The Development of Obstacle Avoidance Algorithm for Unmanned Vehicle Using Ultrasonic Sensor

Whan-Sin Yu*, Woon-Sung Lee**, and Jung-Ha Kim***

* Graduate School of Automotive Engineering, Kookmin University, Seoul, Korea
(Tel : +82-2-916-0991; E-mail:hansin_yu@hanmail.net)
** Graduate School of Automotive Engineering, Kookmin University, Seoul, Korea
(Tel : +82-2-910-4712; E-mail: wslee@kookmin.ac.kr)
*** Graduate School of Automotive Engineering, Kookmin University, Seoul, Korea
(Tel : +82-2-910-4715; E-mail: jhkim@kookmin.ac.kr)

Abstract: Obstacle avoidance algorithm is very important on an unmanned vehicle. Therefore, in this research, we propose a algorithm of obstacle avoidance and we can prove through vehicle test and sensor experiments. Obstacle avoidance must be divided into two parts: the first part includes the longitudinal control for acceleration and deceleration and the second part is the lateral control for steering control. Each system is used for unmanned vehicle control, which notes its location, recognizes obstacles surrounding it, and makes a decision how fast to proceed according to circumstances. During the operation, the control strategy of the vehicle can detect obstacles and perform obstacle avoidance on the road, which involves vehicle velocity. In this paper, we propose a method for vehicle control, modeling, and obstacle avoidance, which are confirmed through vehicle tests.

Keywords: Unmanned Vehicle, Lateral Control, Longitudinal Control, Obstacle Avoidance, Ultrasonic Sensor

1. INTRODUCTION

The unmanned vehicle is composed of three parts: The first, the front & side sensor system for keeping the lane and avoiding obstacles, Secondly, the acceleration & brake control system for longitudinal motion control, and third, the steering control system for the lateral motion control. Each system helps the unmanned vehicle to locate and recognize obstacles around the place by itself and make a decision how much fast to proceed according to circumstances. During the operation, the control strategy that the vehicle can detect obstacles and avoid collision on the road involves with vehicle velocity very much. Therefore, we have to define a traction system which is powered by DC motor so that, unmanned vehicle can control its velocity accurately.

In this paper, chapter 2 explains about the vehicle control system of an unmanned vehicle, which it is included in longitudinal control and lateral control. And chapter 3 explains sensor system of an unmanned vehicle. Chapter 4 explains the test evaluation and algorithm. Finally, in this paper, we present vehicle modeling for the traction and the steering control and it is included in obstacle avoidance algorithm.

2. VEHICLE CONTROL SYSTEM OF UNMANNED VEHICLE

2.1 Longitudinal control

In this paper, the longitudinal control of a vehicle is operated by a motor control. The motor driving system is controlled by the input voltage to the motor by digital signal processing and conversion to an analog signal via a D/A converter [1].

The vehicle's velocity is calculated from the wheel rotation, which is measured by counting a Hall sensor signal. The velocity data use total vehicle moving distance calculation, which also is used as a velocity profile for path planning. Consequently, the vehicle velocity and distance are calculated from the wheel rotation counter.

In the research, we used the DC motor modeling for vehicle control of longitudinal distance. It directly provided rotary motion and, coupled with wheels or drums and cables provided transitional motion. The electric circuit of the armature and the free body diagram of the rotor are shown in Fig. 1 [2-3]. The control objective was determined by vehicle velocity and safe distance maintenance [4].

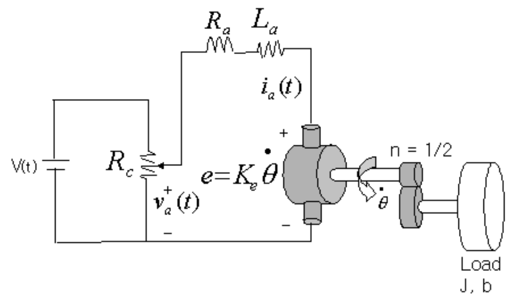

Fig. 1 Wire model of driving system

The armature voltage of the motor-electro approval, v_a (t) is controlled proportionally to the source voltage *V (t)* of the equal circuit, where i_a (t) is the armature current, R_a is the electric resistance, L_a is the electric inductance component of the electric windings, and *e* is a counter-electromotive force conduction of electricity while the motor is rotating. From the figure above we can write the following equations based on Newton's law combined with Kirchhoff's law. The torque *T* can be written, as in Eq. 1, where *J* is the moment inertia of the motor, *b* is damping ratio of the mechanical system, and k_t is the armature constant.

$$T = k_t i_a = J\frac{d\dot{\theta}}{dt} + b\dot{\theta} = J\ddot{\theta} + b\dot{\theta} \tag{1}$$

2.2 Lateral control

The steering actuator for accurate steering control uses a stepping motor, which uses a timing belt to connect with the steering column.

The steering torque of the steering column is estimated by a torque measurer, which required about 20[Kg·cm]. This stepping motor torque is controlled by a 10:1 reduced gear ratio. The experimental results show that total steering angle is 1080 degrees and the total number of pulses is 12,000. So, factor (α) of the relationship input pulse and the steering angle is defined as

$$\alpha = \frac{360^{\circ}}{4000}[\deg/pulse] = 0.09[\deg/pulse]$$
$$\frac{1}{4000}[rev/pulse] = 0.00025[rev/pulse] \qquad (2)$$

In Eq. 2, we know the maximum resolution is about 0.18 degree.

Also, we use the bicycle model, which is used for a precise and improved steering system of an unmanned vehicle. We considered that the vehicle has to disregard the rolling motion on normal road conditions and driving constant velocity. If the vehicle, moving on a flat road, has acceleration on the lateral side, the acceleration occurs about the normal direction and the wheel has acceleration, which is the cornering force [5-6]. Fig. 2 shows the dynamic motion parameters of the steering system, which is expressed as the coordinate system for the bicycle model.

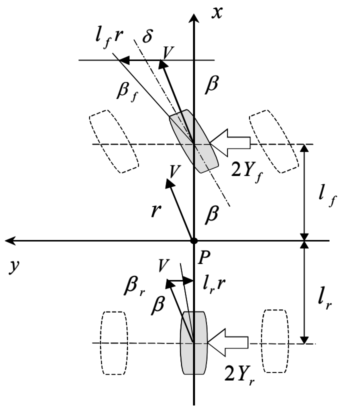

Fig. 2 Bicycle model for steering system modeling

If it is assumed that the steering angle of all the front wheels about the vehicle position is δ , the front and rear bilateral wheel sideslip angles of each tire is β_{f1}, β_{f2}, β_{r1}, β_{r2}, and the cornering forces of the tire are Y_{f1}, Y_{f2}, Y_{r1}, Y_{r2} [7-8].

The cornering force of the front and rear tires is assumed to be K_f and K_r. The sideslip angle is positive and applied in a negative direction from the y axis. From the figure above we can write the following equations about bicycle modeling.

$$mV\frac{d\beta}{dt} + 2(K_f + K_r)\beta + \{mV + \frac{2}{V}(l_f K_f - l_r K_r)\}r = 2K_f\delta \qquad (3)$$

$$2(l_f K_f - l_r K_r)\beta + I\frac{dr}{dt} + \frac{2(l_f^2 K_f + l_r^2 K_r)}{V}r = 2l_f K_f\delta \qquad (4)$$

From Eqs. (3) ~ (4), we can lead to motion equation of vehicle yawing angle acceleration.

3. SENSOR SYSTEM OF AN UNMANNED VEHICLE

It is focused on the sensor fusion and sensor system identification. Especially, longitudinal and lateral control with sensory system is fulfilled. The monitoring of vehicle motion acquires information about position, velocity, heading angle and some environmental data, coming from several sensors. Acceleration sensor, ultra sonic sensor and gyro sensor output the analogous voltage, because these sensors detect physical terms as like, acceleration, angle and sound, etc. So these data should converted to digital data by A/D converter. Fig. 3 shows the principle of the time variable gain amplifier and the functional diagram of the ultrasonic sensor [9].

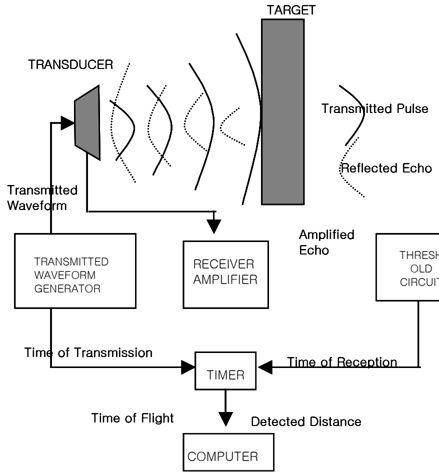

Fig. 3 Functional diagram of the ultrasonic sensor

4. TEST EVALUATION AND ALGORITHM

Obstacle detection and avoidance experiment estimation are one of the foremost experiments in unmanned vehicles. Generally, the ultrasonic sensor is one of the range sensors, which can measure a distance to objects, and it is more commonly used with an unmanned vehicle and mobile robots because it is small, inexpensive, and it is easy to calculate the object's distance. In this paper, we used the ultrasonic sensor made by the Senix Company (ULTRA-U) [10]. We attached sensors on both sides and front in the vehicle for characteristic analysis and a collision avoidance test. They can detect the front and side objects.

The first experiment stage is environment detecting by the corridor and finding the center position of bilateral wall of the ultrasonic sensor. The test result of the ultrasonic sensor shows in Fig. 4, and it shows average distance values from the centerline of the corridor to the wall and the sensor error rate from the centerline to the wall.

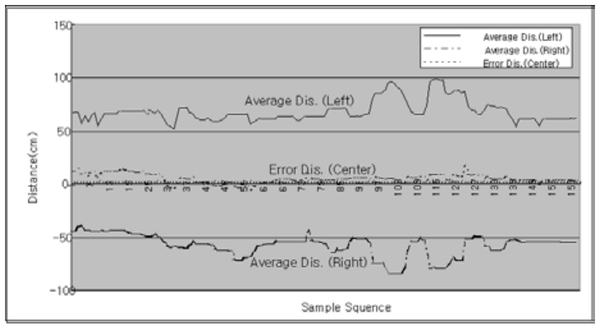

Fig. 4 Ultrasonic sensor experimental result in corridor [average and error rate]

Fig. 5 is shown comparision of the test result values of the ultrasonic sensors. Four sensors are used for this experiment. Two of those are mounted in front and others are rear of both sides. Each of the sensor's signal measures a distance between the vehicle and corridor wall, and each curve shows a state of the corridor wall. We know from the results that it is only a small-time delay and it shows a similar trend from the sensor signal.

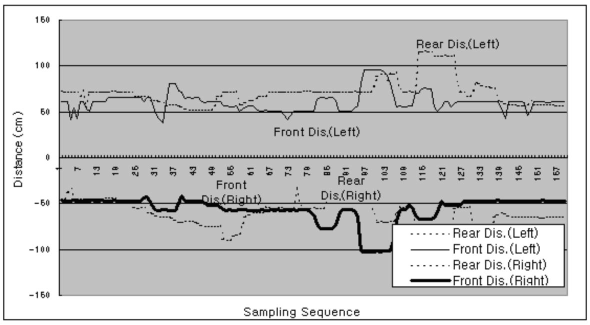

Fig. 5 Ultrasonic sensor experimental result in corridor [compare sensor signal]

As the result of another experiment, Fig. 6 compares the test results of S-turn driving under the same conditions. We know from the results that it is only a small-time delay and it shows a similar trend from the sensor signal.

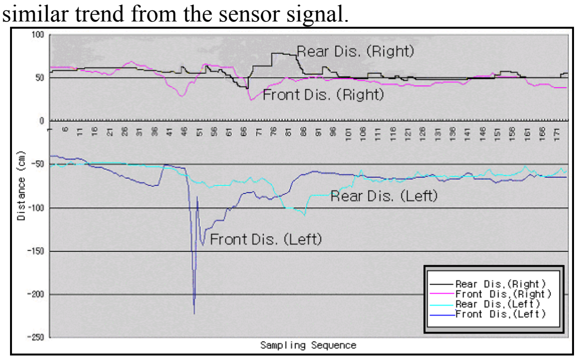

Fig. 6 Ultrasonic sensor experimental result in corridor [compare sensor s-turn signal]

The experiment concerns the object avoidance method of an ultrasonic sensor. Fig. 7 shows the test environment on the road, which has an obstacle in the front.

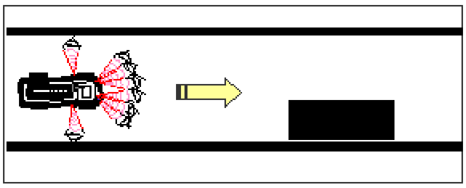

Fig. 7 Environment of road, which has an obstacle in the front

Figs. 8 ~ 9 show the method of the obstacle avoidance in the Fig. 7 condition.

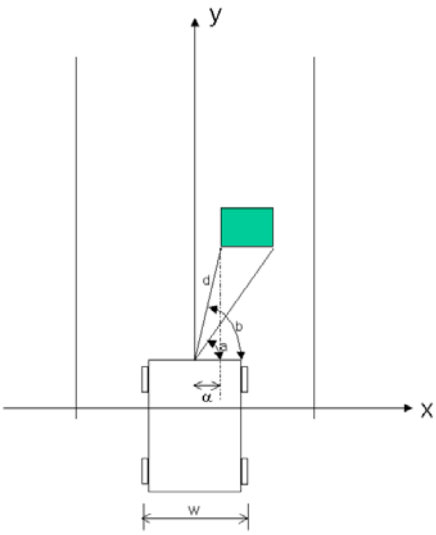

Fig. 8 Obstacle on the right of the vehicle

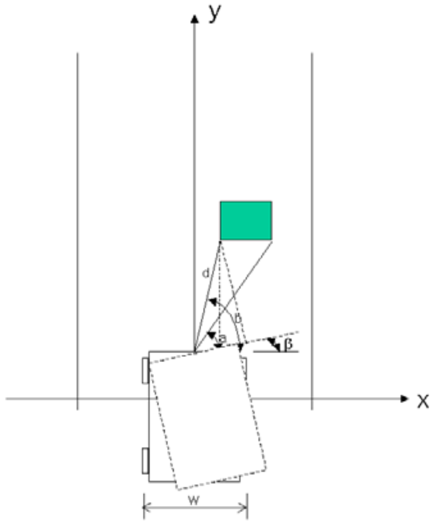

Fig. 9 Obstacle avoidance by turning an angle (β)

If obstacle on the right of the vehicle, it is described as following step. (condition, a<90° and b<90°)

(1) Check if vehicle can maintain same path and avoid obstacle without offsetting the centroid of the vehicle from the center of the track.

(2) $\alpha = d * Cos(b)$ and $\alpha > \frac{1}{2}w$ it can continue on straight path without offsetting vehicle centroid.

(3) When $\alpha = d * Cos(b)$ and $\alpha <= \frac{1}{2}w$ Calculate steering angle (β) that the vehicle has to turn such that $\alpha new = (\frac{1}{2}w + safety\ \ factor)$ where safety factor =1ft.

(4) Vehicle starts turning left and continues turning left till $d * Cos(b - \beta) = \alpha new$ and β is the steering angle vehicle has turned from its original position.

(5) The vehicle now starts to turn right to maintain its centroid along a path parallel to the centerline of the track and offset by a distance of $\alpha new - \alpha old$.

(6) Thus the hugging distance (the distance of the vehicle from the centroid of the road followed) is calculated as the previous hugging distance ± the offset.

Figs. 10 ~ 11 show the display software to detect an obstacle and the result of the path planning, which see all the necessary information about the object, such as size, data, and environment (road) profile.

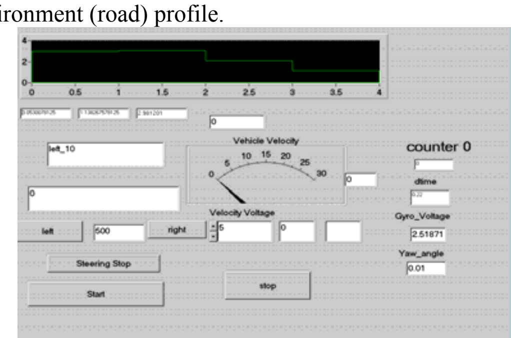

Fig. 10 Display of detecting obstacle and avoidance

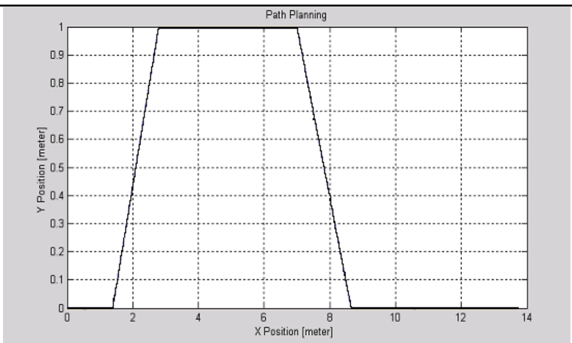

Fig. 11 The experimental result of the path planning

Fig. 12 shows the vehicle is vehicle's yaw angle of interpolation for obstacle detection or collision avoidance, and it shows spline graphics by gyroscope and ultrasonic sensor input data.

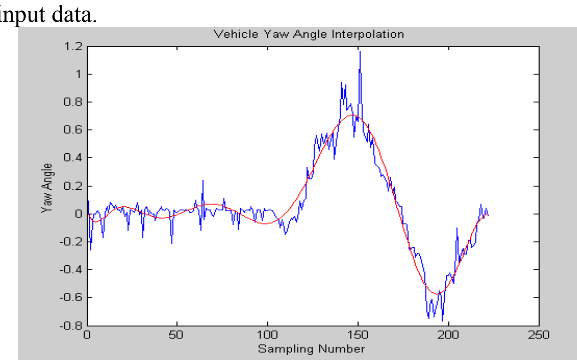

Fig. 12 Interpolation curve result of yaw angle

Figs. 13 ~ 14 show the algorithm of the obstacle avoidance and comparison between vehicle position and path planning according to the vehicle driving.

From figure 14, we knew that it is similar trend of the vehicle trajectory and path plan. Also, steering control law of the vehicle for obstacle avoidance shows through the algorithm flowchart.

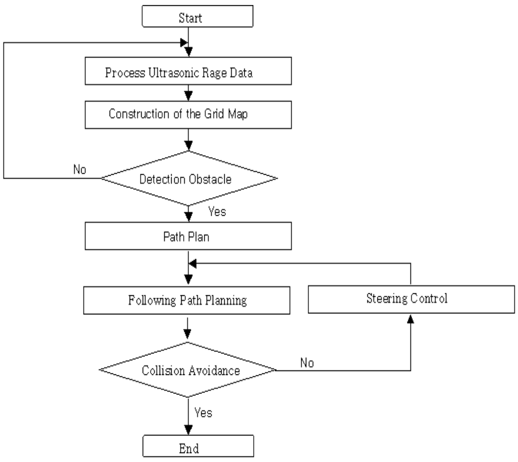

Fig. 13 The flowchart of the obstacle avoidance algorithm

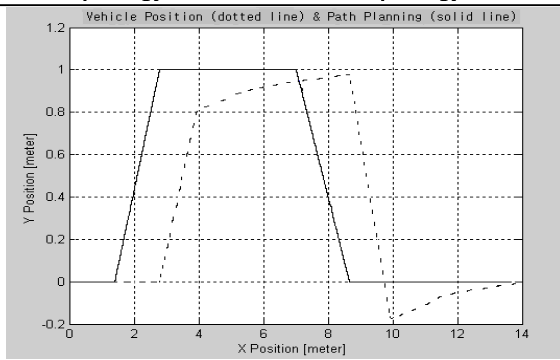

Fig. 14 Comparison between vehicle position and path planning

The vehicle is yaw angle interpolation versus the steering input graphic is shown in Fig. 22. The interpolation curve by gyroscope and ultrasonic sensor input data is the reverse of the steering input data curve. Fig. 23 shows the collision avoidance trajectory for an unmanned vehicle in the Figure 14 condition, which used an ultrasonic sensor and laser scanner algorithm for reducing the calculation time and error rate. The vehicle trajectory of collision avoidance is larger than the minimum radius of the target trajectory because the ultrasonic sensors and laser scanner are giving an unstable signal output on the vehicle experiment. This problem can be solved by using ultrasonic sensor signal filtering and developing the more advanced control algorithm, such as PID control and fuzzy logic.

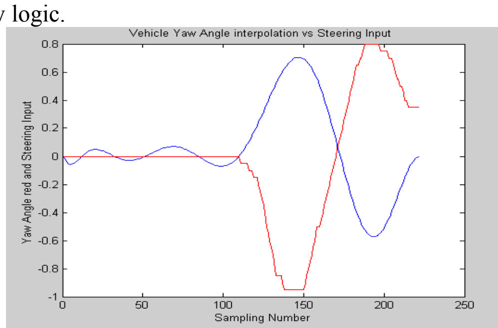

Fig. 15 Vehicle yaw angle interpolation versus steering input

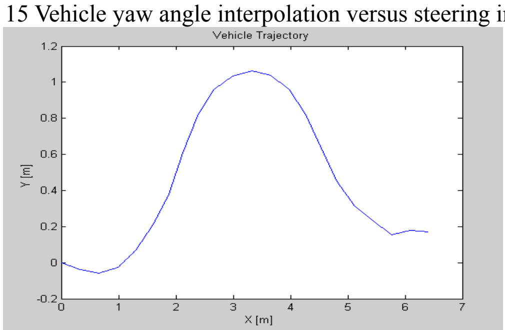

Fig. 16 Vehicle trajectory of collision avoidance

5. CONCLUSION

In this research, we showed the modeling and design analysis of a utility unmanned vehicle system for autonomous vehicle control. The designed unmanned vehicle system can be operated by sensors, actuators, and possibly a controller, as well as a stationary unit with a main computer and a remote control station.

In longitudinal control, we showed the modeling, design, and simulation of DC motor.

In lateral control, the vehicle is controlled by a gyroscope and an ultrasonic sensor, and PID control was designed for reducing a steady-state error, rising time, and overshoot in a velocity control of the vehicle's traction system. We showed the analysis and experiment of the gyroscope's character used for lateral control of vehicle, and the steering system was modeled and controlled through experimental parameter tuning. The performance of the system was evaluated through a simulation program. Also, we showed the analysis and signal process of an ultrasonic sensor character used for lateral control of the vehicle and ultrasonic sensors for obstacle detection and collision avoidance. For more precise control, analysis and signal process require a variable experiment method and algorithm development, which will be used for advanced lateral control. This research on obstacle detection and avoidance can be used in places where humans cannot go. This could have a military application: a robot could go in a minefield where it would be very dangerous for humans.

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