case of imminent lane departure, the active–steer-