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A study on Lane Keeping Assistance System based on steering torque control

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Abstract: In this paper, the design of steering torque controller for lane keeping assistance system and the experimental results of test driving are presented. The control system dynamics including vehicle-road relationship and steering system is modeled by system identification procedure based on experimental data. This paper is mainly focused on optimal control law for the desired lane keeping by using linear quadratic control theory. Moreover, nonlinear characteristic of vehicle lateral motion by variant vehicle speed has been compromised control gain scheduling methodology.

1. INTRODUCTION

There have been a lot of works dealing with vehicle automation or driving assistance systems such like Inter-vehicle spacing including cruise control function, lane keeping assistance system or so, and implemented successfully in practice. In these decades, vehicle lane-keeping control system is, especially, becoming a new research focus of drive assistant system following the adaptive cruise control system. In this paper we will briefly outline the overview of the lane keeping assistance system which is now developing especially with focusing on an adopted control design and then present the experimental results.

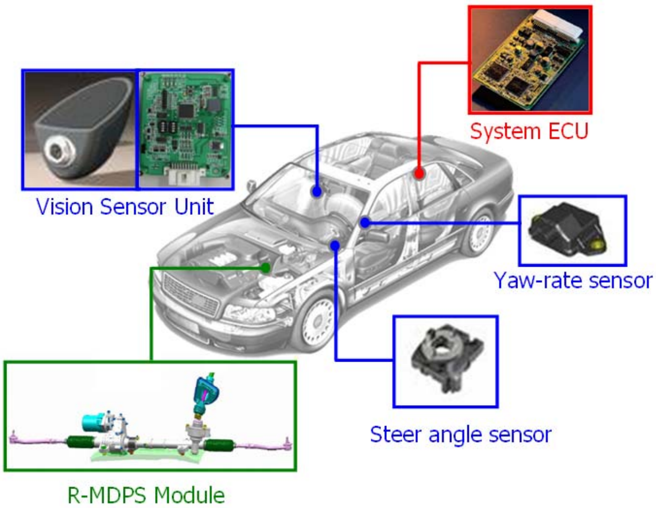

Fig. 1. System Configuration

2. SYSTEM CONFIGURATION

Lane keeping assistance system is composed of mainly vision sensor unit, system ECU and steering actuator as well as steer angle sensor and yaw-rate sensor to measure vehicle lateral motion. Vision sensor unit plays a role of extracting the departure distance, departure angle and road curvature. System ECU determines the desired steering torque which gets the vehicle to keep near the centre line of lane. Rack-type motor driven power steering system is considered as the steering actuator for this study. The system configuration is illustrated in Fig. 1.

3. CONTROLLER DEVELOPMENT

3.1 System Dynamics

System model for designing a controller consists of vehicle lateral dynamics including vehicle-road relationship and steering dynamics as shown in Fig. 2.

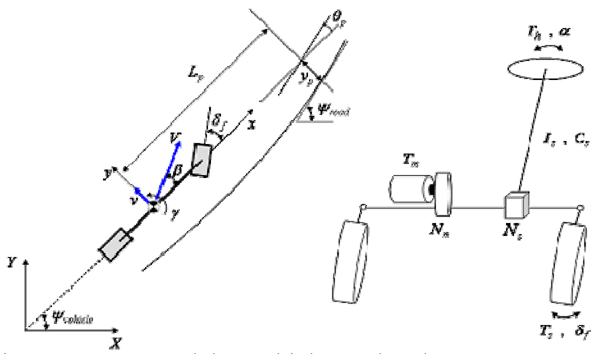

Fig. 2. System Model – Vehicle-road and Steer system

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3.2 Controller Design

Equation (1) describes the augmented state equation where the desired motor toque is considered as the control input.

$$\frac{d}{dt}\begin{bmatrix}\dot{\delta}_f\\ \delta_f\\ \gamma\\ v\\ \theta_p\\ y_p\end{bmatrix}=\begin{bmatrix}a_{11} & a_{12} & a_{13} & a_{14} & 0 & 0\\ 1 & 0 & 0 & 0 & 0 & 0\\ 0 & a_{32} & a_{33} & a_{34} & 0 & 0\\ 0 & a_{42} & a_{43} & a_{44} & 0 & 0\\ 0 & 0 & 1 & 0 & 0 & 0\\ 0 & 0 & L_p & 1 & V & 0\end{bmatrix}\begin{bmatrix}\dot{\delta}_f\\ \delta_f\\ \gamma\\ v\\ \theta_p\\ y_p\end{bmatrix}+\begin{bmatrix}\frac{N_m}{I_s}\\ 0\\ 0\\ 0\\ 0\\ 0\end{bmatrix}T_m+\begin{bmatrix}\frac{N_s}{I_s} & 0\\ 0 & 0\\ 0 & 0\\ 0 & 0\\ 0 & -V\\ 0 & 0\end{bmatrix}\begin{bmatrix}T_h\\ \rho_p\end{bmatrix} \quad (1)$$

where

$$a_{11}=-\frac{C_s}{I_s}, a_{12}=-\frac{\xi C_f}{I_s}, a_{13}=\frac{\xi C_f l_f}{I_s V}, a_{14}=\frac{\xi C_f}{I_s V}$$

$$a_{32}=\frac{C_f l_f}{I}, a_{33}=-\frac{C_f l_f^2+C_r l_r^2}{I\cdot V}, a_{34}=-\frac{C_f l_f-C_r l_r}{I\cdot V}$$

$$a_{42}=\frac{C_f}{m}, a_{43}=-V-\frac{C_f l_f-C_r l_r}{mV}, a_{44}=-\frac{C_f+C_r}{mV}$$

The state variables are front wheel angular velocity $\dot{\delta}_f$, front wheel angle δ_f, yaw-rate γ, lateral velocity v, departure angle at preview point θ_p, and departure distance at preview point y_p. Other parameters are vehicle mass m, vehicle speed V, vehicle yaw inertia I, gear ratios of motor and steer system N_m, N_s, inertia of steer system I_s, motor torque and driver torque T_m, T_h, road curvature at preview point ρ_p, cornering power of front and rear wheel C_f, C_r, distance from vehicle centre of gravity to front and rear wheel l_f, l_r, trail length of tire ξ.

In this study, an optimal controller is adopted as a feedback controller to minimize the errors of departure distance and angle with satisfying the lane keeping accuracy and ride smoothness. Moreover, feed-forward controller for compensating the effects of disturbances induced by the self alignment torque, road reaction torque and driver steering torque of which the level is assumed to be under the torque level for system override is also included in the controller. Fig. 3 is shown the block diagram of steering torque controller. Gain scheduling methodology is applied to compensate the non-linear characteristics of vehicle lateral motion by variant vehicle speed.

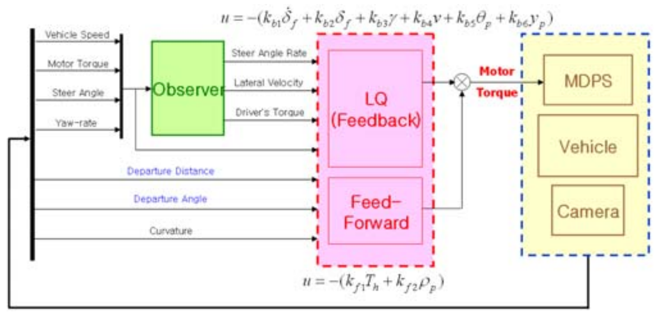

Fig. 3. Block Diagram of Controller

4. EXPERIMENT

Field test is conducted at proving ground which consists of the straight section with the length of about 1.2km. Fig. 4 demonstrates the departure distance, departure angle and the frequency analysis of departure distance. The experiments shows that the departure distance remains within the range of ±30cm around 80km/h of vehicle speed without driver's steer operation. According to frequency analysis of the driving pattern of experienced drivers with attention, the oscillation frequency of departure distance is near 0.1 Hz. The result of the proposed lane keeping assistance control system shows the performance similar to normal driver's driving result. It is considered that if the gains would be tuned with deliberation, the riding comfort could be improved to be compatible with human driver or more.

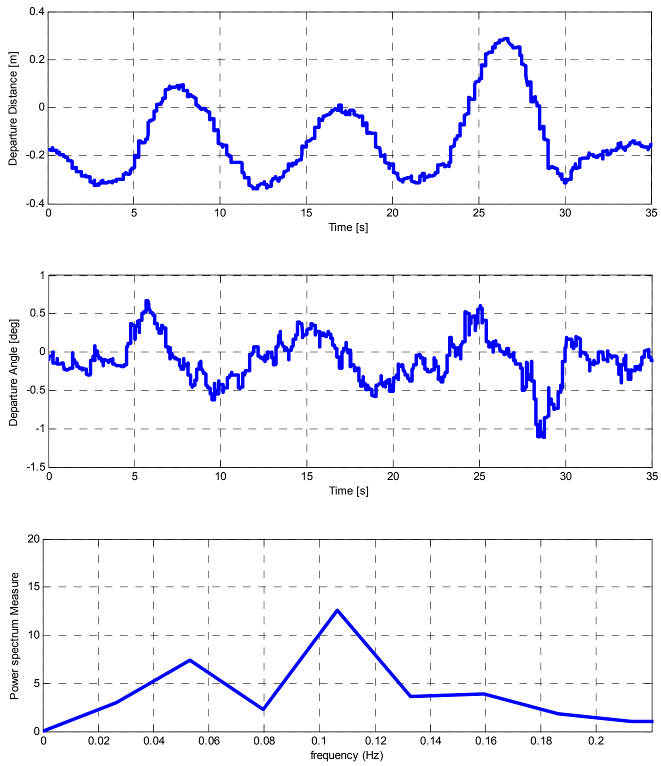

Fig. 4. Experimental Results of controlled vehicle

5. CONCLUSIONS

A steering torque controller has been designed by optimal control theory to support driver's steering effort in case of lane keeping. Controller gains have been scheduled for maintaining consistence performance with variant vehicle speed. As a result of frequency analysis, proposed controller was validated that performed similar tendency compared to normal driver's driving result.

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