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Design of a Longitudinal Vehicle Velocity Tracking Controller Using a Lead Screw and Cam-Type Actuator

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Abstract : The main concern of this paper focuses on the control of the vehicle longitudinal velocity with the use of a lead screw-type throttle pedal actuator and a cam-type brake actuator. With the input data from the vehicle CAN which provides the real-time wheel speeds and throttle angle, and from the encoder attached on the brake pedal which provides the brake pedal angle, a cascaded PID controller is designed. A confirmatory assessment of the entire system is arranged via actual experiments involving severe acceleration and deceleration with the aid of dSPACE MicroAutoBox and Matlab/Simulink.

Key words : braking control; throttle control; longitudinal control; robust control; velocity tracking; vehicle control.

Nomenclature

α_t : throttle position angle

α_b : brake encoder angle

V: input voltage

v_{ref}: reference velocity

v_{car}: vehicle velocity

Subscripts

t: throttle
b: brake
p: proportional gain
i: integral gain
d: derivative gain
ref: reference

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1. INTRODUCTION

Given a reference speed, accurate longitudinal speed tracking for vehicles significantly facilitate the reliable performance of electronic vehicle safety control technology, such as ACC (adaptive cruise control), ROM (roll over mitigation), highway platoon control, and automated vehicle control. This is known to require a complex modeling of the engine or a torque map whose accuracy may be degenerated in a specified region of engine operation, or a risky assumption of disregarding the nonlinearity involved in the relationship between the control input and the vehicle velocity. Such requirements have served obstacles in the previous efforts to develop a wholly satisfactory vehicle velocity tracking algorithm [1)-5)]

This paper introduces an integrated vehicle velocity tracking controller comprising a throttle pedal actuator, brake pedal actuator, and cascaded control methods. The choice to use a lead screw type throttle pedal actuator allows the fine-scale control of the throttle angle without having to prepare the complex engine modeling or mapping. As a novel contribution of this paper, it must be also noted that the use of the cascaded loop for the throttle control resolves the issue of the response time delay regarding the feedback control loop, so that the chattering of the output is minimized.

The basic organization of this paper is as follows. Section 2 contains information on the layout of the throttle controller with the data flow description. Section 3 denotes the principle behind the brake actuator and the control algorithm. Section 4 describes the performance verification process as well as the presentation of the test results.

2. Throttle Controller

The throttle controller is designed using an actuator composed of a solenoid and a lead screw driven by a motor. A simplified diagram of the actuator is shown in Fig. 1.

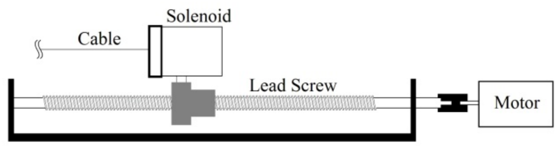


Fig. 1 Conceptual illustration of the throttle actuator

The motor drives the lead screw which induces the linear motion of the solenoid. When the solenoid is powered, it picks up the cable that is connected to the pedal. The linear motion of the solenoid then actuates the throttle pedal. The actuator is designed to let go the throttle pedal by cutting the power off from the solenoid in case of emergency. This type of actuator is chosen to guarantee a fine scale control of the throttle pedal and also to be able to quickly release the pedal for the safety issue.

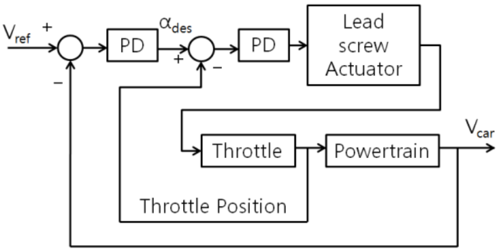


Fig. 2 Block diagram of the throttle control

As shown in Fig. 2, the throttle is controlled through cascades, using two types of feedback information: throttle position and the wheel speed. It is assumed that the vehicle velocity obtained from the wheel speeds is fairly accurate. Regarding the velocity feedback, it is possible to further consider the application of velocity observers.[6)-9)]

A PD control is selected for the control method, and the error value used to compute the control effort is obtained as shown in (1).

$$e_t = C_t\left(v_{ref} - v_{car}\right) - \alpha_t \tag{1}$$

where C_t is a positive constant.

Here, $C_t\left(v_{ref} - v_{car}\right)$ works as a reference throttle angle, which also can be obtained as an output of another PD type controller.

Using e_t obtained in (1), the control effort in the form of voltage input for the motor is calculated in (2).

$$V_t = \begin{cases} V_{t,high} & , \left|K_{ap}e_t + K_{ad}\dot{e}_t\right| > V_{t,high} \\ \left|K_{ap}e_t + K_{ad}\dot{e}_t\right| & , \left|K_{ap}e_t + K_{ad}\dot{e}_t\right| \le V_{t,high} \end{cases} \tag{2}$$

where K_{ap}, K_{ad} are the tuning parameters, and $V_{t,high}$ is a maximum allowable value of the voltage input for the motor.

It must be noted that the final control input voltage is made to zero when the solenoid moves out of the safe range of operation. This is done by attaching a limiter switch onto the throttle actuator.

Through controlling the throttle by the cascaded structure, the issue involving the response delay between the pedal and the vehicle velocity is resolved without having to use a well-prepared mapping table between the throttle angle and the change in the vehicle velocity. This is because the delay between the pedal actuation and throttle angle is much smaller than that between the pedal actuation and the vehicle speed.

Table 1 Throttle actuator motor direction

Direction	Condition
Pedal Push	$e_t > 0$ AND $K_{ap}e_t + K_{ai}\int e_t dt + K_{ad}\dot{e}_t > 0$
Pedal Release	otherwise

The direction of the motor is decided according to the rules in Table 1.

3. Brake Controller

The brake controller is designed using an actuator composed of a cam system and a motor that drives it. A simplified diagram of the actuator is shown in Fig 3.

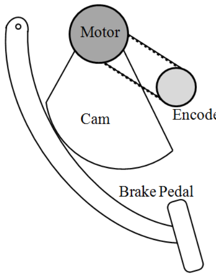


Fig. 3 Conceptual illustration of the brake pedal actuator

The motor turns the cam which presses onto the pedal. An encoder is attached to provide the real-time cam angle information. This type of actuator is selected for it excels in quickly providing a large amount of force need for the abrupt deceleration of the whole vehicle. The control process is illustrated in Fig. 4 shown next.

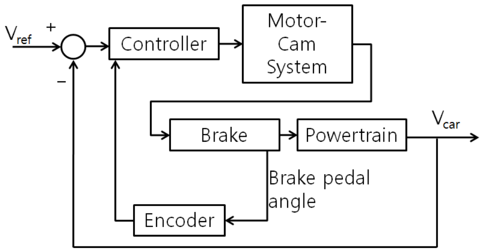


Fig. 4 Block diagram of brake control

Similar to the throttle control, a PID control is selected for the control method, and the error value is computed as shown in (3).

$$e_b = v_{ref} - v_{car} \tag{3}$$

Using e_b obtained in (3), the control effort in the form of PWM voltage input for the motor of the cam actuator is calculated in (4).

$$V_b = \begin{cases} V_{b,high} & , \left| K_{bp}e_b + K_{bi}\int e_b dt + K_{bd}\dot{e}_b \right| > V_{b,high} \\ \left| K_{bp}e_b + K_{bi}\int e_b dt + K_{bd}\dot{e}_b \right| & , \left| K_{bp}e_b + K_{bi}\int e_b dt + K_{bd}\dot{e}_b \right| \le V_{b,high} \end{cases} \tag{4}$$

where K_{bp}, K_{bi}, K_{bd} are the tuning parameters, and $V_{b,high}$ is a maximum allowable value of the voltage input for the motor.

Like how the control effort of the throttle actuator is limited for the safety issue, the PWM voltage input for the motor used in the cam system is made to zero when the brake pedal is out of the safe operation range. Whether the brake pedal is within the safe operation range or not is decided based on α_b sensed by the encoder attached to the brake pedal.

Now, simply letting the brake direction change threshold be at $e_b = 0$ will not guarantee a smooth velocity tracking control, since there exist occasions in which both throttle and brake pedals are pressed. Thus, to avoid the overlap, it is required that for the cases with a fairly small amount difference between v_{ref} and v_{car}, neither pedal is pressed.

Table 2 Brake actuator motor direction

Direction	Condition
Pedal Push	$e_b < -\varepsilon$, where $\varepsilon = \begin{cases} \varepsilon_{high} & , (mv_{ref} - \delta) - v_{ref} > \varepsilon_{high} \\ (mv_{ref} - \delta) - v_{ref} & , \varepsilon_{low} \le (mv_{ref} - \delta) - v_{ref} \le \varepsilon_{high} \\ \varepsilon_{low} & , (mv_{ref} - \delta) - v_{ref} < \varepsilon_{low} \end{cases}$
Pedal Release	otherwise

In doing so, however, the direction must be well defined, since the vehicles with an automatic transmission exhibits different characteristics depending on the speed. Regarding the cases in which both pedals are released, the vehicle tries to accelerate when it starts from a stop or an extremely low speed. In contrast, it tries to decelerate when the pedals are released at a fairly high speed due to rolling resistance and aerodynamic drag. To consider these effects, Table 2 is arranged to define the appropriate direction for the brake control.

Here, m and δ are the positive tuning parameters to determine ε, and ε denotes the threshold value for the brake actuator direction to switch. ε_{high} and ε_{low} are the upper and lower limiting value for ε, where ε_{high} is a positive value and ε_{low} is a negative value. This way, the vehicle can be allowed to decelerate from a high speed without pressing on any pedal if $-\varepsilon_{high} \le e_b < 0$, and remain at the low v_{ref} by pressing onto the brake if $0 \le e_b < -\varepsilon_{low}$.

4. Experimental Results

Performance of the designed controller is experimentally verified using Kia Soul – a compact sized multipurpose vehicle, shown in Photo. 1.

Photo. 1 Kia Soul

Photo. 2 Throttle actuator

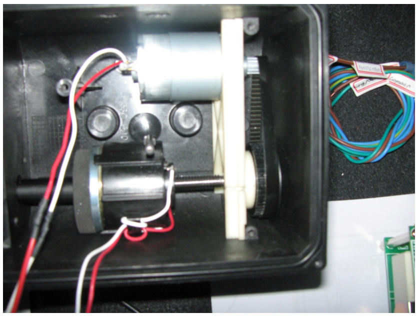
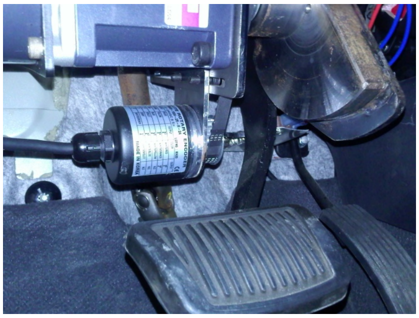


Photo. 3 Brake actuator



The lead screw type throttle actuator and the cam type brake actuator are prepared for the experiment as shown in Photo. 2 and 3, respectively.

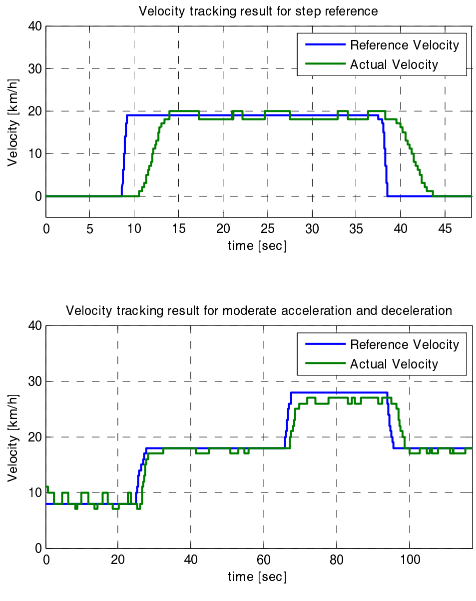


Fig. 5 Experiment result

It can be seen in Fig. 5 that the vehicle fairly accurately tracks the desired velocity. The above test is performed under constant addition of external disturbance, such as rough noise condition, bumps, and varying steering input. It must be noted that the actual vehicle speed is only roughly provided, since the vehicle CAN provides the wheel speed only with the resolution of 1 km/h. Here, vehicle CAN information of the wheel speeds and α_t are obtained through the use of dSPACE MicroAutoBox.

The phase lag of the tracking performance in case of the step reference can be reduced through increasing the upper limits imposed on the voltage input for the actuator motors, but they are set at $V_{t,high}$ and $V_{b,high}$ for the sake of safety.

5. CONCLUSION

An original method to implement a robust velocity tracking control is proposed. Making use of the lead screw type and cam type actuators, the proposed controlling system shows a fairly accurate tracking performance, even under the influence of road disturbance and steering input. Summarizing the paper, the original contributions distinguished from the previously reported papers are the following:

1) The ability to track the reference velocity with a sufficiently small amount of error through a fine-scale control effort of the lead screw type throttle actuator.
2) Not requiring a mapping table or a complex vehicle power train model between the throttle angle and the change in velocity.
3) A robust tracking performance even under the influence of the external noise and disturbance which may resist the desired movement.

6. Acknowledgments

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