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Development of Autonomous Vehicle Control Algorithm Based on DGPS(RTK) and Test Vehicle Performance Verification

Young-Geun Moon[1], Moon-Sik Kim[2] and Min-Cheol Lee[3*]

[1] Department of Intelligent Mechanical Engineering, Pusan National University, Busan, Korea
(Tel : +82-51-510-3081; E-mail: ygmoon@pusan.ac.kr)
[2] Korea Automotive Technology Institute, 74 Yongjung-Ri, Pungse-Myun, Chonan, Chungnam 330-912, Korea
(Tel : +82-41-559-3099; E-mail: mskim@katech.re.kr)
[3] School of Mechanical Engineering, Pusan National University and RIMT, Busan , Korea
(Tel : +81-51-510-2439; E-mail: mclee@pusan.ac.kr) * Corresponding author

Abstract: Recently, advanced automobile parts with functions of ASV (Advanced Safety Vehicle) and ADAS (Advanced Driving Assistance System) are developed by various automotive manufactures and major parts companies. To develop and commercialize these advanced parts, various test methods including unit function test, compatibility test, VDS (Vehicle Driving Simulator) based test and T-Car test are needed because reliability is the most important factor for safety. But it is very difficult to make same experimental condition in T-car test as a final test, because driver feels hardness to repeat movement of the vehicle such as speed and path of travel. So we develop the driving robot adaptable to various kinds of vehicles, speed control and path following algorithm based on RTK-DGPS(Real Time Kinematic-Differential Global Positioning System) to guarantee repeatability of test condition in T-car test. The proposed speed control algorithm is used to make the vehicle keep its velocity and decrease overshoot of vehicle speed. The proposed path following algorithm makes the vehicle pass along the predefined path. Two algorithms don't need to any additional sensor except RTK-DGPS and the vehicle dynamic model. So it is very convenient to apply these algorithms to various cars with different dynamic characteristics. Developed algorithms are verified by a computer simulation and the real-car test.

Keywords: Driving Robot, Speed Control, Path Following, Autonomous Vehicle, RTK-DGPS.

1. INTRODUCTION

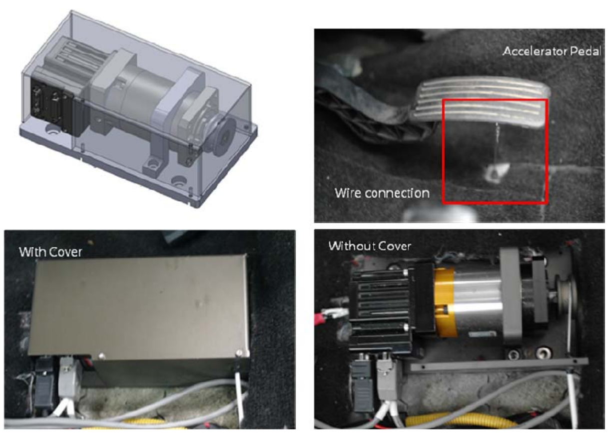
In developing automotive parts, T-car test is the final test method for its commercialization. But it often shows limitations because it is hard to repeat the same test condition like velocity, travel path of subject or target vehicles even experienced drivers. But in order to have reliability of automotive parts, repeated test is essential in same test condition. To make same T-car test condition such as velocity and travel path of vehicle, the wire-guide method widely has been adopted. The electric wire having specific signal is laid under the test ground according to travel path, and the steering robot system mounted on the vehicle sensing the signal of wire controls its lateral position to constrain vehicle position along wire. But this method has some problems because it needs high cost and much time to lay wire under the ground and new wire must be laid whenever travel path is changed. So recently, the method based on DGPS and INS (Inertial Navigation System) with a gyro sensor is studied by various universities, research institutes and companies. But matters relevant to the method are not became generally known in case of the real car.

In this paper, we propose the RTK-DGPS based speed control and path following algorithm available to various kinds of real cars for an autonomous vehicle mounting the driving robot. In first, the driving robot system with steering wheel, accelerator and brake pedal is developed available to various automobiles. Secondly, speed control and path following algorithm are developed, it need only RTK-DGPS without any additional sensor and vehicle dynamic model. Finally, its performance is verified by computer simulation and the real car test[1-3].

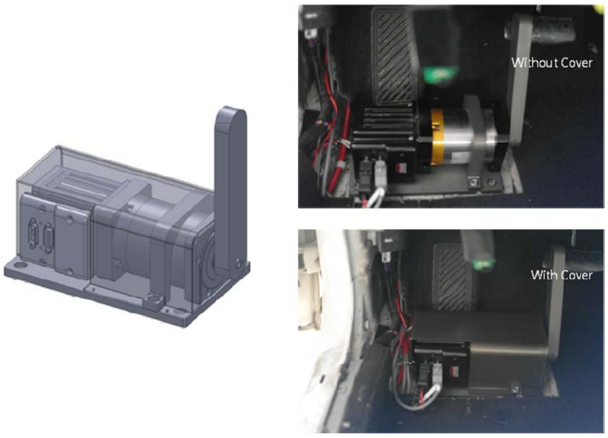
2. PAPER SIZE AND FORMAT

DRIVING ROBOT

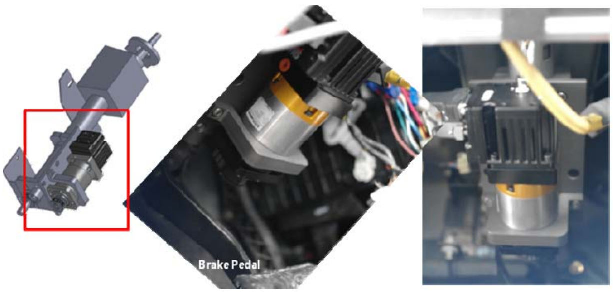
In general, autonomous vehicle is developed and customized for special purpose. In this paper, we develop the general purpose driving robot adaptable to various kinds of vehicle by mounting it on outside of a steering wheel, accelerator and a brake pedal. It is mounted on the space of the driver's seat. Driving robot is consisted of steering wheel, a gear selection (auto transmission), accelerator and brake pedal robots.



(a) Accel. actuator



(b) Brake actuator



(c) Steering actuator

Fig. 1 Driving Robot.

3. SPEED CONTROL

For the speed control of vehicle, wheel speed sensor or characteristics of engine parts of the vehicle are needed in general. But the proposed speed control algorithm only use the vehicle velocity calculated by RTK-DGPS, so it is adaptable to various vehicle model. The reference velocity is compared with the current velocity, and then the driving robot controls the acceleration pedal position to keep the velocity. Thus, in this research, the proportional and derivative control with acceleration compensation is presented. The acceleration error is used for the compensation element with gain K_a. The control output u_{inc} is determined by both velocity error and acceleration error. u_{inc} has lower and upper bound values defined by user. This speed control algorithm is described from the following equations.

$$v_{error} = v_{ref} - v_{cur} \tag{1}$$

$$a_{error} = a_{ref} - a_{cur} \tag{2}$$

$$u_{inc} = (K_p + K_d) \cdot v_{error} - K_d \cdot v_{old\_error} + K_a \cdot a_{error} \tag{3}$$

$$u = u_{old} + sat(u_{inc}) \tag{4}$$

where, v_{ref} is the reference velocity, v_{cur} is the current velocity filtered in moving average method, a_{ref} is the reference acceleration of vehicle and a_{cur} is the current acceleration of vehicle. The velocity calculated by RTK-DGPS has some variation, v_{cur} is filtered by moving average method to eliminate high frequency variation. In order to apply the proposed speed control algorithm to various vehicles, the final output value is set as the incremental or decremental step value instead of the absolute position of the acceleration pedal[5].

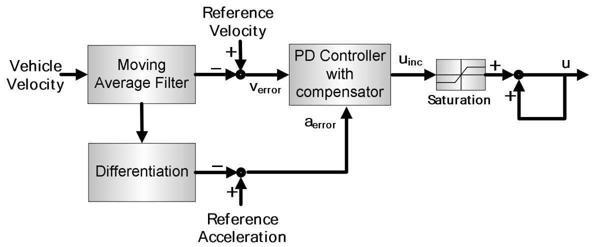


Fig. 2 Structure of the proposed speed controller.

4. PATH FOLLOWING

In order to make an autonomous vehicle trace the specified path by using only RTK-DGPS, it is important to select next target position in real-time. In this paper, we define candidate zone around the vehicle and select the next target position in this zone. The candidate zone is described in Fig. 3 [2-4].

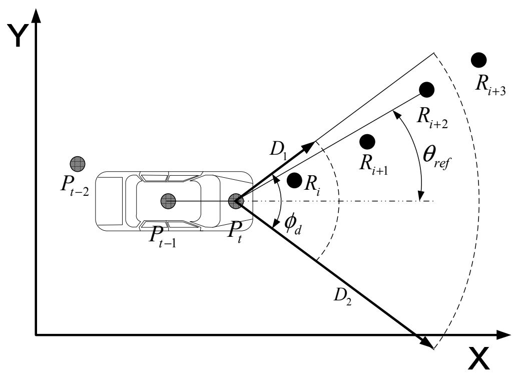


Fig. 3 Candidate zone and next target position.

P represents past positions of the vehicle and R represents reference positions in the storage of the path following controller. P_t is the current position of the vehicle received by RTK-DGPS at time t. R_i is i-th reference position. D_1 is the minimum distance, D_2 is the maximum distance and ϕ_d is the angle range of the candidate zone. The proposed path following algorithm selects the next target position which is most close to curvature D_2 in the candidate zone.
Because the heading angle of the RTK-DGPS has much distortion and disturbance, it is very difficult to estimate

the heading angle of the vehicle. So in this paper, the past position is not used.
Theta_ref is steering angle for move to the target position.

$$\theta_{ref} = \cos^{-1}\left(\frac{\overrightarrow{P_{t-k}P_t} \bullet \overrightarrow{P_t R_{i+l}}}{\left|P_{t-1}P_t\right| \cdot \left|P_t R_{i+l}\right|} \right) \tag{5}$$

The direction of θ_{ref} is derived by the outer product as follows:

$$d(\theta_{ref}) = sign(P_{t-k}P_t \times P_t R_{i+l} - P_{t-k}P_t \times P_t R_{i+l}) \tag{6}$$

D_1, D_2 and □$_d$ are defined by user according to vehicle dynamics characteristics such as velocity and angular speed. If the vehicle has the high speed and user defines small D_1 and D_2 values, then the vehicle may be oscillated. In converse case, accuracy of the path following may be not good.
To determine the D1 and D2, the time-to-access (TTA) is adopted. D1 and D2 are written in the following equation.

$$\begin{aligned} D_1 &= V_t \cdot TTA_{D_1} \\ D_2 &= V_t \cdot TTA_{D_2} \end{aligned} \tag{7}$$

Where Vt is the vehicle speed at time t. TTA_{D_1} and TTA_{D_2} represent the necessary time that the vehicle accesses to D_1 and D_2 curvature. In real time, D_1 and D_2 are changed according to vehicle speed V_t because fixed TTA values. After all, the vehicle has only available movement in TTA_{D_1} and TTA_{D_2} time, so we can restrict the motion frequency of the vehicle. A short time TTA_{D_1} and TTA_{D_2} provide more accurate tracking while a longer time provides smoother tracking.
The angular velocity of the vehicle is computed by Equation (8).

$$\dot{\theta} = V_t \cdot \frac{\sin\phi_d}{l} \tag{8}$$

where L is the distance between the front axle and real axel of the vehicle. A flowchart illustrating the procedure for setting the candidate zone and selecting the next way point is shown in Fig. 4.

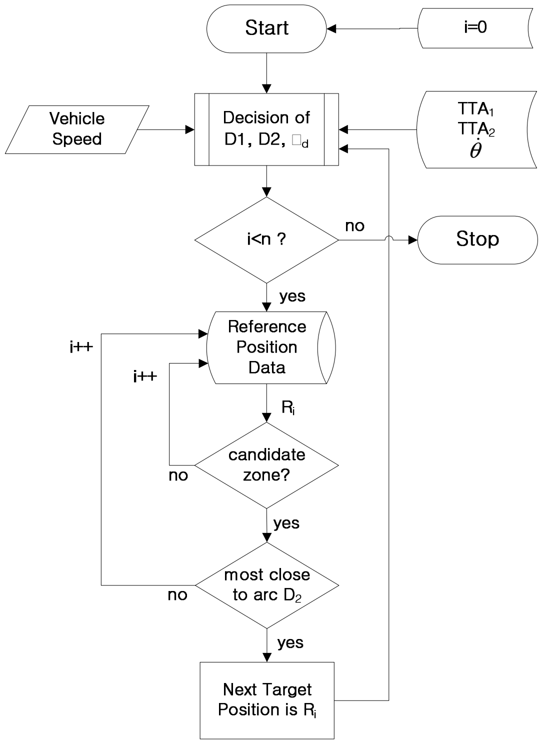


Fig. 4 Flow chart of the path following

5. EVALUATION

The proposed speed control and path following algorithm is evaluated by a computer simulation with Carsim and a real vehicle test.

5.1. Simulation

Carsim developed by mechanical simulation corporation simulates the dynamic behavior of various cars including passenger cars and can be integrated with various simulation tools including Simulink. The proposed algorithms are evaluated by Carsim and Simulink. The vehicle model is designed as possible as to be similar to the real vehicle for test.

5.2. Real-Vehicle based Experiment

The proposed speed control and the path following algorithm are evaluated by using the developed T-Car.
The real vehicle based test is carried out in the proving ground in KATECH (Korea Automotive Technology Institute). The RTK-DGPS has ±2cm resolution and its data update frequency is 20Hz.
In path following test, four test scenarios such as a straight, a single lane change, a double lane change and a slalom driving are conducted at 10km/h. Most tracking errors are under 20cm except the slalom driving. In the slalom driving, error is increased to 27cm because nonlinear characteristics of the vehicle. Test results are shown from Fig. 7 to Fig. 10. Table 1 lists the summarized test results. The root-mean-square errors of all test scenarios are under 10cm.

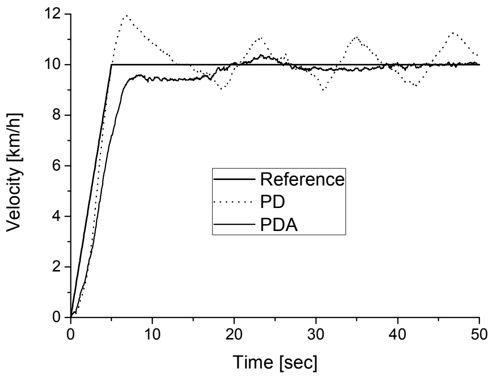


Fig. 5 Speed Control at 10km/h

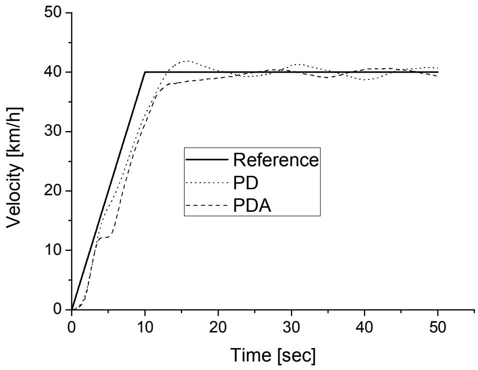


Fig. 6 Speed Control at 40km/h

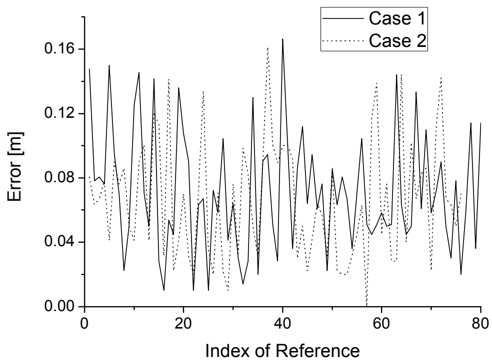


Fig. 7 Distance error in case of straight

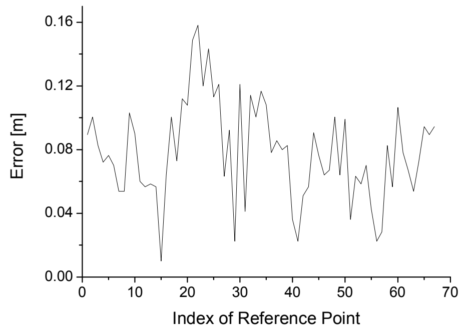


Fig. 8 Distance error in case of Single Lane Change

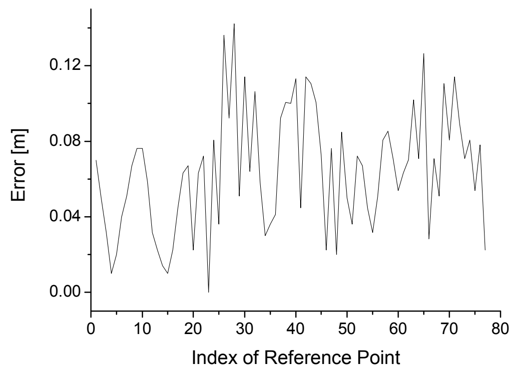


Fig. 9 Distance error in case of double lane change

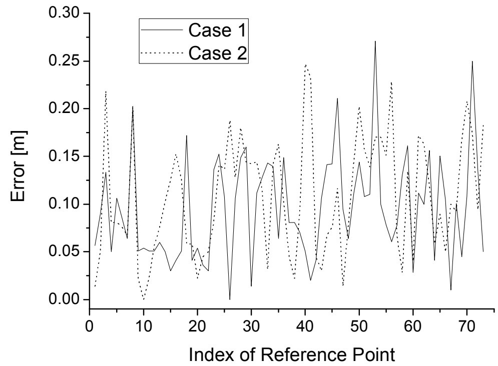


Fig. 10 Distance error in case of slalom

Table 1 Distance error in test scenarios

Driving Case	Error [m]		
	Minimum	RMS	Maximum
Straight	0	0.06	0.16
Single Lane Change	0.01	0.08	0.16
Double Lane Change	0	0.06	0.14
Slalom	0	0.10	0.27

4. CONCLUSION

In this paper, the speed control and path following algorithm are proposed which use only the RTK-DGPS. The proposed algorithm has various parameters in order to apply it the test environment based on the real vehicle and can eliminate disturbance and variation of RTK-DGPS easily.

The proposed algorithms were evaluated by computer simulation and T-car test. In computer simulation using CarSim and Simulink, we verified that the proposed speed control algorithm decreased the overshoot caused by nonlinear parts of the vehicle dynamics and the performance of the path following algorithm. In T-car test, the proposed algorithms are verified which can be applied to the real vehicle environment efficiently.

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