Unmanned Navigation of the 1/10 Vehicle Using U-SAT

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Abstract. In order for a vehicle to follow a predetermined trajectory accurately, its position must be estimated accurately and reliably. In this paper, we propose new lateral control methods for unmanned vehicles and a positioning system using ultrasonic waves. The positioning problem is considered as an important issue of control problem for unmanned navigation of a vehicle. Dead Reckoning is widely used for positioning of vehicle. However this method has problems because it accumulates estimation errors. We propose a new method to increase the accuracy of position estimation using the Ultrasonic Satellite system. It is shown that we will be able to estimate the position of vehicle precisely, in which errors are not accumulated. We also propose new lateral control methods including a new path planning method and a heading angle modulator. The experimental results show that the proposed methods enable accurate vehicle trajectory tracking under various environmental factors.

Keywords: Ultrasonic satellite system (U-SAT), unmanned navigation, lateral control

1 Introduction

In modern society, the road capacity is limited, but the number of vehicles is increasing continuously. Therefore, the smooth traffic of vehicles becomes difficult, which increases the threat to the safety of drivers. Under such circumstances, research is under way worldwide to develop unmanned navigation including ITS (Intelligent Transportation System), PATH (Partners for Advanced Transit and Highway) and AHS (Automated Highway System) [1], [2], [3].

The prerequisite for such unmanned navigation is the positioning of a vehicle. Only when the position of the vehicle is known, the vehicle could be drive associated with specific routes, which is generated using the general information needed for unmanned navigation. To this end, researchers have conducted various studies on INS (Inertia Navigation System), GPS (Global Positioning System), Vision System, and Ultrasonic System [4], [5]. In the case of INS, which uses an accelerometer or a gyroscope, there is no limitation regarding the recognition area. However, accumulative errors will occur with the passage of running hours, even though it is easy to construct a path planning. GPS guarantees precise positioning, but it created cost problems and limitations in recognizing environments. In the case of Vision

System, its image processing speed is improving, owing to the development of microprocessors, but it has failed to completely overcome the challenge of recognizing environments.

This paper proposes an Ultrasonic Satellite system (U-SAT) for the unmanned navigation of vehicles accordingly. One of the difficulties associated with the study of unmanned navigation, is to conduct a test to verify the algorithm using an actual car. To resolve such a difficulty, this study conducted unmanned navigation experiments indoors using a 1/10 vehicle and a U-SAT. In addition, overcome the limitation of the existing lateral control, this study suggests a new lateral control algorithm, in which the performance of the algorithm has been verified and evaluated.

2 Position estimation using ultrasonic waves

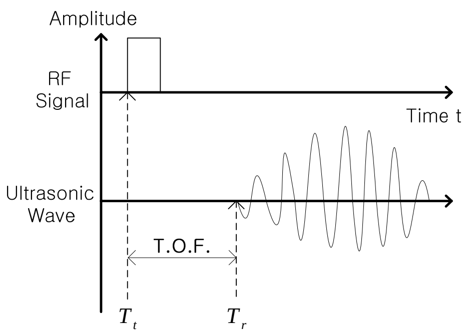

Fig. 1. Definition of T.O.F

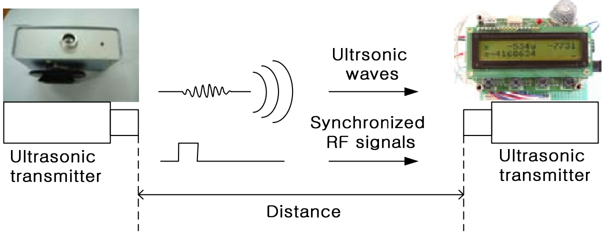

Fig. 2. Ultrasonic distance measurement system

As shown in Fig. 1, the basic formulation of positioning using ultrasonic waves is to use Expression (1) in conjunction with Expression (2), to measure the Time of Flight (T.O.F), the gap between the time of transmission of ultrasonic waves (T_t) and the time receives of the waves (T_r). It is necessary to measure the T.O.F. precisely for exact positioning and, to this end, this study used the period detecting method [6]. Using the 40 kHz MA40BR/S ultrasonic sensor of Murata and the radio frequency (RF) transmitting-receiving module, the point of time of ultrasonic wave transmission is measured. This study also constructed a ultrasonic distance measurement system as shown in Fig. 2 [7].

$$d = c \times T.O.F \quad (1)$$

$$c = 331.5 + 0.60714T \quad (2)$$

Based on the ultrasonic distance measuring system shown in Fig. 2, this study constructed the U-SAT shown in Fig. 3. As shown in Fig. 3, the ultrasonic wave transmitter of Fig. 2 transmits ultrasonic waves and synchronized RF signals from four fixed positions. The ultrasonic receiver of Fig. 2 is attached on the moving object to receive ultrasonic waves and synchronized RF signals, as well as measuring the distances between ultrasonic transmitters and receivers. Based on this, the precise three-dimensional positions can be estimated through trilateration. In addition, ultrasonic waves are transmitted consecutively at the interval of 0.1 second in order to prevent interference of ultrasonic waves generated among each of the ultrasonic transmitters [8].

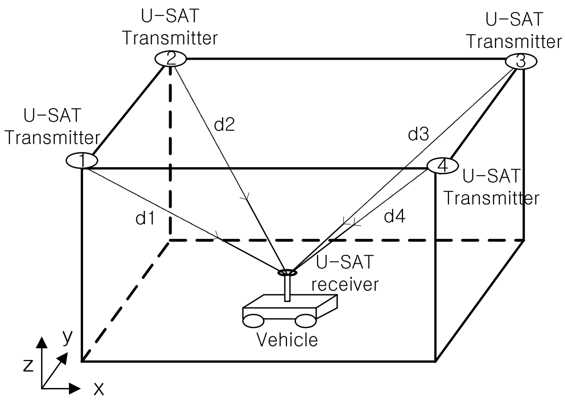

Fig. 3. Configuration of U-SAT

3 Configuration and modeling of the 1/10 vehicle

Fig. 4 indicates the configuration of a vehicle analogously reduced to 1/10 of an actual vehicle. As shown in Fig. 4, the configuration of the 1/10 vehicle acquires the absolute position (x, y) with the sampling time of 0.4 seconds through the U-SAT and obtains the heading angle (θ) from the electronic compass (CMP303-Robot Compass Module) at the interval of 0.1 second. The electronic compass has an error of about. The central processing part conducts wireless communications with the computer through a Bluetooth and receives data (x, y, θ, v) transmission and control inputs (δ, V) at the speed of 115200 bps. The steering part of the vehicle drives the HS 500 thermo motor of Hitec. The maximum right and left steering angle is $\pm 30°$.

This study uses modeling that considers the look-down and actuator elements based on a bicycle model [4]. The bicycle model is a model that equalized two front wheels and two rear wheels as virtual wheels on the vehicle central line, respectively. This is to control steering and therefore, it ignores the vehicle roll and pitch movement. The premise is that the difference of angles in the small yaw rate and the longitudinal speed are maintained constantly. Linearization takes place under these conditions. The dynamic equation is expressed in the form of the differential equation like Eq. 3. The parameters are shown in Table 1.

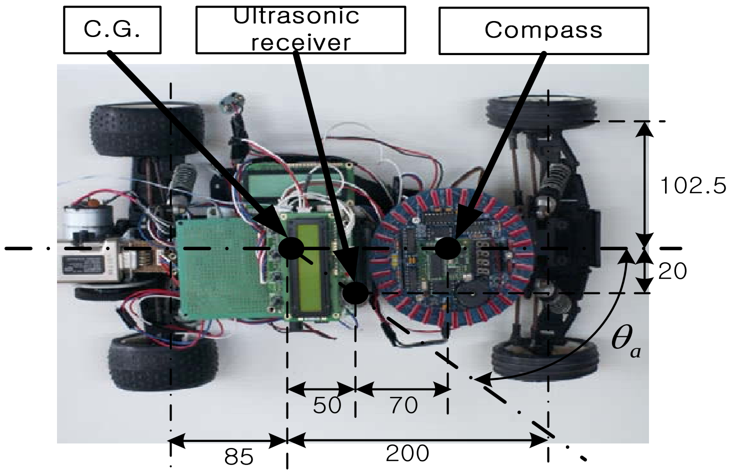

Fig. 4. Configuration of 1/10 vehicle (uint: mm)

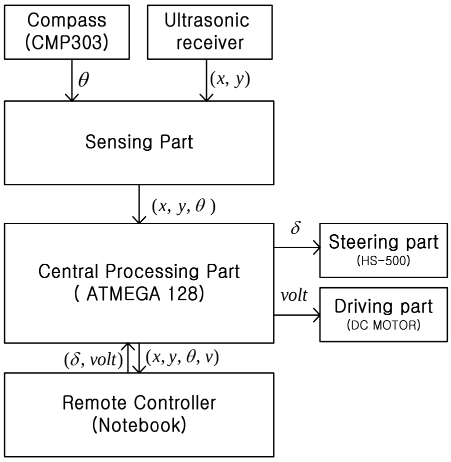

Fig. 5. Configuration of hardware

$$\begin{bmatrix} \dot{v} \\ \dot{r} \\ \dot{\theta} \end{bmatrix} = A \begin{bmatrix} v \\ r \\ \theta \end{bmatrix} + B\delta_f \qquad (3)$$

$$A = \begin{bmatrix} -2(C_f + C_r)/mu & -u - l(aC_f - bC_r)/mu & 0 \\ -2(aC_f - bC_r)/I_{zz} & -2(a^2 C_f + b^2 C_r)/I_{zz}u & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} 2C_f / m \\ 2aC_f / I_{zz} \\ 0 \end{bmatrix}, \quad C = [0 \;\; 0 \;\; 1], \quad D = 0$$

Where,

a : Distance from the vehicle C.G. to front axle

b : Distance from the vehicle C.G to rear axle

C_f / C_r : front/rear tire cornering stiffness [N/rad]

I_{zz} : yaw moment of inertia

l : wheel base l= a+b

m : vehicle total mass

r : yaw rate

u : longitudinal velocity of the vehicle at C.G.

v : side-slip velocity of the vehicle at C.G.

δ_f : front steering angle input

Table 1. Parameters of 1/10 car

Parameter	value	
m	2.105	[kg]
l	285	[mm]
a	200	[mm]
b	85	[mm]
C_f	0.191	[N/rad]
C_r	0.51	[N/rad]

4 Path planning method and unmanned navigation algorithm

As indicated in Fig. 6, a new path planning method is generated in a point-to-point manner. First of all, the vehicle moves toward the target route point $P_p(i)$. When the vehicle's center of gravity comes into a certain radius d_e of the target route point $P_p(i)$, the vehicle is considered to have reached the target route point. Then, the target point is converted to the next target route point $P_p(i+1)$ iteratively. Here, the purpose of the radius d_e is to facilitate natural movement to the next target route point. In this study, the vehicle speed is set at 40 cm/s and d_e at 25 cm in consideration of position errors.

Next, the lateral control algorithm controls the heading angle of the vehicle so that the error θ_e between the target route point $P_p(i)$ and the heading angle can be maintained at zero, as shown in Fig 6. As for the feedback loop, when the target route point $P_p(i)$ is given as shown in Fig. 7, the vehicle position $P_c(x, y)$ at that time is feedbacked to generate the target angle (θ_{r1}) of the vehicle. This angle is set as a basic input and the heading angle error (θ_{e1}) is made to converge at zero using the heading angle (θ) which comes in through the electronic compass. Then, the vehicle moves to the target route point P_p . The heading angle sampling time on the electronic compass is four times faster than the positioning sampling time of the U-SAT. Therefore, when the compensation is made simply by feedbacking the heading angle, $\theta_{e1} = \theta_{r1} - \theta$ is sent to zero. However, the vehicle can't realistically approach the target route point P_p . To overcome this problem, this study proposes a new lateral controller using the heading angle modulator $C_1(t)$, shown in Fig. 7. $C_1(t)$, as shown in Fig. 7 can be expressed as Eq. 4. Here, d_k represents the distance error between the current vehicle positions while P_c and K_r indicate the heading angle modulation gain. K_r , which is determined by the rotational radius of the vehicle and the distance to P_p . Based on this, unmanned navigation of the 1/10 vehicle is conducted through lateral control. Also, the performance of the proposed lateral control algorithm is verified.

$$\theta_{r2}(t) = \theta_{r1}(t) + K_r \frac{\theta_{e1}(t)}{d_k(t)} \tag{2}$$

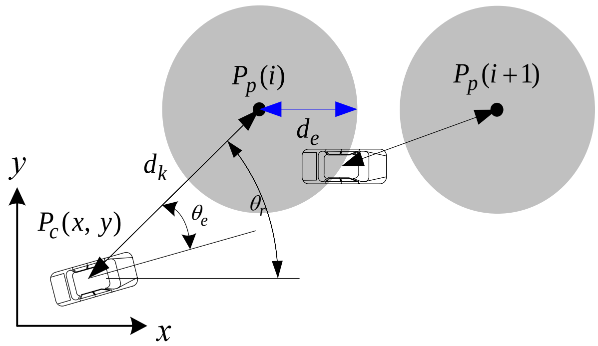

Fig. 6. Path planning, method and Lateral control algorithm

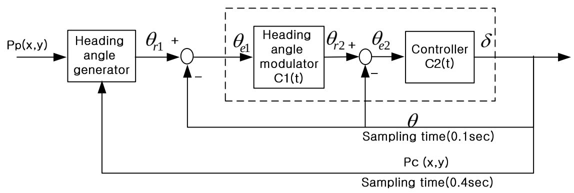

Fig. 7. Block diagram of feedback loop by using heading angle modulator

5 Unmanned navigation experiment

The lateral control experiment of the 1/10 vehicle is conducted in an indoor space with an area of 7000mm x 4000mm. Fig. 8 indicates the target route points $P_p(i)$ $(i = 1, \cdots, 20)$ of the vehicle. The points are located at an interval of 50 cm and the range of the target route points were set at 25 cm. In the unmanned navigation experiment, the first vehicle starts from the position of “5000, 3500”. The first target route point is set at the position of “2500, 3000”. While changing its target route points, the vehicle continues to move counterclockwise along the track at a constant speed of 400mm/s.

Fig. 8 shows the result of an unmanned navigation experiment using the existing PID controller. They indicate that the vehicle travels in a relatively stable manner along the target points, but it deviates varies the route from time to time. To overcome such a problem, a lateral controller equipped with a heading angle modulator is employed. The experiment result is shown in Fig. 8. The experiment include the heading angle modulator, the vehicle follows the track well within an error range of 250mm, which is the range of the target route points. The lateral errors of the experiments are shown in Fig. 24. In the case using the existing PID controller, the maximum error is 336mm and the average error is 109mm. The case include the heading angle modulator, however, the maximum error fell to 240mm and the average error to 61mm. The latter represents much more stable performances than the former. Its driving performance can be said to be stable since the maximum error range is below 250mm. Through the unmanned navigation experiment, this study can confirm that unmanned navigation was (is) possible with the application of the U-SAT and that the performance of the lateral control algorithm added with a heading angle modulator was better than that of the (the) existing method. In addition, the algorithm verification was conducted easily with the use of the 1/10 vehicle.

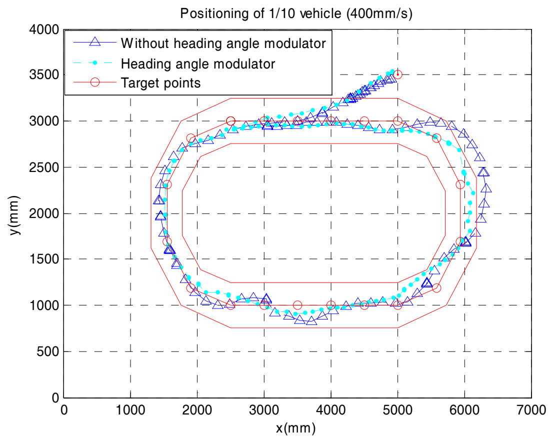

Fig. 8. Experiment result of unmanned navigation

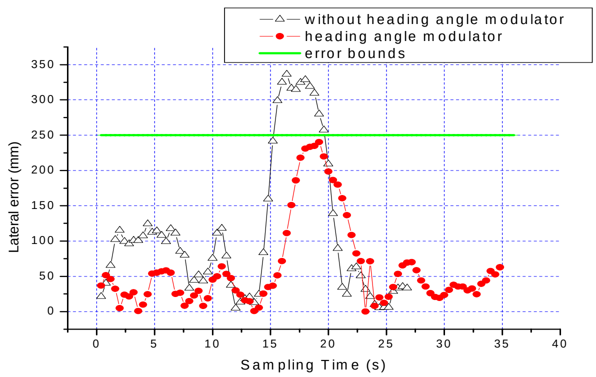

Fig. 9. Experiment result of lateral errors

6 Conclusion

While overcoming the shortcomings of the existing positioning methods, this study suggests an U-SAT which enables precise positioning indoors, in addition to the configuration of the system. Based on this, the study used the U-SAT which is needed for the unmanned navigation of vehicles. In addition, this study has developed an unmanned navigation system for a 1/10 vehicle and propose a new lateral control algorithm which is suitable for the system. Also, we have applied the algorithm and evaluated the performances. Based on the experiment results, this study has verified the appropriateness of the proposed lateral control algorithm, making it possible to conduct more stable unmanned navigation. In addition, the 1/10 vehicle developed with the unmanned navigation system has removed the risks that can be found in actual vehicle experiments. As this vehicle enables various tests in an easier and more convenient way, it could be used as a pre-test vehicle applicable before actual car tests. With respect to the research challenges to be addressed in the future, the U-SAT shows rather large errors for high-speed vehicle driving and therefore, further research will be necessary on this matter.

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