Autonomous SpeedSprayer Using Fuzzy Control

Seong In Cho	No Hoon Ki	Jae Hoon Lee	Chang Hyun Choi *
Associate Professor	Research Assistant	Research Assistant	Associate Professor

Department of Agricultural Engineering
Seuol National University
Suwon, Korea, 441-744
E-mail : sicho@plaza.snu.ac.kr

* Department of Bio-mechatronic Engineering
Sung Kyun Kwan University

ABSTRACT

Autonomous speedsprayer operation in an orchard was conducted using a fuzzy logic controller(FLC). Orchard image analysis and signals of ultrasonic sensors were processed in real time. The speedsprayer was modified to be steered by two hydraulic cylinders. The FLC has two inputs of direction of running and distance from obstacles. Operation time of the hydraulic cylinders were inferred as output of the FLC. Field test results showed that the speedsprayer could be autonomously operated by the FLC along with the image processing and the ultrasonic sensors. The ultrasonic sensors didn't contribute to the improvement of guidance performance, but the speedsprayer could avoid trees or obstacles in emergent situations with them.

Keyword : speedsprayer, simulation, autonomous operation, fuzzy logic control, image processing, ultrasonic sensor

INTRODUCTION

The traditional method to protect man from agri-chemicals has been done with protective gears. Farmers couldn't be free from the agri-chemicals, though. Agri-chemicals also have the characteristics penetrating into skin immediately. Safe spraying operation is crucial for farmers health. The best way is to operate the sprayer autonomously in a field.

Blackmore et al.(1993) steered the mechanical weeder using intelligent sensing and self organizing fuzzy logic technique. Kamada et al.(1992) tested the autonomous operation of low speed vehicle using color image processing and fuzzy logic. Smith et al.(1993) and Toda et al.(1993) used fuzzy logic in mechanical weeder and agricultural vehicle, respectively. In these papers, fuzzy logic was used because agricultural environment deals with ambiguous information. Mathematical modeling isn't necessary with the fuzzy logic and the system can be controlled with simple fuzzy rules.

To operate autonomously a speedspryaer in an orchard, an algorithm to detect direction of running and obstacle avoidance technique and a fuzzy controller for unmanned operation are to be developed.

METHOD AND MATERIALS

Structure of Autonomous Guidance System

Autonomous guidance system is drawn in figure 1. The information from both image processing and ultrasonic sensing were used as the inputs of the FLC. The direction of running is found by the image processing and the distance between the obstacle and speedsprayer is found by the ultrasonic sensors. A Korean speedsprayer was used for a test model. It has the dimension of $3180 \times 1255 \times 1275$ mm (length×width×height) with 3 pairs of wheels and is steered by two levers.

PC Vision plus Frame Grabber(Image Tech. Co., USA) and a black and white CCD camera were used. The frame grabber has resolution of 512×512 pixels and offers various image processing functions which can be compiled with MSC.

The sequence of image processing is in figure 2. Firstly, acquired image was compressed to 128×128 pixels. Vertical components in the compressed image were enhanced using Prewitt mask and the vertical edges were detected using Sobel mask. Edge detected image was binarized with the magnitude and direction by Sobel operation. The vertical direction histogram of binarized image was made to detect the direction of running. In the histogram, the lowest valley implied the direction of running. It took 1.2 second per one image to process the whole image processing.

The speedsprayer was steered by two hard levers. A hydraulic system is used to steer automatically. The hydraulic system is shown in figure 3. It was composed of two bi-directional hydraulic cylinders, two 3-port-4-way direction control valves, one relief valve, and a hydraulic pump. Solenoid valves were used in the direction control valves to control hydraulic cylinders with the FLC signals. Intel 8255 and relays were used as a I/O interface.

Four ultrasonic signals were used as the inputs of the FLC. A circuit was designed to drive the ultrasonic sensors 50kHz, 15~1050cm range and for distance measurement. Transmitting and receiving units were integrated in one body. The range of distance measurement in an orchard was 4~5 m. To simplify the circuit, the 8255 for counting units and relays for hydraulic cylinders were arranged in one PCB.

Fuzzy Logic Controller

The direction of running and four ultrasonic signals were used as the inputs of the FLC. Operation time of the hydraulic cylinders is the output of the FLC. The left and right hydraulic cylinders were operated separately and had different linguistic variables.

The linguistic variables and membership functions for the direction of running, ultrasonic signals and operation time of hydraulic cylinder are figures 4, 5 and 6. The negative values in figure 6 are the operation time of the left hydraulic cylinder and the positive values are the operation time of the right hydraulic cylinder. Total number of fuzzy rules were thirteen.

An example of the rules is shown in Table 1. The conditions in If clause represent the linguistic variables, DC(Don't Care) means that it doesn't matter. The direction of running is located in right side and the first ultrasonic sensor detects the obstacle not far from the speedsprayer. Then, the FLC infers Pull the right hydraulic cylinder for the short period of time and release it. The spreedsprayer turns a little to the right as a result.

RESULT AND DISCUSSIONS

Evaluation of Guidance Performance

To evaluate the guidance performance, an ideal path was compared with the path produced by FLC(Kehtarnavaz et al.(1991), Li et al.(1994)) and RMS(root mean square) was calculated to represent the error produced. This is below in equation (1).

$$RMS=\sqrt{\frac{\sum(deviation)^2}{(number\ of\ data)}} \qquad (1)$$

where, deviation : difference between ideal path and FLC path

number of data : number of data collected

The other method of evaluating performance is considered. The area between ideal path and FLC-made path were compared with the possible area in which the speedsprayer can run(figure 7). The possible area was 133 m^2 (3.8 m × 35 m). To evaluate the RMS values and the ratio of areas, 36 deviation points from the acquired path were collected in every 1m operation.

Autonomous Guidance in Graphic Simulation

As the input to the FLC, the direction of running was used in simulation. The control interval of hydraulic cylinder was 4 sec and 1.5 sec. Tables 2 and 3 show the RMS values and the ratio of areas. They had smaller values when the control interval is shorter. When the width of running was 5m, the maximum deviation was the 53cm at the control interval of 1.5 sec and it means that the speedsprayer could be operated within 21% of running width.

Modeling of Speedsprayer and Orchard

The simulation for autonomous speedsprayer guidance had the same conditions of a real orchard. The speedsprayer was modeled with equations (2), (3), and (4) (figure 8).

$$x(t+1)=x(t)-r\cdot\cos(\theta(t)+\varphi(t+1)) \qquad (2)$$

$$y(t+1)=y(t)-r\cdot\sin(\theta(t)+\varphi(t+1)) \qquad (3)$$

$$\theta(t+1)=\theta(t)+\varphi(t+1) \qquad (4)$$

where, θ : angle between centerline of speedsprayer and X axis (radian)

φ : steering angle (radian)

r : moving distance in one time step (m)

x : x position of speedsprayer (m)

y : y position of speedsprayer (m)

t : time (s)

To simulate the speedsprayer operation, the elapsed time(t) was calculated during each speedsprayer control action and was determined with the velocity multiplied by the elapsed time. The ground condition was considered to be flat and no slipping between wheels and ground was assumed.

The simulation speed were 1.6 km/h which was the same speed of real speedsprayer operation. The speedsprayer in simulation was set to the same direction and location as in the real test. Figure 9 shows the speedsprayer with one camera and 4 ultrasonic sensors. Figures 10 and 11 show simulations of the autonomous speedsprayer operation. Figure 10 is the simulation along a straight path and figure 11 is along a curved path.

In the simulation, the speedsprayer could be autonomously operated with the image processing algorithm and ultrasonic sensors. The performance when using the image processing only was worse than using both the image processing and the ultrasonic sensors in the control interval of 4.0 sec. But there was no significant difference at the control interval of 1.5 sec. The operation on a curved path was tested in the simulation and the autonomous operation was possible(figure 11). Speedsprayer turning was also simulated(figure 12). To find the turning point, obstacles such as trees were placed at the end of path. When the speedsprayer detected the obstacles near the end point as shown in figure 12, it turned right.

Autonomous Guidance in Real Operation

The speedsprayer was tested in an chestnut orchard, which is located in college of agricultural and life sciences, Seoul National University. The orchard was almost flat. The width of the speedsprayer running is 5m. The distances between the trees are 6m and the total length of speedsprayer running is 35m.

Figure 13 is the compressed image acquired in May 1995. The image was processed with the Prewitt mask and Sobel operator to enhance the vertical components. Figure 14 is the histogram of vertical direction from the binarized image and the direction of running is marked. As mentioned earlier, the lowest valley in the histogram is the direction of the running.

The vertical components near the direction of running are a little or rare, due to the perspective. Images were acquired in various seasons, times, and with shade of trees. Image processing algorithm could find the direction of the running in all cases.

Firstly, only the image processing results were used as the input. This could be done by setting the ultrasonic signals infinite and pretending that there were no obstacles. The real operation was conducted at the control interval of 4.0 sec and 1.5 sec. Tables 4 and 5 show the RMS values and the ratio of areas.

The RMS values and ratio of areas were smaller when the control interval is shorter as shown in the simulation. When the width of running was 5m, the maximum deviation was the 64cm at the control interval of 1.5 sec. It means the speedsprayer could be operated within 21% of running width. The shorter is the control interval, the performance is better. The FLC with the image processing results only can autonomously operate the speedsprayer.

Secondly, both image processing results and ultrasonic sensors signals were used as the inputs. The RMS values and the ratio of areas are in tables 4 and 5. The maximum deviation was 72cm at 1.5 sec of control interval and this is worse than when using the results of image processing only. This result was due to the wrong recognition of ultrasonic sensors under the long tree branches or leaves. RMS values and the ratio of areas are not quite different from the results of image processing only. The ultrasonic sensors didn't contribute to the improvement of guidance performance, but the speedsprayer could avoid trees or obstacles in emergent situations with them.

In the real operation, the shorter is the control interval, the performance is the better as shown in the simulation. When using both image processing results and ultrasonic signals, the results at the control interval of 4.0 sec were different from the simulation. However, at 1.5 sec, the trends were similar with the simulation. The weather, test time, the number of leaves caused noises in the image processing. The image processing algorithm alone couldn't find the direction of running exactly as a man did. However, this ambiguity was eliminated with the FLC.

Speedsprayer turning was tested. The speedsprayer could turn near the end of an orchard using electronic compass and ultrasonic sensors. When the speedsprayer reached the end, a rotary encoder sends signals to the controller to make turning. Two ultrasonic sensors located in front were used for input, and fuzzy rules for turning operation were applied. The radius of curvature for turning was set to 2.5m and the speedsprayer was set to turn right. The performance was evaluated by calculating the RMS value and area ratio. The method of evaluation is the same as the case of the straight path running. Data collection with the electronic compass used for calculating the direction angle was performed with serial interface. The result was shown in Tables 6 and 7.

SUMMARY AND CONCLUSIONS

In this study, a FLC was developed for the autonomous operation of speedsprayer. The FLC had two inputs ; direction of running and distance from obstacles. The operation time of hydraulic cylinder for steering was inferred as output of the FLC. To perform autonomous operation, a image processing unit, a hydraulic system, and four ultrasonic sensors were utilized. A black and white CCD camera with a frame grabber was used for the image processing. The speedsprayer modified to be steered by two hydraulic cylinders. Four ultrasonic sensors were installed ; two of them on the front of speedsprayer and the other two on the back of it.

To demonstrate the autonomous guidance of speedsprayer, it was simulated graphically under the conditions of a real orchard. The simulation proved that the speedsprayer could be operated autonomously with the image processing and ultrasonic sensors. With these results, the speedsprayer was tested on the real orchard. Field test results showed that the speedsprayer could be operated autonomously by the FLC along with the image processing and ultrasonic sensors. The ultrasonic sensors didn't contribute to the improvement of autonomous operation in straight paths, but the ultrasonic sensors prevented the speedsprayer from approaching to trees or obstacles. However, they could improve the autonomous operation in an orchard which has a curved path or where the speedsprayer makes turns at the ends of paths.

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Table 1. An example of fuzzy rules

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If
        [ Direction  = RT ] and
        [ US_Input_1 = MD ] and
        [ US_Input_2 = DC ] and
        [ US_Input_3 = DC ] and
        [ US_Input_4 = DC ],
Then
        [ Cylinder_Time = RS ]
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Table 2. RMS values as performance indices (graphic simulation) unit : cm

Cycling time	Number of trials	Image processing	Image processing and ultrasonic sensing
4.0sec	1	38.07	26.64
	2	24.52	25.61
1.5sec	1	22.93	23.14
	2	20.90	19.48

Table 3. Ratio of area as performance indices (graphic simulation) unit : %

Cycling time	Number of trials	Image processing	Image processing and ultrasonic sensing
4.0sec	1	7.81	6.21
	2	5.78	6.03
1.5sec	1	4.95	5.19
	2	4.61	4.39

Table 4. RMS values as performance indices (real operation) unit : cm

Cycling time	Number of trials	Image processing	Image processing and ultrasonic sensing
4.0sec	1	42.17	42.82
	2	52.62	44.76
1.5sec	1	38.39	33.26
	2	25.29	25.45

Table 5. Ratio of area as performance indices (real operation) unit : %

Cycling time	Number of trials	Image processing	Image processing and ultrasonic sensing
4.0sec	1	9.67	10.52
	2	12.34	11.30
1.5sec	1	9.34	7.97
	2	5.72	5.68

Table 6. RMS value about turning (real operation) unit : cm

Initial Place	Number of Acquired Data	RMS Value
2.1m	9	9.111
2.8m	9	10.037

Table 7. Ratio of area about turning (real operation) unit : %

Initial Place	Sum of deviation area(m^2)	Ratio of area
2.1m	1.68	7.596
2.8m	1.84	8.319

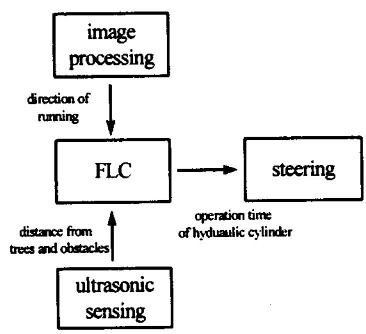

Fig. 1 Structure of the autonomous guidance system

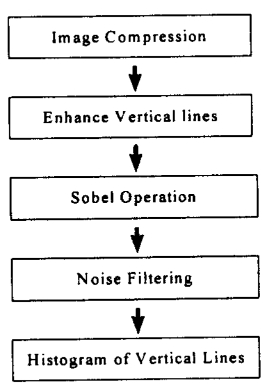

Fig. 2 Flowchart of the image processing

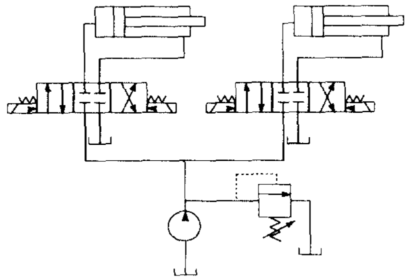

Fig. 3 Hydraulic system

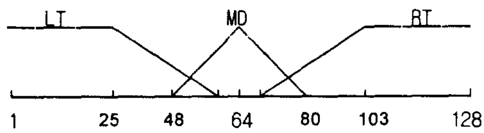

Fig. 4 Membership functions of "Direction of running"

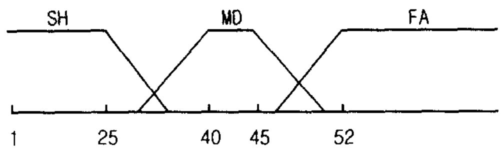

Fig. 5 Membership functions of "Ultrasonic signal"

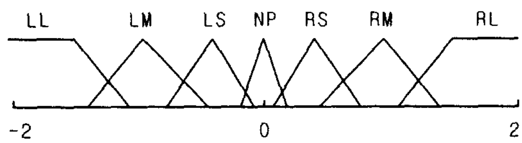

Fig. 6 Membership functions of "Operation time of hydraulic cylinder"

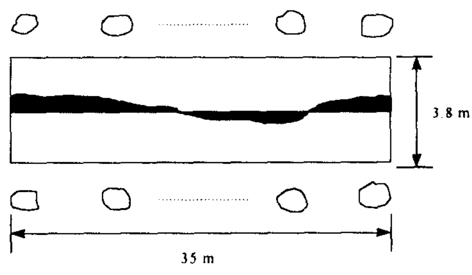

Fig. 7 Calculating the ration of areas

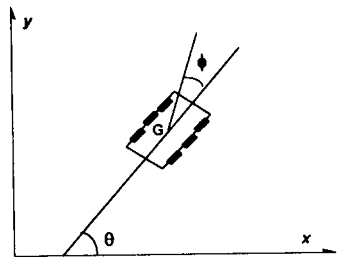

Fig. 8 Modeling of the speedsprayer

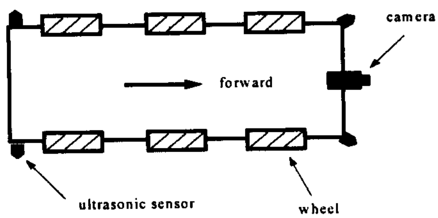

Fig. 9 Installation of camera and ultrasonic sensors

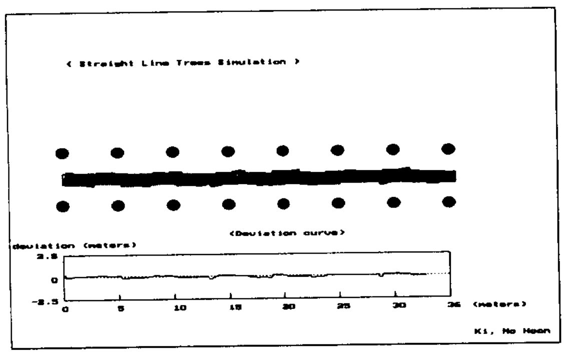

Fig. 10 Simulation of autonomous speedsprayer operation(along the straight line)

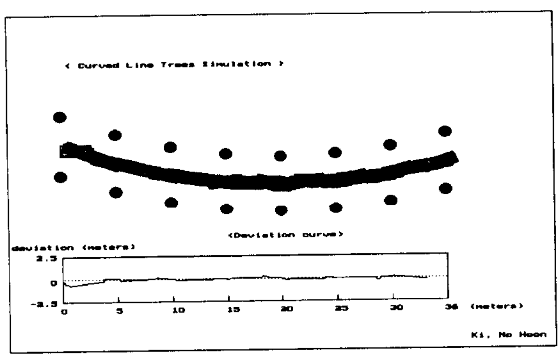

Fig. 11 Simulation of autonomous speedsprayer operation(along the curved line)

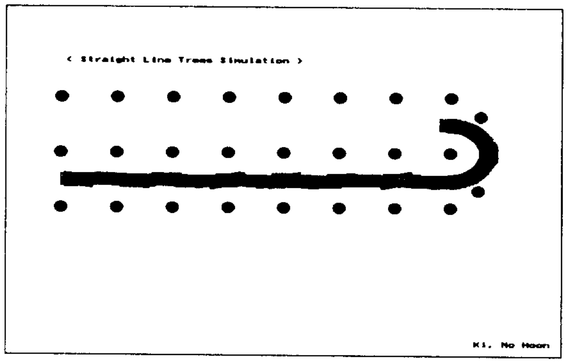

Fig. 12 Turning of speedsprayer

Fig. 13 Image compressed

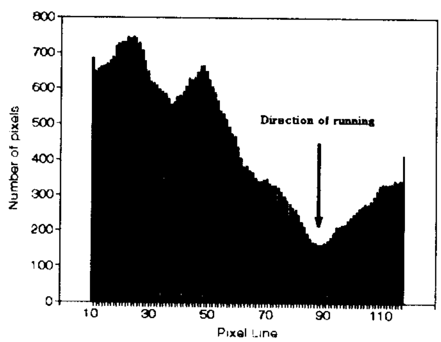

Fig. 14 Vertical histogram and direction of running