STEERING CONTROL SYSTEM FOR AUTONOMOUS SMALL ORCHARD SPRAYER

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ABSTRACT

For self-guiding track-type orchard sprayer, a low-cost steering controller was developed using two ultrasonic sensors, two DC motors and 80196kc microprocessor. The operating principle of controller was to travel the sprayer between artificial targets such as wood stick placed every 1m along both sides of the demanded path of speed sprayer. Measuring distances to both targets ahead with the ultrasonic sensors mounted on the front end of sprayer, the controller could determine how much offset the position of sprayer was laterally. Then the steering angle was calculated to actuate DC motors connected to the steering clutches, where the fuzzy control algorithm was used.

Equipped with the controller developed in this research, the sprayer could be traveled along demanded path, the centerline between targets, at speeds of up to 0.4m/sec with an accuracy of ± 20cm.

Key Word : steering control system, track-type orchard sprayer, autonomous travel, ultrasonic sensor, artificial target

INTRODUCTION

The chemical application is essential process for the agricultural production, but it is one of the most dangerous agricultural works. Especially in the domestic vineyard or the tangerine farm in Cheju island the farmer can not avoid the chemical exposure during the work, because the working area is narrow and closed space like tunnel due to tree canopy. Therefore, it was needed to work autonomously.

For the autonomous work, first above all, the autonomous travel technology is required and many research works have been done in the area of agricultural engineering as well as robotics engineering. This technology developed domestically and internationally has some merits and demerits, and can be used in very limited condition. There are several methods in the autonomous travel. One is to have the sprayer follow special indication or mark such as buried induction cable [Jang et al.(1995)] and guidance pipe [Kim et al.(1999)]. Another one is to determine the travel path by recognizing the environment with machine vision and acoustic sensor [Cho et al.(1996)] or by using GPS

[Cho et al.(1997)]. However, these methods might be inappropriate for some types of farms because the former one needed to build some kinds of fixed device or facility in the farm, and the latter one was expensive and might be useless in the closed working space as well.

This study was intended to develop the autonomous travel system for small-size sprayer, which was small enough to be used in such narrow and closed working space. Also the cost of system was seriously considered not to increase the total price of sprayer itself. This system consisted of 80196kc microprocessor, two ultrasonic sensors, two DC motors and steering control algorithm, and designed to be adopted into the commercial sprayer without large modification. The operating principle of this autonomous travel system was to move the sprayer between the portable markers such as wood stick, placed every 1 m along both sides of demanded path of speed sprayer. By measuring distance to targets with two ultrasonic sensors, the microprocessor could calculate desired steering angle.

The developed system was equipped on small track-type sprayer and the performance of autonomous travel was evaluated. The specific purposes of this research were as follows.

1) to develop distance measurement system with ultrasonic sensor and microprocessor,
2) to develop interface circuit for DC motor as an actuator,
3) to develop fuzzy control algorithm for the steering control,
4) to evaluate system performance in the field.

MATERIALS AND METHODS

Orchard sprayer

The specification of sprayer used in the experiment was presented in Table 1. The steering in this sprayer could be done by manually pulling left- or right-side cable connected to each steering clutch lever. This is two stages clutch, and the first stage is disengaging clutch while the second stage is braking for minimum radius of steering. For autonomous travel these cables were replaced by two DC motors and gear sets, which could be controlled by the microprocessor.

Table 1. Specifications of orchard sprayer

Engine		3.5 HP, air cooling
Body	Length	2.0m
	Width	0.7m
	Height	1.0m
Clutch		V-belt
T/M		HST
Steering clutch		jaw-type
Travel equipment : 2 rubber track		width : 0.18m, length : 2.2m

Controller

1. Distance measurement system

Acoustical Transducer and 6500 series Sonar ranging module(Polaroid, U.S.A.) were used as the ultrasonic sensor to measure distance to target. Initiated by HSO signal from 80196kc microprocessor, the ranging module sent out echo signal when the ultrasonic transducer received the ultrasonic wave reflected from the target. The interrupt occurred by echo signal stop running the timer initiated by init signal (HSO output). This time difference between init and echo signals is the elapsed time which ultrasonic wave round trip to target, and the distance to target becomes half of the propagation speed of ultrasonic wave in air multiplied by the elapsed time.

Two HSO ports were used to initiate two ultrasonic sensors and two echo signals from each ranging modules were OR-gated to be input to P2.2/ExtInt pin. Therefore, two ultrasonic sensors could measure distance to target sequentially.

For the system calibration the digital counts as the elapsed time were measured as the flat surface target perpendicular to the ultrasonic sensor moved from 50cm to 250cm. Linear regression result showed 0.9989 of R^2 and the following calibration equation could be obtained.

$$Y = 0.0137\,X - 0.6602$$

where, X : digital counts (in decimal)

Y : range(cm).

2. DC motor interface

Two relays on one DC motor were used to control the direction of revolution of DC motor. Fig. 1 showed the interface circuit for the DC motor with the microprocessor. Some photocouplers were used to block the microprocessor from the motor driving part to remove any possible noise effect on the microprocessor. Also the response of relay coil was slower than the motor activation signal from the microprocessor, and the motor driving circuit might be short at the time of switching. 74LS154(decoder) was used to eliminate the possibility of short circuit and the relay interlock circuit was constructed as well.

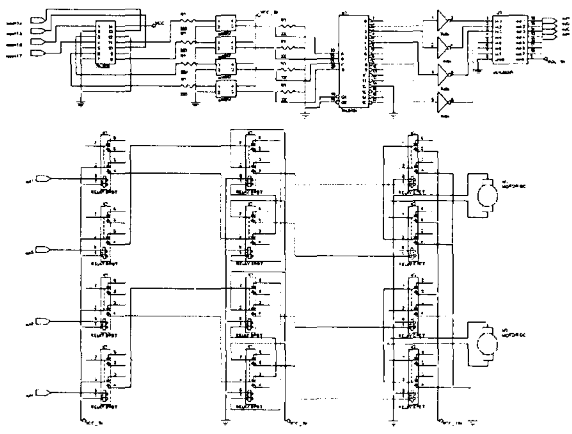


Fig. 1 Motor interface circuit.

Data processing algorithm

The ultrasonic sensor on sprayer would receive noise-like signal because of high frequency of engine vibration. In addition, there were many false data caused from weeds and irregular unpruned tree. These kinds of data shown in the form of spike could affect the steering control seriously. To remove the noise, the data processing algorithm was developed.

If the sprayer goes straight at constant speed and the ultrasonic sensor keeps measuring distance to target continuously, the quantity of change in the sequence of data acquired must be maintained constant. That is, the difference between the previous data and the current data maintained constant. The preliminary test showed that the above difference was satisfied within a certain range. Supposed that the data sequence was represented as $\{x_1, x_2, x_3, \ldots, x_{n-1}, x_n, \ldots\}$, and the difference between data values $\{d_1, d_2, d_3, \ldots, d_{n-1}, d_n, \ldots\}$, the following equation should be satisfied.

$$|d_n| = x_n - x_{n-1}$$
$$|d_n| \leq k \; |d_{n-1}|$$

where, k is the gain. If the new data value is not satisfied the above conditional equation, this data might be wrong. Thus, it is replaced by the previous one. Otherwise, this new data updates the current data. From the preliminary test result, the conditional equation was $|d_n| \leq$ 10cm at ground speed of 0.3m/sec. Also, if the conditional equation is satisfied referred to wrong first data, the current data is continuously updated by wrong data. It was, therefore, necessary to set new initial data after 4 data values were processed.

Steering control algorithm

The steering control was based on the principle that the path of speed sprayer is the centerline between rows of targets placed on both sides of demanded path. Since the jaw clutch and the gear set with DC motor took around 450 msec for being disengaged and re-engaged, respectively, the sprayer could not proceed and only turn the direction at the moment of disengaging clutch. The sprayer would keep turning as long as the clutch maintained at the state of disengagement. After then, the clutch should be re-engaged to proceed a certain amount of distance to complete the steering action. If the direction of sprayer is no longer parallel with the imaginary line of target rows, however, the sprayer might lose the information about target. Therefore, after proceeding a certain amount of distance, the sprayer should be turned opposite direction by same amount of steering angle, as shown in Fig. 2.

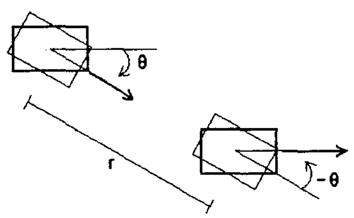


Fig. 2. Proposed scheme of steering action.

The steering angle, θ and the distance proceeded, r could be determined as

$$\theta = k_1\, v(t)\, T_{c1}$$
$$r = k_2\, v(t)\, T_{c2}\,.$$

where, k_1 and k_2 are gain, T_{c1} and T_{c2} are control time and $v(t)$ is ground speed.

In this research, the steering angle θ was fixed by setting the control time for turning constant, as presented at Table 2, and only the value of r was controlled.

Table 2. Control time setting on order of steering action

Order of Steering action	control time (sec)	Remark
Disengaging	0.45	time for disengaging
time delay, T_{c1}	0.1	time for maintaining disengagement
Re-engaging	0.45	time for re-engaging
time delay, T_{c2}	fuzzy output variable	time for proceeding

The fuzzy logic controller (FLC) was used to get r value. The left-side and right-side distance data measured by the ultrasonic sensors were input to the data processing routine and the error, defined as the following, was calculated.

$$\text{Error} = S_L - S_R$$

The error was used as an input variable to FLC. If Error = 0, it was not needed to operate the clutch. If Error > 0, the sprayer should be turned left. Otherwise, the sprayer should be turned right. After turning the head of sprayer, the proceeded distance depended on the control time, T_{c2}, which was the output variable of FLC. The membership function of input variable and output variable were shown in Fig. 3.

The allowable deviation of path from the centerline between target rows was set within ±20cm. The trajectory of mid point of speed sprayer rear end, where the spraying nozzle located, was used as the reference for determination of deviation.

Through the fuzzification, the error calculated the fitness measure, *u(E)*. The Max-Min method was used as the fuzzy inference engine and the Center of Gravity method was used as the defuzzification [Lin and Lee(1996)].

$$u^* = \frac{\sum_{i=1}^{N} u_i\, u_{out}(u_i)}{\sum_{i=1}^{N} u_{out}(u_i)}$$

where, u_i indicated the fitness measure, u_{out} (u_i) indicated the fuzzy output, and u^* represented the crisp value of fuzzy output.

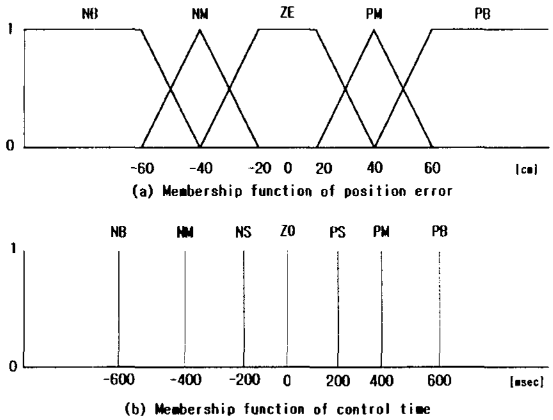


Fig. 3 Fuzzy membership function.

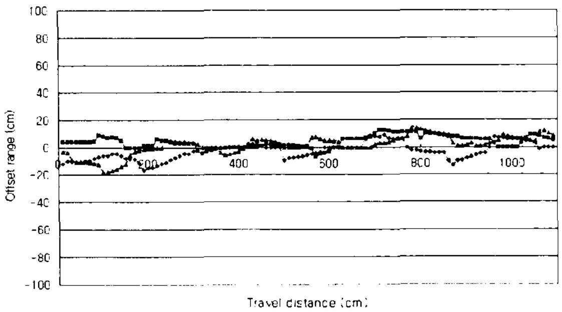
Experimental method

The performance of developed system was evaluated on flat surface, where the portable targets placed every 1 m on both sides of demanded path, and the width of path was 2m. This trial was limited to the straight path. The portable targets were made of 1"x1" wood stick and its height was 1m.

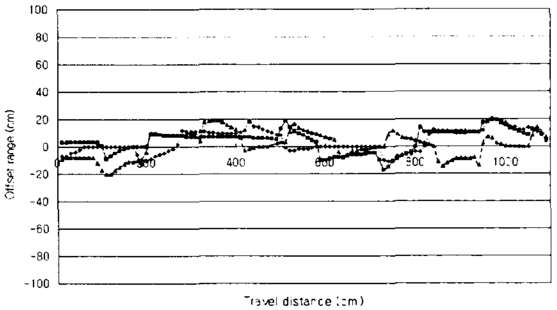
Total distance the sprayer traveled was 11m and the levels of ground speed were 0.3m/sec, 0.4m/sec, 0.5m/sec. The trajectory of mid point of sprayer read end was measured every 10cm along true path and the deviations were calculated and represented in RMS value. Each trial was replicated 3 times.

RESULTS AND DISCUSSION

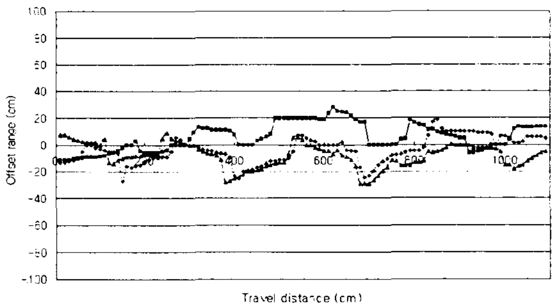
The results of performance evaluation were shown in Fig. 4. The deviation increased as the ground speed increased. This was the reason why the steering angle in the developed system was dependent on the ground speed. For the same amount of time, the total steering angle increased as the ground speed increased at the fixed value of control time T_{c1}. As long as the ground speed did not exceed 0.4 m/sec, the speed sprayer could travel within the allowable deviation. The average RMS errors on different ground speeds were presented in Table 3.



(a) travel speed : 0.3 m/sec



(b) travel speed : 0.4 m/sec



(c) travel speed : 0.5 m/sec

Fig. 4 Real travel path of sprayer with fuzzy algorithm.

Table 3. RMS errors on different travel speeds

	0.3 m/sec	0.4 m/sec	0.5 m/sec
Rep. 1	6.54	8.88	10.53
Rep. 2	5.75	8.91	11.81
Rep. 3	6.97	9.39	12.00

(Unit : cm)

CONCLUSIONS

For the automation of chemical application in narrow and closed working space such as vineyard and tangerine farm, the steering controller was developed and its system performance was evaluated with small-size track-type sprayer. The controller consisted of two ultrasonic sensors, two DC motors, 80916kc microprocessor and the steering control algorithm.

The research results were summarized as follows:

1) The distance measurement system was developed using two ultrasonic sensors, driven by 80196kc microprocessor.
2) The interface circuit to operate DC motor robustly was developed.
3) The steering control algorithm was developed using the fuzzy logic. In addition, the data processing algorithm was developed to eliminate some false information to affect the steering control.
4) The field trial showed that the sprayer could travel at speeds of up to 0.4 m/sec with an accuracy of ±20cm.

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