Actuator Control of Throttle Valve of An Automobile

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Abstract: Accurate and quick positioning of the throttle valve in driving situation is required to implement the Traction Control System(TCS). Also, unlike a conventional throttle valve which is connected to the accelerator directly by a wire, an Electronic Throttle Valve(ETV) is driven by a DC motor and can move dependently upon the accurate position of the accelerator. In the research, the Electronic Throttle Body(ETB) and Controller for TCS application was developed. In order to drive the DC motor, the developed controller was built and interfaced to the ECU and ETB. The PID position control algorism and developed systems are designed to realize the robust tracking control of the ETV. Actual vehicle tests with these systems and PID position control algorithm. Finally, the performance of the proposed those are evaluated with the experimental studies.

Keywords: NTB, ETB, Throttle valve, Velocity Profile

1. INTRODUCTION

Research has performed automobile external design and stability to rapid progress of electronic and control engineering. Recently, it has advanced effort to environment harmony engine development with combustion structure, combustion method, mixer creation method, fuel supply method, exhaust gas disposal [1-3]. Specially, it has been brought to a focus on Electronic Throttle Valve (ETV) to improve circling stability when automobile is acceleration and high-speed circling. ETV has been controlled of actuator, Moreover ETV control of engine dynamometer system is important to engine control [4].

But, not only previous engines don't control mechanical linkage between Throttle Valve and acceleration pedal or desiring speed using wire, but finally it is no way to conform accuracy of throttle valve. Accordingly switching mechanical linkage or wire to electronic linkage, terminal the object is real time control of desired value to compare desired acceleration pedal displacement and open degree of throttle valve. So, it is necessary for accurate or speedy control as electronic feedback controller [5]. Merit of electric system is low manufacture cost and large flexibility about system change. So, Adaptation of electric equipment will grow large in automobile.

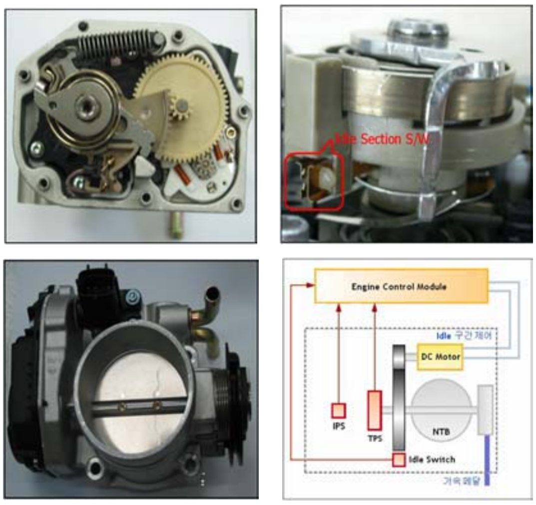
This paper develops controller and ETB to control electronically Throttle Valve which acceleration pedal and wire operate through mechanical connection with previous ECU. The existing ETV control method is Sliding Mode Control Method [6-7]. Sliding Mode Control has a robust characteristic because of influence to switching surface about uncertainty. Control input to overcome uncertainty generates chattering phenomenon during modeling. To conquest, control or system must be added [8]. Control mechanism of this paper is PID Position control Algorism that complex system can be linearization at operating point, that can perform Actuator control, is programmed in ECU and Controller, secure the accurate speedy operation of Throttle Valve. In this way, that will actually be settled some parts of production satisfaction of drivers.

This paper is organized as follows. Structure and function of Throttle Actuator Control System is presented in section 2. Position Control algorithm based Velocity Profile is discussed in section3. An efficiency of Position Control algorithm is experimented in section 4, followed by conclusion in section 5.

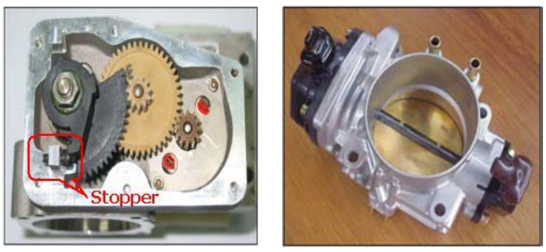
2. THROTTLE ACTUATOR CONTROL SYSTEM

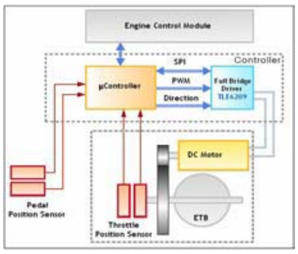
2. 1 Structure and function of Throttle Body

Existing Throttle body and structure is shown in Fig. 1(a). The developed Throttle body and structure is shown Fig. 1(b).



(a)

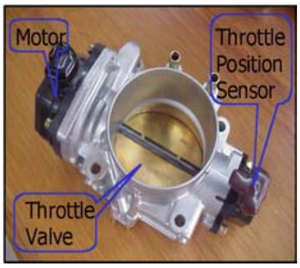




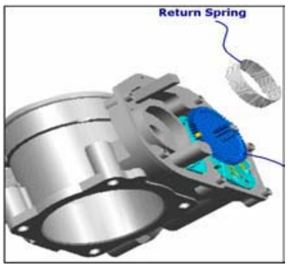
(b)

Fig. 1 Throttle Body and Structure
(a) Throttle Body and Structure of A typical NTB
(b) Throttle Body and Structure of The developed ETB

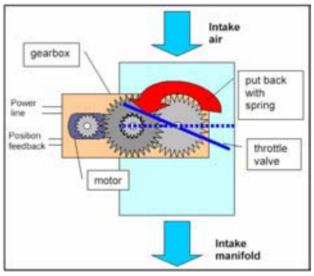
A detailed figure of developed ETB in this research is shown in Fig. 2.



(a)



(b)



(c)

Fig. 2. Electronic Throttle Body
(a) Appearance of ETB (b) A portion assembly of ETB
(c) Inner Structure of ETB

The throttle valve is controlled by the motor, open degree of the throttle valve is measured by Throttle Position Sensor (TPS) in Fig. 2(a). If User manufactures the acceleration pedal, the throttle valve will be controlled electrically. Fig. (b) is partial assemblage of ETB.

When the accelerator pedal is pressed down completely, the throttle valve becomes full open form (The open degree of throttle valve is 90°). When the accelerator pedal is not pressed down, the throttle valve is became full close form by return spring (The close degree of throttle valve is 0°). Fig. (c) is interior structure. Open degree of the throttle valve is controlled by the motor which is acted by the signal which input power line of controller. The important point of Throttle Actuator Control System (TACS) is to control open degree of throttle valve quickly and exactly. So, we use position control algorithm of DC motor. It is difficult point that torque to the return spring is not a load torque which has regular size.

2.2 Structure and function of throttle actuator control system

First, the important point in control of throttle valve control is to organize position control system accurate and quickly. Organization map of Throttle Actuator Control System is shown in Fig. 3.

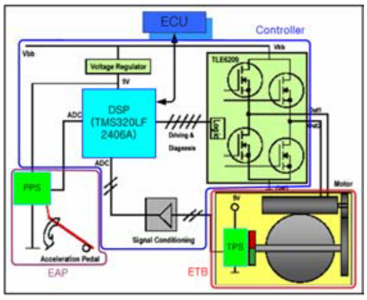


Fig. 3 Schematic of TACS

This system is organized the part of electronic acceleration pedal, the part of throttle valve and controller. Controller is realized in micro-processor by digital control method [9]. Generally, the motor using in the control of the actuator is Stepper motor and DC motor. Stepper Motor is optimality to maintain during the long period, however it is not efficient to quick movement. So DC motor is compatible with accuracy and quick movement. Stepper motor is not appropriate in designing controller.

Another special feature is to reduce a gear between motor and throttle valve. To reduce a gear decreases static friction and uses to low bulk. When we compare with gearless, throttle valve controls desired value accurately in low power.

Principle of controller and Electric Throttle Body (ETB) is that change of accelerator pedal is detected by PPS, then convert analog to digital. So the open degree of throttle valve is changed, change value of the open degree returns to micro processor to TPS.

3. DEVELOPMENT OF THROTTLE VALVE CONTROL ALGORITHM

In this research, we are getting parameters of DC Motor which using TACS by experiment, and established model for DC Motor. And we consider kinematical characteristic and limitation experimentally which is PWM motor driving circuit with Motor, Return Spring and some parts of kinematics. In addition, we use Velocity Profile which is concerned about variable speed for prevention of overshoot caused by Throttle reference position.

3.1 Modeling and Characteristic of DC Motor for Throttle Valve Actuator

Normally the first step for development of Motor's position or speed control algorithm grasps Motor's characteristic which we will use, and finds parameters of Motor through experiment. We mention simply in here.

At first, the Eq. (1) is Motor speed equation of general second order system K_i is constant of Torque, $V_a(s)$ is armature voltage, R_a is armature internal register, L_a is armature inductance, $T_L(s)$ is load torque, J is inertia, B is damping, K_b is constant of counter electromotive force,

$$\Omega_m(s) = \frac{K_i\, V_a(s) - (R_a + L_a s)T_L(s)}{JL_a s^2 + (JR_a + L_a B)s + K_b K_i + R_a B} \quad (1)$$

We know that Motor's speed is defined input voltage and outside load in the fraction Eq. (1). When we control real motor, the outside disturbance is outside load $T_L(s)$, Return Spring operates it. This meaning is that if Throttle Valve moves closed direction, it moves direction of help ($T_L(s) < 0$), when Throttle Valve moves open direction, it moves direction of disturbance ($T_L(s) > 0$). Further more, its size changes proportionally which is changing ratio of both direction springs.

In this paper, however, our final purpose is finding a transfer function which Motor's angle position is output, angle is differential of angular velocity, so we gets transfer function at fraction Eq. (2).

$$G(s) = \frac{\Theta_m(s)}{V_a(s)} = \frac{K_i\, V_a(s) - (R_a + L_a s)T_L(s)}{s[JL_a s^2 + (JR_a + L_a B)s + (K_b K_i + R_a B)]} \quad (2)$$

From fraction Eq. (2), we can get block diagram like Fig. 4.

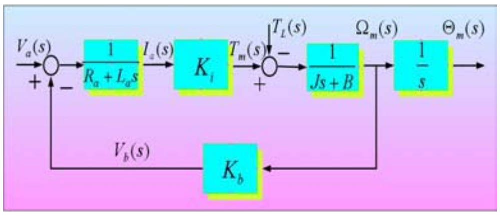


Fig. 4 Block Diagram of DC Motor

When you see this Block Diagram, we know that inside DC Motor makes internal feedback loop by counter electromotive force. Counter electromotive force is generated with negative value by motor's speed proportionally $I_s(s)$ is armature current, $T_m(s)$ is motor's revolution, $V_b(s)$ is counter electromotive force.

Table 1 System Parameters and Conditions.

R_a (Armature Resistance)	1.5 (Ω)
L_a (Armature Inductance)	$1\ (mH)$
J (Inertia Constant)	$6.0\times10^{-5}\ (kg\cdot m^2)$
B (Damping Constant)	$3.0\times10^{-3}\ (N\cdot m\cdot s/rad)$
K_i (Torque Constant)	$6.0\times10^{-2}\ (N\cdot m/A)$
K_b (Back Emf Constant)	$6.0\times10^{-2}\ (V\cdot s/rad)$

3.2 Throttle Actuator System Response Characteristic

Fig. 5 describes Response which is input of ETB following time and Throttle Angle.

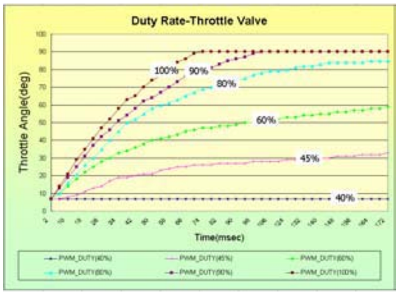


Fig. 5. ETB Responses of Various Duty Ratios

The Fig. 5 is ETB, watch while the Duty Rate of Voltage which from PWM Motor driving circuit to motor is changing, and open degree of Throttle Valve. At this time, if we doesn't operate an accelerator, Throttle Valve approached almost closed state (Open degree of Throttle Valve is); If an accelerator is operated fully, when increasing Duty Rate of supplied voltage into the Motor, the motor's angle of rotation will be increase, and finally Throttle Valve approached almost open state (Open degree of Throttle Valve is), it will be doesn't rotate. For rotating Throttle Valve, it has to tolerate the torque by load and part of kinematics by Return Spring; Throttle Valve doesn't work under 40% Duty Rate. And case of having big Duty Rate, Throttle Valve doesn't response beginning period of , because motor needs some time for generating torque for toleration which is load torque and restorations of valve kinematics by Return Spring.

However, this delay is usually happened, when power doesn't supply into the motor, and the initial stage of power supply into the motor; the state of supplying power to motor, when it moves by new operation for each sampling interval, in this delay period of time is decreasing, so we can control it almost real time. When Duty Rate is 100% and supplying the maximum current, it takes from the state of absolutely closing to the state of absolutely opening and from this we can calculate the Throttle Actuator's the highest speed is about

In this the highest speed is Response limitation of Throttle Actuator, so we determine position control system parameters considering its limitation.

3.3 Algorithm of throttle actuator control system

The PID algorithm used to control the DC motor angular position control in this experiment. This algorithm uses proportional, integral and differential feedback to control the output to the DC motor. PID Position Control Algorithm is very important to the system characteristic of the DC motor: settling time, steady state error and system stability. Each terms in the PID algorithm makes an effect on each system characteristic differently and the block diagram of the PID algorithm is illustrated in Fig. 6.

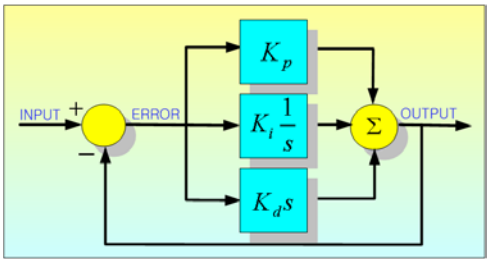


Fig. 6 Block Diagram of PID Algorithm.

The proportional term drives the DC motor with an output directly proportional to the error between the desired and measured position. To accurately control a small change in motor position, a large gain is desired but the large gain makes a greater overshoot and longer settling time. The integral term consists of the integral of the position errors multiplied by and integral constant. The integral feedback drives the steady state error to zero by increasing the output in response to a state error. The integral term, although driving the steady state error to zero, can cause overshoot and ringing. This has the undesirable affect of poorer system response. The differential term is the change in error multiplied by a differential constant. This term predicts an error, so can makes a suitable output for fast response.

However, most of the system instability is caused by too high of a differential constant, so we must select an adequate constant. Fig. 7 shows an block diagram of TACS position control system.

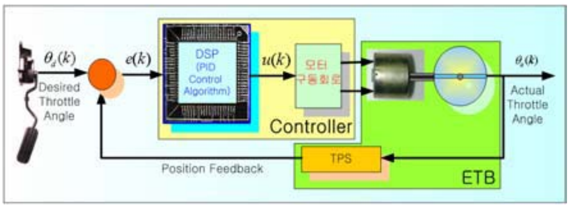


Fig. 7 Block Diagram of TACS Position Control System.

The error between actual throttle angle by TPS and desired throttle angle by TACS is used to PID position control of DC motor.

In our research, the Micro processor is used for discrete PID position control to the DC motor. Eq. (3) shows a position error and Eq. (4) shows a transfer function of PID control. Input value to plant as discrete PID control is shown in Eq. (5).

$$Position\ error: e(k) = \theta_d(k) - \theta_a(k) \quad (3)$$

$$C(s) = \frac{U(s)}{E(s)} = K_p + \frac{K_i}{s} + K_d s \quad (4)$$

$$u(k) = K_p e(k) + K_i \sum_{h=1}^{k} \frac{e\{(h-1)+e(h)\}T}{2} + K_d \frac{\{e(k)+e(k-1)\}}{T} \quad (5)$$

At the Eqs. (3)~(5), θ_d and θ_a represent the desired throttle angle and actual throttle angle. And K_p, K_i, K_d and T indicate proportional gain, integral gain, differential gain and sampling period, respectively. At the each sampling period, the input control signal, $u(k)$ drives a DC motor by changing the duty rate of input signal.

3.4 Necessity and decision of Velocity Profile

We perform location control of motor. In this case, a step function is often used for a standard input. TACS for the use of driving control system is provided opening value of Throttle Valve that is calculated at driving control system on every sampling time. Therefore, a step function is used for a standard input for all of the driving time.

But, Error of between a standard input and a real output is suddenly increased and control signal that is computed by the error is very increased, because a standard input that changes for a step function suddenly changes.

Therefore, the troubles–saturation condition of actuator or a response of big overshoot-break out. Throttle Valve driving of TACS is limited by location of Throttle Valve that is set up by accelerator operation of driver and Stopper(kinematic structure) of Throttle Valve 0°.

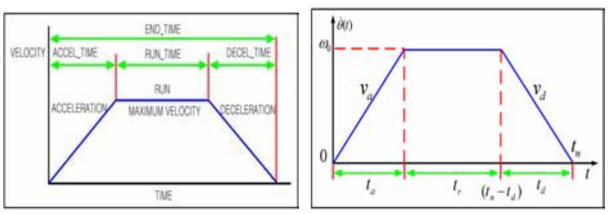
If these kinematic structure was confronted with limitation, because of friction, Throttle Valve instigates a noise and has a bad effect to the actuator.

On the other hand, we can examine Control method of TACS [13]. If driver was faced with situation that was necessary TACS control method, driver must close the Throttle Valve that has been open to decrease engine torque.

In this case, Throttle Valve is often suddenly moved with all closed state. If the overshoot exists, necessarily Throttle Valve will have friction. These situations bring about a noise and decline capability of control system. Therefore driver must keep away from these situations. These overshoot can escapes when standard input is changed step form.

Position of motor using only PID position control algorithm spends much power. The velocity profile offers smooth movement between each angle and reduces power of motor. The velocity profile is Trapezoidal, Triangular and Parabolic. The parabolic profile is the best of efficiency and offers smooth acceleration and deceleration at edge point.

But it requires a lot of time for calculating profile at real time. The triangular Profile is faster than Parabolic Profile, but it makes change value at top point. The trapezoidal Profile offers efficiency of power and convenience of calculation. Therefore we use the trapezoi-dal Profile in this experiment. The trapezoidal Velocity Profile is shown in figure 8. The Fig. 8(a) consists of accel_time, run_time and decel_time. The Fig. 8(b) shows angular velocity which considers feature of position control system about time.



(a) (b)

Fig. 8 Trapezoidal Velocity Profile.
(a) Velocity versus Time (b) Angular Velocity versus Time

Angular acceleration v_a, maximum angular velocity ω_o

and angular deceleration $v_d(>0)$ is decided, v_a and v_d is equal. The value of angular acceleration, angular deceleration and maximum angular velocity is decided by experiment. Acceleration time t_a and deceleration t_d is obtained by

$$t_a = \frac{\omega_o}{v_a}, \qquad t_d = \frac{\omega_o}{v_d} \tag{6}$$

Because Fig. 8(b) shows each position, angle during acceleration time and deceleration is given by

$$\theta_o = \frac{1}{2}t_a\omega_o + \frac{1}{2}t_d\omega_o \tag{7}$$

Fig. 9 simplifies generation program of velocity profile.

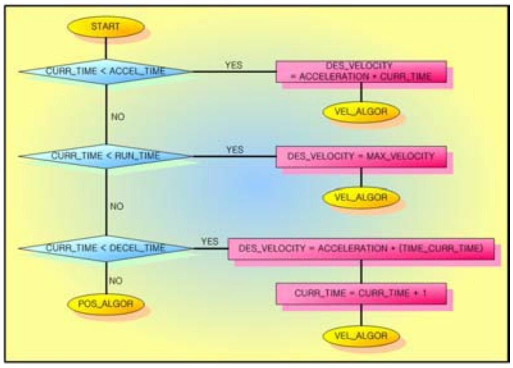


Fig. 9 Velocity Profile Generation Program.

If velocity profile flows ideally, it will reach desired position. It makes position error when motor moves other place. This error removes using PID position control at edge point of velocity profile. So control algorithm carries out both accurate each position and excellent motor performance.

4. EXPERIMENT

In order to develop Position Control Algorithm, we make an experiment using the DC motor modeling, control method and velocity profile. We have investigated the experiment by using two manners. The first case is that PID control does not use velocity profile and the second case is that PID control uses velocity profile. The experiment result which does not use velocity profile is shown in Fig. 10. The experiment result which is P position control is shown in Fig. 10(a), PI position control is shown in (b), PD position control is shown in (c) and PID position control is shown in (d).

When we do not use velocity profile, we must apply other gain respectively. That requires gain scheduling, it makes tiresome because of using interpolation on fitting time. The range of open degree of the throttle in experiment is limited at the angel of 7~80 degrees.

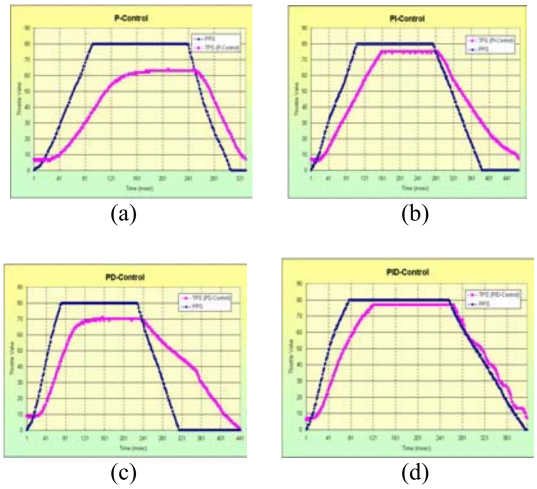


Fig. 10 Throttle Angle Responses for Variable Control without Velocity Profile.
(a) P Control (b) PI Control (c) PD Control (d) PID Control

Next we look over using velocity profile. The experiment result which uses velocity profile is shown in Fig. 11.

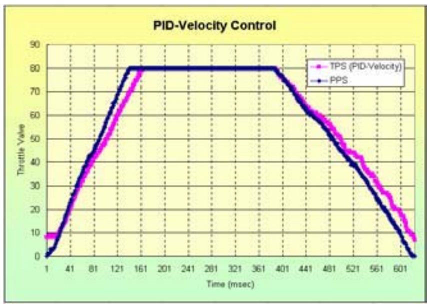


Fig. 11 Throttle Angle Responses for PID Control with Velocity Profile.

We investigate response of the throttle valve about input of the acceleration pedal to be changed random, the open degree of the throttle valve is complied with desired open degree accurately in Fig. 12.

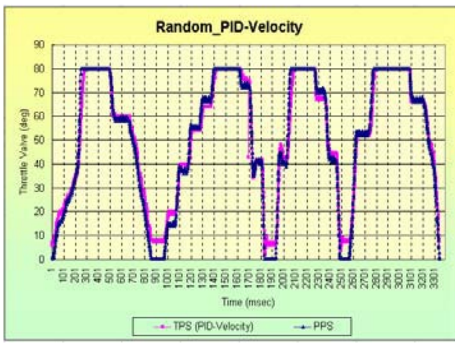
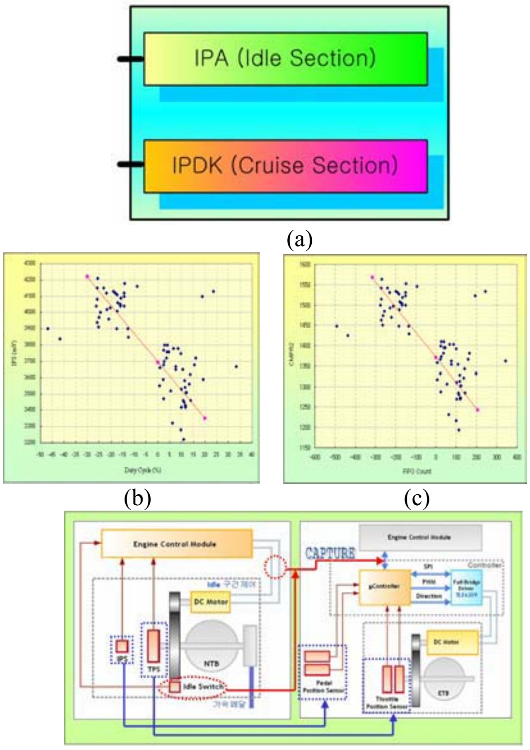


Fig. 12 Responses of Throttle Angle for Random Accelerator Pedal.

Finally, we apply to test a car using developed controller, ETB and developed PID-Velocity Position Control algorithm. The idle and cruise section control signal about NTB and ETB is shown in Fig. 13.

A portion of NTB Connector is shown in Fig. 13(a), The output voltage of idle position sensor(IPS) about duty rate for idle and cruise section control is shown in (b), idle and cruise section control signal which is captured NTB idle and cruise section control using controller, ETB and PID-velocity control algorithm in engine control module is shown in (c). Figure (d) replaces Fig. (b) with Fig. (c).



(a)

(b) (c)

(d)

Fig. 13 Transformation of Idle and Cruise Section Control Signal.
(a) A portion of NTB Connector (b) A typical NTB (c) The developed ETB (d) Control Signal Transformation from NTB to ETB and Control Structure

The automobile and system which uses this research is shown in Fig. 14.

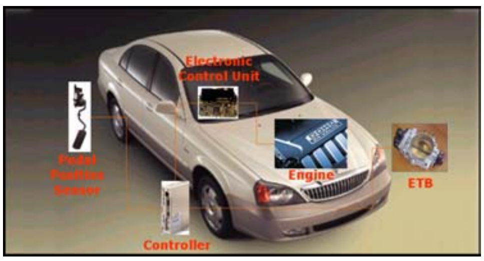


Fig. 14 Schematic of Automobile and Whole Systems.

5. CONCLUSION

In this paper, we have been designed the PID position control algorithm and the velocity profile for throttle valve in the engine dynamometer system. We have been applied this algorithm to a real automobile and also have developed the controller and the ETB for each part, so we can experiment with the various feature of the engine.

The conventional engine was not sufficient for the velocity control accurately because which has a mechanical linkage between the acceleration pedal and the throttle valve. Therefore, we changed the mechanical linkage to the electronic linkage and as compare the acceleration pedal position with the throttle valve position so we have shown the ability to the control of the desired velocity in real-time. Beside, using the ETB(Electronic linkage) instead of the NTB(Mechanical linkage) offer the flexibility for the system alteration.

The result of our investigation can be made a module type, so it is easy to repair and it will lead to the manufacture technology. Also, many countries established several agreements which decrease an automobile exhaust gas so it is necessary to make automobile parts to an electronic type and lightweight type.

ACKNOWLEDGMENTS

This research was supported by the Program for the T raining of Graduate Students in Regional Innovation whic h was conducted by the Ministry of Commerce, Industry and Energy of the Korean Government

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