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Control of obstacle avoidance for autonomous vehicle using laser scanner

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Abstract: This paper describes the development of the obstacle sensing and collision avoidance for Adaptive Cruises Control(ACC) system with an automated vehicle using the laser scanner and RTK – DGPS(Real Time Kinematic - Differential Global Positioning System) system for autonomous navigation. The real scale vehicle for experiment is constructed using RTK-DGPS and laser scanner. Laser scanner is detects the obstacle of the vehicle front. The controller applies to RTK-DGPS and laser scanner based real scale autonomous vehicle, and the performance of the contr1oller and the results of experiments are suggested.

Keywords: Laser scanner, RTK-DGPS, Fuzzy control.

I. INTRODUCTION

Research centered on ITS (Intelligent Transportation System) and PATH (Partners for Advanced Transit and Highways) has led to the development of the autonomous vehicle. Generally, it has been realized using ultrasonic sensors and vision sensors, among other technologies. Though the autonomous vehicle was created in part by using them, it is difficult to operate autonomous vehicles in all conditions [1]. For example, if we use ultrasonic sensors and vision sensors the problem is that they are sensitive to weather conditions or light [2]. Now, concerning about the obstacle avoidance navigation systems by using the optimal obstacle-recognition and absolute coordinate system has progressed [3]. So, we realized an autonomous vehicle using the obstacle-recognition and absolute coordinate system with an RTK-DGPS (Real Time Kinematic-DGPS) and the LMS(Laser measurement system).

Generally, a differential GPS has been used for improving the accuracy of GPS. All the DGPS reference stations have transmitters to forward the error factors to DGPS receivers by radio or other methods, which gives the information to the GPS receiver so it can use the data to correct its own measurements and calculations. This differential correction technique applies to GPS receivers performing code-phase navigation.

When a receiver navigates in carrier-phase mode, it is measuring a different GPS observable, namely the GPS carrier wave. In order to obtain high accuracy with carrier-phase measurements, it is necessary to compute the number of GPS wavelengths between the roving GPS receiver's antenna and the satellites using the information (i.e., carrier-phase measurements) from a base receiver. This technique yields accuracy to the cm-level in dynamic environments called RTK-DGPS.

The Laser scanner SICK®, used for environment detection is based on a time-of-flight measurement principle. The pulse laser beam is deflected by an internal rotating mirror so that a fan-shaped scan is made of the surrounding area. The contour of the target object is determined from the sequence of impulse received. The measurement data is available in real-time for further evaluation via the data interface.

In this paper, the fuzzy control by the feedback of the yaw angle error was used to design a robust lateral control against modeling uncertainty [4].

II. vehicle modelling for the simulation

1. Vehicle modelling

This section considers a classic linearized bicycle model with two degrees of freedom for the lateral and yaw dynamics of a vehicle. We used the PATH car model (Fig. 1) in order to design controller. Because our main interest is with steering control, we ignored the roll, pitch, and vertical movement of the vehicle. And if we suppose that the vehicle runs on a flat road, we can regard the lateral slip angle and the yaw angle as small [5]. Also, if the speed of the vehicle is constant, the complex car model equation can be simplified. The curvature of the road was not considered in this study for simplifying the model, since the effect of the

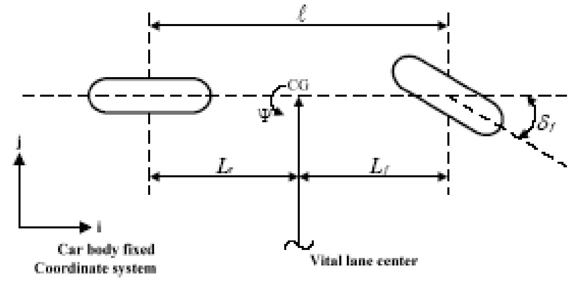

Fig. 1 Bicycle model of a vehicle

curvature on vehicle control at the low speed and in the large curvature is less than that of other uncertainties and external disturbances.

The linearized dynamic equation can be simple, as follows:

$$\frac{d}{dt}\begin{bmatrix} y_r \\ \dot{y}_r \\ \Psi_r \\ \dot{\Psi}_r \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & \frac{A_1}{V} & -A_1 & \frac{A_2}{V} \\ 0 & 0 & 0 & 1 \\ 0 & \frac{A_3}{V} & -A_3 & \frac{A_4}{V} \end{bmatrix}\begin{bmatrix} y_r \\ \dot{y}_r \\ \Psi_r \\ \dot{\Psi}_r \end{bmatrix} + \begin{bmatrix} 0 \\ B_1 \\ 0 \\ B_2 \end{bmatrix}\delta_f \quad (1)$$

where A_1, A_2, A_3, A_4, B_1, and B_2 are defined as

$$A_1 = -\frac{C_f + C_r}{m}, \qquad A_2 = -\frac{(C_f L_f - C_r L_r)}{m},$$

$$A_3 = \frac{(-C_f L_f + C_r L_r)}{J}, \quad A_4 = -\frac{(C_f L_f^2 + C_r L_r^2)}{J},$$

$$B_1 = \frac{C_f}{m} \quad \text{and} \quad B_2 = \frac{C_f L_f}{J}.$$

The front wheel steering actuator is assumed to be dominated by the first order delay.

$$\theta_m = \frac{1}{T_m s + 1} u_f, \quad (2)$$

where, T_m is the time constant of the motor and u_f is the control input and θ_m is the motor (or steering wheel) angle.

The steering system from the motor (or steering wheel) angle θ_m to the wheel angle δ_f is modeled as a gear with the gear ratio of n. So, δ_f is given by

$$\delta_f = n\theta_m \quad (3)$$

Combining the dynamics of the actuator and the vehicle dynamics, a 5th order state space model with states $X = \begin{bmatrix} y_r & \dot{y}_r & \Psi_r & \dot{\Psi}_r & \theta_m \end{bmatrix}^T$ is obtained as follows:

$$\dot{X} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & \frac{A_1}{V} & -A_1 & \frac{A_2}{V} & B_1 \cdot n \\ 0 & 0 & 0 & 1 & 0 \\ 0 & \frac{A_3}{V} & -A_3 & \frac{A_4}{V} & B_2 \cdot n \\ 0 & 0 & 0 & 0 & -\frac{1}{T_m} \end{bmatrix} X + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \frac{1}{T_m} \end{bmatrix} u_f \quad (4)$$

2. Fuzzy controller for yaw control

Our goal is to design a yaw controller of vehicle which emulates the human driver behavior using the fuzzy control[6]. We design the fuzzy controller that uses mamdani inference rule. The objective is to design a control law so that the yaw angle error Ψ_{error} converges to 0. Design proceeds in the following sequence: (1) fuzzification of the input-output variables, (2) rule base construction, (3) reasoning process and (4) defuzzification of output variables.

The input of the proposed fuzzy controller is $\underline{\Delta\Psi}_{error}$ which is the fuzzified variable of $\Delta\Psi_{error}$. The output of the fuzzy controller is $\underline{u}_f$ which is the fuzzified variable of u_f.

Each fuzzy variable can take nine linguistic terms:

PB : Positive Big
PM : Positive Medium
PS : Positive Small
ZE : Zero
NS : Negative Small
NM : Negative Medium
NB : Negative Big

Fuzzy membership functions(MFs) of the above stated fuzzy variables are chosen of trapezoidal shape to simplify the computation. The configuration of membership functions is shown in Fig. 2. And, Fig. 3 is the steering wheel control rules are constructed based on human reasoning.

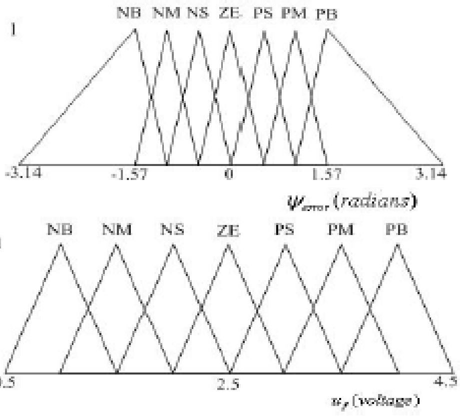

Fig. 2 Configuration of MFs

If ($\Delta\Psi_{error}$ is positive big) then (u_f is positive big)
If ($\Delta\Psi_{error}$ is positive medium) then (u_f is positive medium)
If ($\Delta\Psi_{error}$ is positive small) then (u_f is positive small)
If ($\Delta\Psi_{error}$ is zero) then (u_f is zero)
If ($\Delta\Psi_{error}$ is negative small) then (u_f is negative small)
If ($\Delta\Psi_{error}$ is negative medium) then (u_f is negative medium)
If ($\Delta\Psi_{error}$ is negative big) then (u_f is negative big)

Fig. 3 Rule base

And we use the center of gravity method for defuzzification of output variables. This equation is

$$u_f = \int \frac{\mu_Y(u_f)\cdot u_f du_f}{\mu_Y(u_f) du_f} \quad (5)$$

where, $\mu_Y(u_f)$ is the membership function of the output variables.

III. Navigation Algorithm

A car avoidance navigation system consists of several subsystem, such as a positioning system, a avoidance route guidance system, a communication system, and a user interface system. But, the main role of a car avoidance navigation system is to find the car position and obstacle detection precisely as possible. In this paper, a vehicle avoidance navigation system merely means the positioning and obstacle searching system.

Our navigation system needs saved map data in a navigation computer. The map data is used as a reference trajectory. It makes a virtual lane in the navigation computer. Through we drive the road for the unmanned vehicle before driving itself, we acquire map data by using RTK-DGPS. Also, in case that unmanned vehicle would find an obstacle on the reference trajectory, it makes avoidance trajectory in order to keep away from the obstruction by using laser scanner.

The navigation concept is shown in Fig. 4. Laser scanner calculates the distance from the obstacle and the size of it and obtains the data about the next target point. M_i is i-th map data. P_t is the current position that is acquired by using RTK-DGPS. When an obstacle appears, P_t is the position acquired from the laser scanner. And it calculates maximum moving distance r of the vehicle by using velocity of the vehicle until acquiring next RTK-DGPS or laser scanner data.

It compares the current position with maximum distance position M_{n+2} within the circle that has radius r. It calculates the yaw reference $|\psi_{ref}|$ by the dot product of vectors.

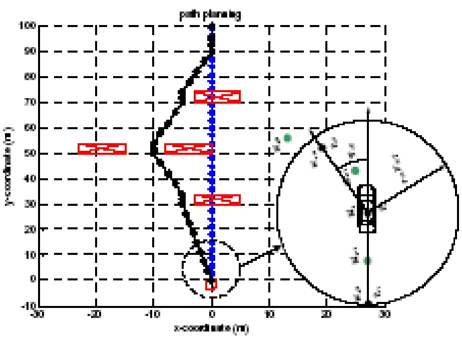

Fig.4. Navigation concept dot product of vectors.

It uses the prior position P_{t-1}, the current position P_t and the target position M_{n+2}. It is equation (5).

$$|\psi_{ref}| = \cos^{-1}\frac{\overline{P_{t-1}P_t}\cdot\overline{P_tM_{t+2}}}{|\overline{P_{t-1}P_t}||\overline{P_tM_{t+2}}|} \quad (5)$$

And the sign of direction is solved by using the sign of the cross product of vectors.

$$\overline{P_{t-1}P_t}\times\overline{P_tM_{t+2}} = \begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ P_{t-1}P_{t_x} & P_{t-1}P_{t_y} & P_{t-1}P_{t_z} \\ P_tM_{t+2_x} & P_tM_{t+2_y} & P_tM_{t+2_z} \end{vmatrix} \quad (6)$$

We can acquire ψ_{ref} by using equations (5), (6)

$$\psi_{ref} = sign(\vec{k}(P_{t-1}P_{t_x}\times P_tM_{t+2_y} - P_{t-1}P_{t_y}\times P_tM_{t+2_x}))\times|\psi_{ref}| \quad (7)$$

Fig. 5 shows the flow chart of the proposed navigation algorithm.

IV. Experiment

1. Experimental System

Fig. 6 shows the total composition of system for the actual experiment. The experiment vehicle is SPORTAGE of KIA motors. RTK-DGPS system is Z-family of Ashtech. The accuracy of synchronized RTK mode of it is 0.5cm+1ppm.

And the maximum position output rate at the remote receiver is 1Hz. The communication between the base station and the remote station in the vehicle is accomplished by PDL(Positioning Data Link) system that uses RF connection.

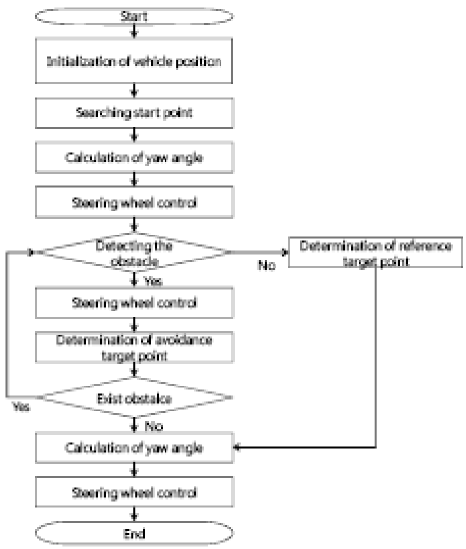

Fig. 5 Flow chart

And we use the laser scanner of SICK. Its maximum scanning angle 180°and lateral resolution which can be variably defined between 0.25°and 1°. The accuracy of measurement in a single shot is about ±2cm.

The GPS receiver and PDL rover are located on the roof of the vehicle and the laser scanner is installed on the front bumper. A handle mechanism is installed at the front seat of the vehicle. The navigation computer is PXI-1002 of National Instrument. And the navigation software is coded by using LabVIEW 6.1.

2.Experiment Results

The distance error from the avoidance trajectory and velocity are shown in Table. 1.
This experiment uses RTK-DGPS and laser scanner data for real time correction of current position. If we do not use it, the position error would increase by unconsidered factors; for example, slip of tires, for example, slip of tires, crushed tires and delay time of the motor for actuating steering wheel.

Fig. 6 Total composition of the system

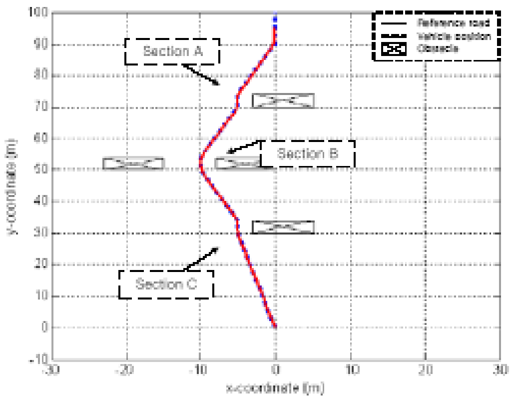

Fig. 7 Total composition of the system

Table 1. The illustration of something

	10km/h	15km/h	20km/h
A	0.135m	0.296m	0.551m
B	0.191m	0.427m	0.674m
C	0.106m	0.229m	0.474m

When the vehicle is operated in the obstacle area, maximum distance error from the avoidance trajectory is 0.674m. It comes from the section B of avoidance trajectory. A reason's curvature of a section B part is big, and the heading direction of the vehicle is changed rapidly for tracking of reference trajectory. If the vehicle has more data, the tracking performance about the avoidance trajectory will be improved.

V. Conclusion

An avoidance navigation system based on cooperation between RTK-DGPS and an laser scanner has been designed and implemented on a commercial vehicle for an unmanned transport application. The techniques developed in this work were evaluated by experiment using real vehicle. And we strove to minimize the numbers of the sensors. The weak point of this work is that the autonomous vehicle is operated at the limited driving area with low speed. But it will be applicable to a vehicle that is operated at a port, park and airport. Current related work concerned with developing a high speed unmanned vehicle that is supplemented by using gyro-sensor and wheel-sensor and correction of diameters of tires. It will be more precise and faster than this unmanned vehicle.

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