A Brake Strategy for an Automatic Parking System of Vehicle

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Abstract—The purpose of this research is to develop a braking strategy for an automatic parking system, including the brake controller design, simulation results and system validation. The development of brake control strategy is divided into two parts: PI and Fuzzy-PI control schemes. In addition to the design of controllers, a speed trajectory consisting of acceleration, constant speed, and deceleration is planned in order to provide the driver more comfortable feeling. The simulation is performed in a developed vehicle longitudinal Matlab/Simulink model to observe the response of the overall system. In the system validation, a brake actuator with a microprocessor is equipped and implemented in our experimental platform. The simulated and experimental results indicate that the proposed brake controller can work properly with this automatic parking system and make the process of parking smooth and stable.

Keywords—brake control; automatic parking system; fuzzy control;

I. INTRODUCTION

Automatic parking system for vehicle is developing to provide drivers convenience and safety, and it helps drivers to park their cars automatically in a suitable parking space. Many research institutes and companies are developing the automatic parking system such as XPARK of Intellitech Technology, AISIN World Corp.’s Advanced Parking Guidance System (APGS), etc. In our experimental platform vehicle, an automatic parking system pattern has been equipped and developed. The main feature of this system consists of the measurement of parking space and the auto-steering control via electric power steering, which comprises a motor, steering angle sensor and a power module, to make the vehicle to be parked effectively and safely in the target space. Fig.1 shows the overall configuration of the whole system.

Figure 1. The overview of the automatic parking system

Figure 2. Block diagram of longitudinal model

Firstly, the microprocessor determines the traveled distance by wheel speed sensors. And then, the distance will be matched with the lateral space detected by ultrasonic sensors to establish a full environmental map. Finally, the driver selects a parking space to park and the ECU will control the steering wheel automatically to let the host vehicle to follow the path planned from the starting point to the destination.

It is important to note that in the process of path tracking, the speed control has the influence on the tracking stability and precision. And the vehicle speed is relative directly to brake control during parking. Therefore, this paper will focus on developing a brake control strategy of the automatic parking system and planning a proper speed trajectory to make the parking process smooth and stable. In the following sections, there will be a description about the design of brake controller, simulated results in Matlab/Simulink, and system validation in our experimental platform.

II. VEHICLE LONGITUDINAL SIMULATION MODEL

A vehicle longitudinal model is necessary to build up before starting to design a brake controller. In this paper, the vehicle longitudinal Matlab/Simulink model developed by You-Hua Shiu in 2006[1] will be applied in our simulation. This model links the engine, torque converter, automatic transmission, tire, brake, and vehicle dynamic model. Fig. 2 shows the overall block diagram of this vehicle model. Compared the simulated result in this model with CarSim program, this Simulink model also has a quite similar performance. In overall, it is clear to see that the system depends on the acceleration and deceleration command decided by throttle and brake control to determine the vehicle
speed. When the engine receives these input parameters, the engine will deliver the engine speed to the torque converter, which converts it into the turbine torque. And then the torque will be passed to automatic transmission part. As a result, the automatic transmission block will determine the driving torque to the tire model that outputs the longitudinal driving force of tire. Finally, the force combines the vehicle dynamic model to obtain the final vehicle speed.

In this model, the brake part applies a simplified method to find the braking torque. The brake pedal pressure and wheel pressure with a proportional valve, which arranges the braking force in front and rear wheels, are used in this part. Besides, in order to match the actual condition more exactly, a dynamic time equation is designed in the part. The equation is shown below:

\[ Tb = \frac{1}{\tau_H + 1} H\left(P_s(P_l(P_f), F_z), u\right) \] (1)

Where \( Tb \) is dynamic braking torque, \( H \) is static braking torque, \( P_s \) is the pressure provided by the proportional valve, \( P_l \) is the pressure provided by braking pedal, \( F_z \) is the wheel vertical load, \( \tau_H \) is the hydraulic dynamic time constant, and \( u \) is the vehicle speed.

III. VEHICLE SPEED TRAJECTORY PLANNING

There have been many methods to plan a suitable speed trajectory during the process of braking. The goal of the automatic parking system is to provide the driver a comfortable feeling, and the process of automatic parking should be smooth and stable. According P. Seiler’s research [2], human passengers feel comfortable as the automotive acceleration or deceleration is under 2.5 m/s². Therefore, the parking speed trajectory will be planned as three states, consisting of proper acceleration, constant speed, and deceleration. Due to the reason that the brake pedal control is limited from 0% to 100%, it could cause the control action stays saturated for a while in the initial period of acceleration. In order to avoid this condition, Peng-Syu Liang [3] presents that a smooth trajectory can be designed as:

\[ x(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5 \] (2)

Where \( a_0 = x_0 \), \( a_1 = \dot{x}_0 \), \( a_2 = \frac{1}{2} \ddot{x}_0 \), \( a_3 = \frac{1}{2 \tau_f^2} \left[ 30 \dot{x}_f - 20 x_0 - (8 \ddot{x}_f + 12 \dot{x}_0) \ddot{t}_f - 3(\dddot{x}_0 - \dddot{x}_f) \dddot{t}_f^2 \right] \), \( a_4 = \frac{1}{2 \tau_f^4} \left[ 30 \ddot{x}_f - 30 x_0 + (14 \dddot{x}_f + 16 \dot{x}_0) \dddot{t}_f + 3(\ddddot{x}_0 - 2 \dddot{x}_f) \ddddot{t}_f^2 \right] \), \( a_5 = \frac{1}{2 \tau_f^5} \left[ 12 \dddot{x}_f - 12 x_0 - (6 \ddddot{x}_f + 6 \dddot{x}_0) \dddddot{t}_f - (\dddeeees) \dddeeeed \right] \)

\( x_0 \), \( \dot{x}_0 \), \( \dddot{x}_0 \) present the initial speed, acceleration, and jerk respectively at \( t = 0 \). \( x_f \), \( \dot{x}_f \), \( \dddot{x}_f \) present the final speed, acceleration and jerk respectively at \( t = \tau_f \).

IV. CONTROLLER DEVELOPMENT

In order to approach a good performance of brake control, the section will describe how to design the brake controller in detail. PI and PI-Fuzzy controller will be designed and compared. In this simulation, the speed feedback will be the important parameter. Fig.4 is the basic structure of brake control. Due to the object of this controller, which is to let the vehicle speed to follow a desired trajectory to determine a proper distance, the response of tracking trajectory will be observed. In the next content, the controller will be explained and simulated.

A. PI Control

PI controller is always applied widely in industry because of its simplicity and convenience. Therefore, in the initial phase of our design, PI controller is used as a reference of the performance. In our design, the feedback signal is the vehicle speed (m/s) and the output of the controller is the brake control signal. The range of brake block is limited from 0% to 100% depicting the brake level in actual. These parameters of PI controller are determined by trial and error in order to obtain the best response.

Figure 3. The desired speed trajectory

From the equation above, the desired vehicle speed trajectory is shown in Fig. 3. It is worth to notice that the distance in the period of constant speed is not fixed. This is because in the actual application the parking distance is variable.

Figure 4. The basic structure of brake control
B. PI-Fuzzy Control

This section describes the way of achieving the brake control by fuzzy controller and explains the desired control logic in the application. In contrast of conventional control theory, the main advantage of fuzzy control is that control strategy can be achieved and understood by human behavior without a mathematical model. Fig. 5 shows the architecture of brake fuzzy control. From the structure above, the fuzzy logic decision block outputs a set of suitable Kp and Ki value by the speed error and the error sum, and then the controller produces a brake force passing to this vehicle model. In the process of fuzzification, these two input variables are arranged into five levels consisting of PB (Positive Big), PM (Positive Medium), ZR (Zero), NM (Negative Medium), and NB(Negative Big). According test and experience rules, the fuzzy membership function of the error is defined in Fig.6. The interval of the speed error is limited from -1.6 to 1.6 m/s. The reason is that the vehicle speed will not exceed the value in the speed trajectory planning, and in the period of parking the vehicle stays in the condition of low speed. Another important variable of fuzzy control is the speed error sum. Fig. 7 shows the membership of speed error sum, and the range is from 12 to -6. The other settings of fuzzy control are as follows: (Fig 8 ~ Fig. 9 and Table I)

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After setting these control rules above, the compared results of simulation are shown in Fig.10 and Fig.11. Compared with the result of PI Controller, the designed fuzzy controller provides a faster response and smaller overshoot. Regarding to the tracking of speed trajectory, the figure in the fuzzy control also shows better performance than PI control.
V. SYSTEM VALIDATION

Due to the objective of the brake control that provides an accurate and proper brake force to this process of automatic parking, a vacuum booster with a microprocessor is chosen as the brake actuator. As shown in Fig. 12, the actuator is linked to the braking pedal via a steel rope to achieve the function. While the actuator doesn’t pull the pedal, the braking pedal will be back to the original position. Therefore, the ECU can obtain the braking level by the present position. In the choice of vehicle speed sensor, there are two solutions. One is that the speed information can be obtained via CAN BUS on vehicle, and another is calculated by a high accurate and real-time RTK-GPS. In the controller implementation, the fuzzy control design is selected because of its better simulated results and strength. It means that the controller can be applicable to other vehicle with different operating environments. Generally, the validation of whole system has been tested, and the initial experimental results are acceptable and able to reach our target.

A. Braking Actuator

This section describes the driving method and internal architecture of brake actuator for this paper. The vacuum booster contains three electromagnetic valves, which represent the switch of atmosphere and engine vacuum respectively. The cross-sectional diagram is shown in Fig. 13. The electromagnetic valve A and C controls the flow of atmosphere, and the valve B controls the flow of air from the engine. For the reason of simplifying the control, the valve C remains closed. The system ECU will send a set of electronic signals to the other two valves to produce the different pressure inside the vacuum booster. Furthermore, the variation of pressure makes the movement of braking pedal to control the braking level.

B. Experimental Results

The experimental results include the constant low speed and the desired trajectory tracking tests in our experimental platform. The result of constant speed test and the error situation are shown in Fig. 14(a) and 14(b). The result shows that there is still small oscillation in the figure and the error is about between +0.2 km/h and -0.2 km/h. The reason could be from the difference between the real car and the simulation model in Simulink, and in the real environment the complexity will increases because of other factors. The following test is to make the vehicle tracking a desired speed trajectory.
Fig. 15(a) and Fig. 15(b) present the result of the planned speed trajectory tracking. Apparently, the actual velocity curve of vehicle matches the trajectory we planned in whole; meanwhile, it also can be seen that a delay situation appearing in the beginning state and an obvious overshoot locating on the period which the vehicle speed changes to the constant speed state. The phenomenon is related to vehicle characteristic and response time of brake mechanism chosen. The reason could be from two factors. The main factor is that the vacuum level on the vehicle is not fixed, which depends on different driving condition, and results in varied response time. The other is that hydraulic braking system effect. Due to the hydraulic characteristic when the braking pedal is pressed or released, the vehicle speed needs to wait a short time to response the brake force.

VI. CONCLUSION

In conclusion, we designed a brake controller that is able to provide the automatic parking system a proper braking function generally. Although the performance of the system is keeping improving, the initial simulated and experimental result still increases the possibility of this proposed braking control system. Furthermore, there are still some factors that is needed to enhance. For instance, the accuracy of brake actuator and speed feedback signal in low speed could have the influence on the performance of the control system.

Besides, as a result of the fact that the real vehicle environment is full of noise and disturbance, the enhancement of stability and reliability of the fuzzy control will be the next step in the future. Once the precise vehicle speed control is achieved, the automatic parking system will provide driver comfort and a more precise parking function.

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