

Design of a Model Reference Cruise Control Algorithm

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ABSTRACT

A methodology to design a model free cruise control algorithm(MFCC) is presented in this paper. General cruise control algorithms require lots of vehicle parameters to control the power train and the brake system, that makes control system complicate. Moreover, when the target vehicle is changed, the vehicle parameters should be reinvestigated in order to apply the cruise control algorithm to the subject vehicle. To overcome these disadvantages of the conventional cruise control algorithm, MFCC algorithm has been developed. The algorithm directly determines the throttle, brake inputs based on the reference model parameters such as clearance, relative velocity, and subject vehicle acceleration. This simple structure facilitates human centered design of cruise controller and makes it easy to apply control algorithm to various vehicles without reinvestigation of vehicle parameters. To achieve vehicle safety and driver comfort, control parameters of the model free cruise control algorithm has been designed using the real-world driving test data. Few parameters have been adapted using a learning algorithm to minimize the effects of unawareness of the vehicle parameters. From the simulation study, the performance of the proposed controller has been compared with that of the conventional adaptive cruise controller(ACC). It is shown that the proposed control strategy its behavior is not only similar to that of the conventional ACC in normal driving condition but also more robust than the ACC for model uncertainty and external disturbance.

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INTRODUCTION

The purpose of the adaptive cruise control system(ACC) is reducing the workload of the driver by automatically accelerating and decelerating according to the driving condition. The ACC system generally obtains external road information using frontal radar or lidar sensors. Then it declares target vehicle as the closest preceding vehicle which is in the same lane to the subject vehicle. From the information such as relative velocity and relative position between the target vehicle and subject vehicle, the desired acceleration of the subject vehicle is determined to maintain a proper range with the target vehicle. After that, the ACC system controls the throttle and the brake to tracking the desired acceleration.

There are two quite important problems to design the ACC system. First problem is deals with a range policy between the target vehicle and the subject vehicle. It is also deeply related how to determine the desired acceleration from the external road information. The driver comfort and safety should be considered to obtain proper behavior of the subject

vehicle. The second problem is associated with how to determine the throttle and brake pressure to track the desired acceleration. To follow the exact value of the desired acceleration, the controller should overcome the uncertainty of the vehicle model and the external disturbance such as wind and road grade.

General ACC algorithm uses the inverse dynamics to calculate the control inputs from the desired acceleration. The inverse dynamics means that the controller calculates control inputs backward using the vehicle parameters such as engine map, torque converter map, gear ratio and tire effective radius. However, that approach could be affected from the model uncertainties and the external disturbance and thus additional compensation algorithm is necessary to overcome these problems. This paper deals with these problems. Instead of considering all vehicle power train parameters and model uncertainties, a simplified vehicle model has been used. Then the model uncertainty and external disturbance has been eliminated using an adaptation algorithm. Such formulation is similar to the driving characteristics of a skilled human driver. A human driver controls the subject vehicle without

any information about the subject vehicle. When the vehicle acceleration is larger than the expected acceleration, the driver pushes out the throttle pedal to lower the vehicle acceleration. And opposite, if the vehicle acceleration is slower than the expected value, the driver elevates the throttle angle to reach the desired acceleration. The design approach in this paper imitates such driving characteristics of human driver with an adaptation algorithm.

A number of papers have been reported in the literature. Especially, many papers have been focused on the platoon problem or range policy between two successive vehicles with guaranteed string stability[1],[2],[3],[4],[5],[6],[7],[8],[9]. The study on the platoon problem was initiated by Levine, W[1]. The paper solved string stability problem when the information of all the vehicles in the string is available. The Sheikhleslam shows that the vehicle-to-vehicle communication is necessary to achieve string stability with constant inter vehicle spacing[2]. Jing Zhou has been proposed a nonlinear range policy for improved traffic flow stability and string stability[3]. Liang et al. has been analyzed the string stability problem by applying the optimal control theory[4]. However, these papers used the ideal vehicle model or a first-order time lag function. Instead of that, P. Fancher has been applied inverse dynamics function to determine the throttle angle and the brake pressure[5]. Moon also applied inverse dynamics to calculate control inputs but he introduced a PID controller about the error dynamics to compensate acceleration error[6]. The adaptive cruise controller could adjust the control input using the inverse dynamics, but it should introduce an additional algorithm to handle the model uncertainty and external disturbance. To solve these problems, this paper proposes a model free cruise control algorithm with simplified vehicle model based on the human driving characteristics.

This paper is organized as follows. General adaptive cruise control algorithm and model free cruise control algorithm has been introduced in Section II. The proposed model free cruise control algorithm(MFCC) in this study has been briefly depicted in Section III, In Section IV, The performance of the MFCC has been compared to that of the

conventional ACC Finally, conclusions are presented in Section V.

GENERAL ADAPTIVE CRUISE CONTROLLER

The Conventional adaptive cruise controller consists of the upper-level and the lower-level controller. The upper level controller determines the desired acceleration of the subject vehicle based on the information about the target vehicle such as relative distance and velocity. The upper level controller composed of the in-path target determination algorithm, following control algorithm and free cruise control algorithm. The In-path Target determination algorithm decides target vehicle based on the radar information and gives target vehicle states to the following controller. The following controller calculates the desired acceleration using the linear quadratic regulator. If there is no vehicle in front of the subject vehicle, the free cruise controller calculates the desired acceleration.

The lower level controller determines the throttle angle and brake pressure to track the desired acceleration. The switching algorithm determines switching between the throttle and brake according to the zero throttle deceleration curve with a switching margin. The throttle controller calculates the throttle angle and brake pressure. Therefore, the adaptive cruise controller requires lots of vehicle parameters to calculate the exact throttle angle and brake pressure. Fig 1 depicts the configuration of the conventional adaptive cruise control algorithm.

Generally, the conventional adaptive cruise control algorithm uses the vehicle model to calculate the throttle angle. This is commonly called as an inverse dynamics. The Inverse dynamics contains lots of the vehicle power train parameters such as the inverse engine map, the inverse torque converter map and the gear ratios. The calculation process is shown in fig 2.

The desired turbine torque to track the desired acceleration is obtained from the PI controller using the acceleration error.

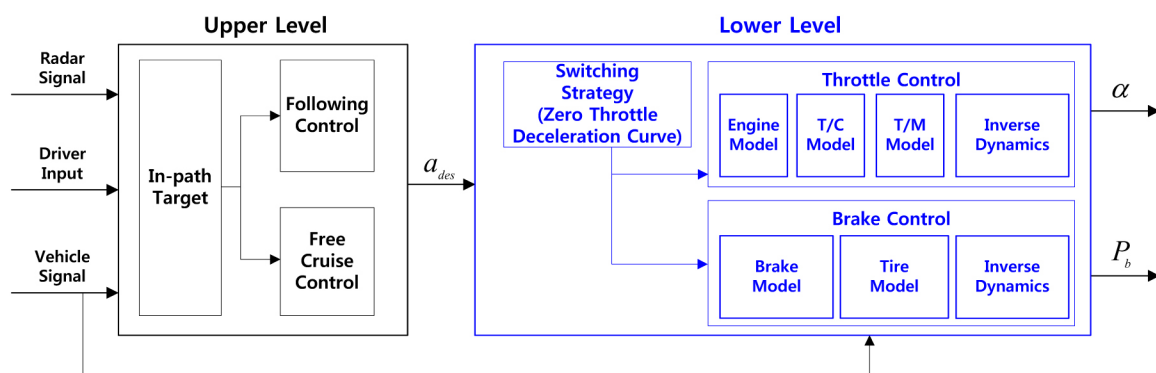


Figure 1. Configuration of adaptive cruise controller

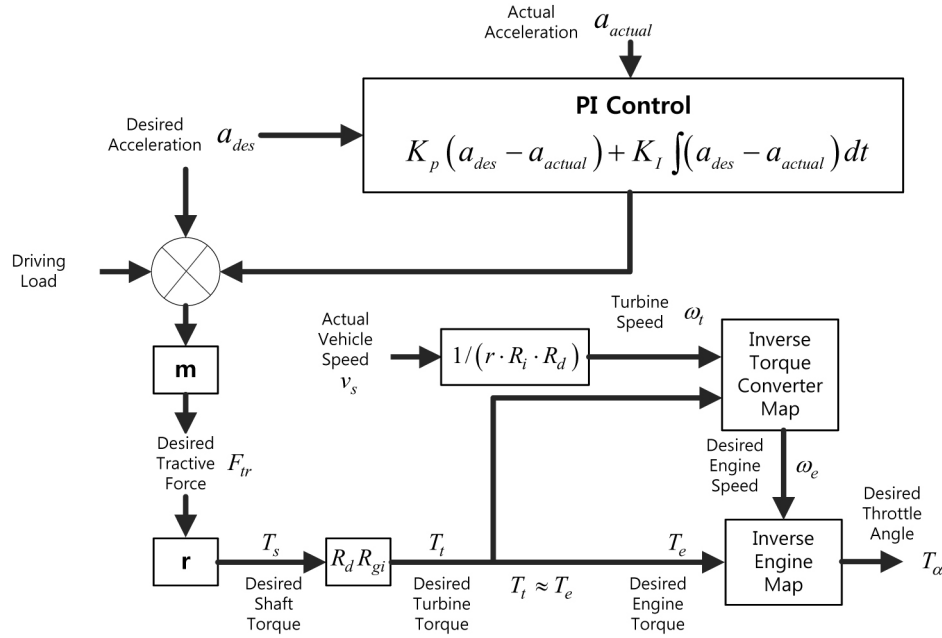


Figure 2. Calculation of a throttle input

$$e_a = a_{des} - a_s$$

$$T_{t,des} = R_g \cdot r \left[M_v \left(a_{des} + K_p e_a + K_I \int e_a dt \right) + F_L \right] \quad (1)$$

where $T_{t,des}$ is the desired turbine torque, R_g is the gear ratio, r is the effective tire radius, M_v is the vehicle mass, F_L is the driving load, K_p and K_I are the proportional gain and integral gain, respectively. The desired engine speed is computed from the desired turbine torque and inverse torque converter map.

$$\omega_{e,des} = TCM^{-1}(\omega_t, T_{t,des}) \quad (2)$$

where $\omega_{e,des}$ is the desired engine speed, TCM^{-1} is the inverse torque converter map, ω_t is the turbine speed. The engine speed which is identical to pump speed and turbine speed are used to calculate the pump torque.

$$T_p = TCM(\omega_e, \omega_t) \quad (3)$$

where, T_p is the pump torque, TCM is the torque converter map. Finally, the desired throttle angle is computed from the inverse engine map as follows:

The algorithm to yield the desired brake pressure is also quite complicated. Detail process of the algorithm is depicted in Fig 3.

The desired brake torque is obtained from the same process to the throttle angle.

$$T_{b,des} = r \left[M_v \left(a_{des} + K_p e_a + K_I \int e_a dt \right) + F_L \right] + T_s \quad (4)$$

where the T_s is the shaft torque which is computed from the engine map and torque converter map. It is also same to the engine torque in zero throttle condition. Then the brake pressure is computed as follows:

$$P_b = \frac{1}{K_b} T_{b,des} + P_{pushout} \quad (5)$$

where K_b is brake gain and $P_{pushout}$ is the pushout pressure.

DESIGN OF MODEL FREE CRUISE CONTROLLER

To obtain the throttle angle and brake pressure in the adaptive cruise controller, the accurate vehicle parameters should be investigated. Moreover, the calculation algorithm contains engine map and torque converter map which include model uncertainties. It also uses control gains such as proportional gain and integral gain for desired acceleration error. These gains should be cautiously investigated to obtain proper performance of the lower level controller. On the other hand, skilled drivers can control the longitudinal motion of the subject vehicle without any information of the vehicle. Although the drivers don't understand the vehicle dynamics, the engine performance, brake design parameters, the driver can press the throttle or brake pedal according to the desired vehicle motion. This is because the driver adapts the throttle and brake input based on the vehicle responses. When the vehicle acceleration is faster than the expected acceleration, the driver pushes out the throttle pedal to lower the vehicle acceleration. And opposite, if the vehicle acceleration is slower than the expected value, the driver elevates the throttle