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Lateral Control of Unmanned Vehicle Using PD Controller

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***Abstract*:** In order to control an unmanned vehicle, steering, acceleration, braking etc.., an actuator control is required. This paper proposes a lateral control system for an unmanned vehicle to improve the responsiveness of the system with a PD control. If a PD controller is used in the system, angle errors from autonomous navigation can be stabilized and the system will improve the transient response characteristics. Generally, when calculating a mathematical model of a vehicle, $4m/s^2$ the lateral acceleration in less as two degrees of freedom bicycle model also shows better performance. In this paper, a mathematical modeling of a vehicle using two degrees of freedom model was calculated with a controller designed by Matlab, and autonomous navigation simulations were carried out. Path estimation method of autonomous navigation was done with the Point to Point algorithm, current position of vehicle gained with GPS. Performance of the designed controller was verified through autonomous navigation with a real vehicle.

Key words : Lateral control, PD Controller, Unmanned Vehicle, P to P algorithm

Ⅰ. INTRODUCTION

Today, society has become more convenient with the rapid development of transportation; however, as a result, traffic congestion and accidents are increasing the seriousness of the traffic problems. The cause of most accidents occurs from the carelessness of an individual. So safety-devices for preventing accidents are being developed [1, 2], and research and development of unmanned vehicles are being conducted in advanced countries as well as our country [3, 4].

Here, lateral control of unmanned vehicles and lateral control method using a PD-controller from existing P to P driving were studied. The original P to P driving is driving from the current location to the next location. The driving method calculates the angle between the current position and the next to obtain the steering value. However, in the original method, stable driving is not guaranteed due to the rapid changes of the steering value at the waypoints which are renewed along the path.

A PD controlled driving can stabilize the occurring error angles of the rapidly changing steering value which makes reliable driving possible. In the main part of this paper, 2WS modeling and PD-controller design is described and the original P to P driving is introduced. And using the PD-controller, the P to P driving and the original driving results are analyzed and compared.

Ⅱ. 2WS MODEL

A 2WS(2 wheel steering) car has two front steering wheels while the rear wheels of the vehicle are fixed. Analysis of the general steering characteristics of the car when driving, that is, if the lateral acceleration is less than 0.4G, a linear model of two degrees of freedom can be used to obtain accurate results. Degrees of freedom linear model uses lateral displacement and yaw. The purpose of this study is a 2WS vehicle steering control so the roll, pitch motions were ignored, and experiments were done assuming that the differences of the angle of yaw direction were small.

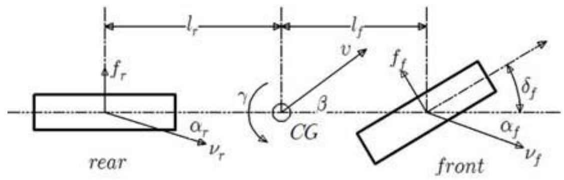

Fig. 1 2WS Bicycle Model.

Slip angle α_f, α_r can be calculated as shown below by speed of vehicle υ , each distance from the center of gravity to the front-wheel and rear-wheel l_f, l_r , the center of gravity of the vehicle yaw rate ν and lateral velocity γ , rear-wheel steering angle δ_r , front-wheel steering angle δ_f , Fig. 1 for each of the front tire and rear tire slip angle α_f, α_r .

$$\alpha_f = \delta_f - \frac{\nu + \gamma l_f}{\upsilon} \tag{1}$$

$$\alpha_r = \delta_r - \frac{\nu + \gamma l_r}{\upsilon} \tag{2}$$

Since a linear tire model is used, the cornering force f_f and f_r acts on the front tire and rear tire so their relevancy are shown as Equation (1) and Equation (2).

$$f_f = c_f \cdot \alpha_f \tag{3}$$

$$f_r = c_r \cdot \alpha_r \tag{4}$$

c_f and c_r are the cornering stiffness. Therefore, using Equation (3) and Equation (4), as shown in Fig. 1, the equilibrium conditions of the vehicle's lateral and yaw moment are used to derive the Equations of motion.

$$m(\dot{\nu} + \upsilon\gamma) = c_f \cdot \alpha_f + c_r \cdot \alpha_r \tag{5}$$

$$J\dot{\gamma} = c_f \cdot l_f \cdot \alpha_f - c_r \cdot l_r \cdot \alpha_r \tag{6}$$

m is the mass of the vehicle, J is the vehicle's yaw moment of inertia. When Equations (1) and (2) are substituted in Equations (5) and (6), then linear Equations of the model are shown in the determinant (7) and then Equation (8) can be expressed in the form of a determinant as.

$$\dot{x}(t) = Ax(t) + Bu(t)$$

$$x(t) = \begin{Bmatrix} \nu \\ \gamma \end{Bmatrix}, \qquad u(t) = \begin{Bmatrix} \delta_f \\ \delta_r \end{Bmatrix} \tag{7}$$

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}, \qquad B = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}$$

$$\begin{bmatrix} \dot{\nu} \\ \dot{\gamma} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} \nu \\ \gamma \end{bmatrix} + \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} \begin{bmatrix} \delta_f \end{bmatrix} \tag{8}$$

Elements of system matrix A and input matrix B are given in the below Equations (9) and (10).

$$b_{11} = -\frac{(c_r + c_f)}{m\upsilon}, \quad b_{12} = -\frac{(c_r l_f + c_r l_r)}{m\upsilon} - \upsilon$$
$$b_{21} = -\frac{(c_r l_f + c_r l_r)}{J\upsilon}, \quad b_{22} = -\frac{(c_r l_f^2 + c_r l_r^2)}{J\upsilon} - \upsilon \tag{9}$$

$$b_{11} = \frac{c_f}{m}, \qquad b_{12} = \frac{c_r}{m}$$
$$b_{21} = \frac{c_r l_f}{J}, \qquad b_{22} = -\frac{c_r l_r}{J} \tag{10}$$

In this study, the necessary parameter is steering angle θ of the unmanned vehicle. Thus, Equation (11) is added, and then Equation (12) is expressed as the Equation of state [5].

$$\dot{\theta} = \gamma \tag{11}$$

$$\begin{bmatrix} \dot{\nu} \\ \dot{\gamma} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & 0 \\ a_{21} & a_{22} & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \nu \\ \gamma \\ \theta \end{bmatrix} + \begin{bmatrix} b_{11} - b_{12} \\ b_{21} - b_{22} \\ 0 \end{bmatrix} \begin{bmatrix} \delta_{fr} \end{bmatrix} \tag{12}$$

Table 1 Unmanned Vehicle Parameters.

Parameter	Value
$m(kg)$	2,055
$\upsilon(m/s)$	2.78~8.33
$J(kgm^2)$	193.25
$c_f(kgf/rad)$	387.3~3690.6
$c_r(kgf/rad)$	848.8~9409.1
$l_f(m)$	1.158
$l_r(m)$	1.737
$L(m)$	2.895

Ⅲ. PD-CONTROLLER DESIGN

PD-Controller reduces error signals effectively since the feedback of the control signal is proportional to the change of the differential value of the error signal, the damping ratio is increased and the overshoot is suppressed. Considering the effect of these differential controls in the controller design, the system can improve the transient response characteristics. Transfer function $K(s)$ of controller is as shown in Equation (13).

$$K(s) = K_p(1 + T_d s) \tag{13}$$

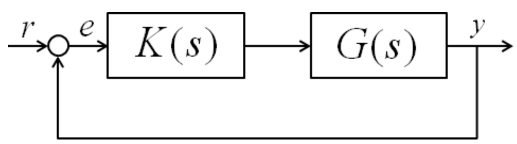

Fig. 2 Block Diagram of PD-Controller.

Fig. 2 is a block diagram of a simulation. Here, r is the control input representing the destination, e is steering angle error which is the difference between the destination and current location. G(s) is represented by Equation (13) as a plant function. The maximum steering angle of the unmanned vehicle was set to ±30 degrees, and control gain was set throughout the experiments.

Proportional gain K_p = 0.8 and derivative gain K_d = 0.35 is calculated [6].

Ⅳ. LOCATION RECOGNITION ANDDRIVING

In autonomous navigation, the vehicle's current position and the heading of the vehicle have to be known. In this study, location-aware system used DGPS (Differential Global Positioning System). The DGPS reference station and rover is composed. Rover's absolute position is known, and then GPS measurements of Rover are calibrated based on this. If the destination station is located within the station's range of about 2km, the system provides a precision of 20cm CEP (95%).

Novatel's GPS receiver ProPak-V3 was used, and antenna, GPS-701-GG was used. For the unmanned vehicle experiments, the roof of the vehicle was equipped with two GPS receivers, so the azimuth of the vehicle can be obtained from two GPS coordinates.

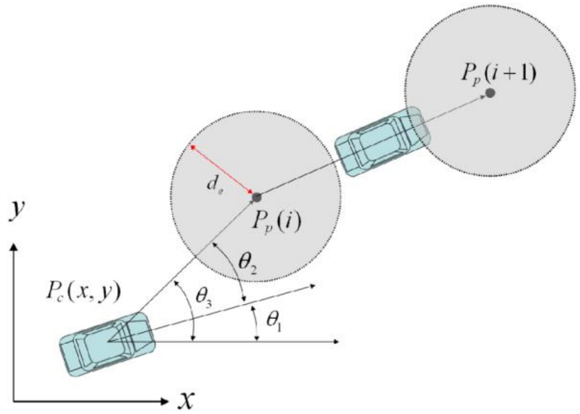

Fig. 3 Lateral Control Model.

Fig. 3 is model for lateral control of vehicle. $P_p(i)$ represents the current position of the vehicle, destination location $P_p(i+1)$, azimuth(heading) of the vehicle θ_1, azimuth(heading) of the destination location θ_3, θ_2 is the steering angle of the vehicle. The vehicle's current location is known by DGPS measurements, and the waypoint on the path to the destination is also known. Therefore, the vehicle's steering angle can be calculated by Equation (14).

$$\theta_2 = \theta_3 - \theta_1 \tag{14}$$

The steering angle is calculated from the difference of the destination azimuth and the current position of the vehicle. When the steering angle is 0 degrees, the vehicle is head in the destination allowing you to reach the destination [6].

Ⅴ. EXPERIMENTS

In this study, a PD-controller is applied to a two-steering unmanned vehicle, general P to P path tracking algorithm and P to P driving algorithm using a PD controller are experimentally compared. When the general vehicle's driving characteristics for analyze, in other words, when the maximum steering angle of 20 degrees at the lateral acceleration of 0.4G is less than the degrees of freedom linear model, approximately 20km/h speed is turning.

Fig. 4 is a vehicle used in the experiment, and driving speed 10km/h, 20km/h, were carried out, respectively. The experiment vehicle used was a Hyundai-Kia MOHAVE, and the experiment was carried out in the school field. GPS coordinates were obtained through P to P driving experiment while turning on an ellipse course.

Fig. 4. Equipment used in the experiment.

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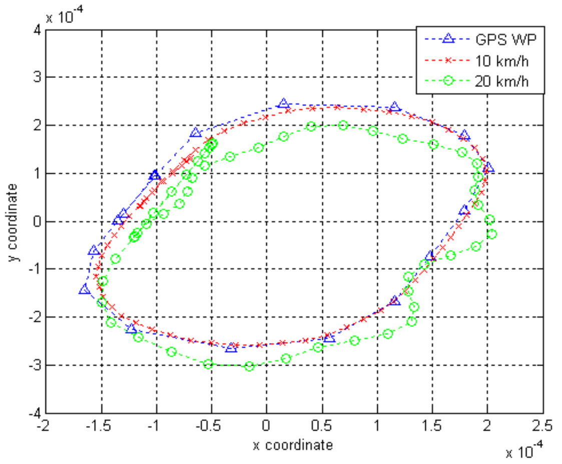

Fig. 5 P to P Driving with P controller.

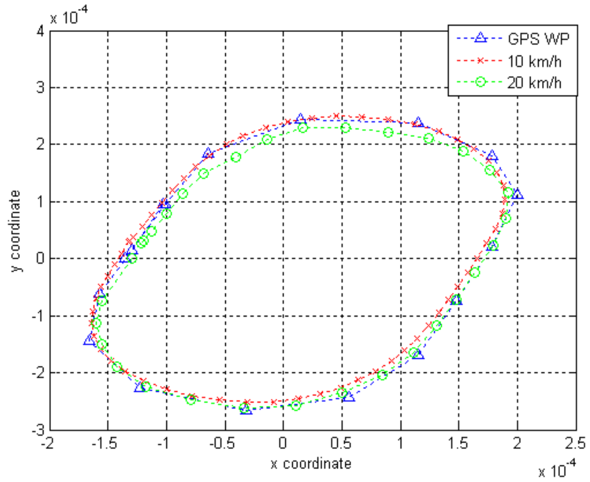

Fig. 6. Using the PD Controller Driving.

The experiment was set up in the path by using DGPS, and driving speed of 10km/h ~ 20km/h were performed while changing the driving speed, and the resulting values were compared with those of the original path.

Fig. 5 is a result of normal P to P driving. GPS path can be tracked successfully while driving at the speed of 10km/h, however, the path was not successfully tracked when at 20km/h.

In Fig. 6, using the PD-controller P to P driving, it shows reliable path tracking regardless of speed. The biggest differences in the two experiments appear when driving along the corners. When you track a straight line path from the current location of vehicle to the destination in the original P to P driving, arrival at the destination causes rapid increase in the steering angle. However, P to P driving with PD controller can reach the destination without a major change in steering angle because of stable driving. Therefore, in this study, using a PD controller P to P road driving than the original P to P driving shows the results of smooth and stable driving.

Ⅵ. CONCLUSION

Lateral control of an unmanned vehicle using PD controller is proposed in P to P driving. To apply to the actual vehicle, DGPS was used. When using DGPS, azimuth of the vehicle can be measured more precisely. A PD controller was applied to lateral control, and results of experiments using the PD controller confirmed it to be stable than general P to P driving. However, when the original path and experiment result's GPS coordinate were compared, the turning radius was larger than that of the original path. This error occurred because the dynamic elements of the vehicle were not considered. Research design considering the dynamic elements need to be done so that reliable path tracking can be performed for variable state of velocity.

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