This is not a peer-reviewed article.
Pp. 221-229 in Automation Technology for Off-Road Equipment, Proceedings of the July 26-27, 2002 Conference (Chicago, Illinois, USA) Publication Date July 26, 2002. ASAE Publication Number 701P0502, ed. Qin Zhang.

Ultrasonic Sensor Development

for Automatic Steering Control of Orchard Tractor

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ABSTRACT

This paper describes the measurement of the relative position between tree canopy and vehicle using ultrasonic sensors for the navigation of a tractor working in the orchard. The tractor working in the orchard travels on the permanent paths between trees. Therefore, the navigation of the tractor using a DGPS seems to be effective. However, since the trees grow up and change the dimension of tree canopies, the tractor needs to detect the tree canopies and travel along them or avoid them. The goal of this research is to navigate the orchard tractor using a DGPS and ultrasonic sensors. For the purpose, the ultrasonic instrument for the measurement of the tree canopy was developed in this research. The performance of the developed ultrasonic instrument was estimated by field tests. Furthermore, a DGPS was used for the measurement of the vehicle position. The performance of the DGPS was also presented.

KEYWORDS. Automatic steering, GPS, orchards, ultrasonic sensor

INTRODUCTION

There are a lot of researches about the navigation of the tractor in order to reduce labor costs and increase the efficiency of farming operations in the world. In addition, there are some commercial tractors with the autopilot control system or the navigation system (referred to the web sites of *Beeline Co. Ltd and Trimble Co. Ltd.*).

Warner et al. (1972) have studied an ultrasonic guidance system for driverless tractors. This system guides the tractor carrying out plowing by detecting the last furrow by ultrasonic sensors as a guide for next run. Matsuo (1998) has studied the unmanned tillage tractor using the RTK-GPS, optical survey instrument and guiding cables. Reid (1991) has researched the vision guidance system of tractor in order to travel along the crop row. Noguchi (1998) has reported the autonomous tractor with an RTK-GPS and a geomagnetic direction sensor. The aims of these researches are to guide the tractor in the upland or paddy field.

Tosaki et al. had researched the automatic sprayer in the orchard (referred to the web site of *BRAIN*). They used the guiding cable installed underground in order to navigate the sprayer automatically. Ogawa had developed the pipe-guided automatic sprayer for the orchard tree (referred to the web site of *BRAIN*). The sprayer has guided wheels in front of the vehicle to detect a hose on the ground. The sprayer travels automatically while tracing the hose by the guided wheels. Shin et al. (2001) have developed a steering controller for a sprayer using two ultrasonic sensors. They used artificial targets to detect the desired path by ultrasonic sensors.

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However, since the trees grow up and change the dimension of tree canopies, the tractor needs to travel along the tree canopies or avoid the leaves and branches. For the purpose, it is necessary to detect the relative position between the tree canopy and vehicle and follow the canopies. Therefore, the ultrasonic measuring instrument was developed in order to determine the relative position between tree and vehicle. In this paper the field experiments and results of the ultrasonic measuring instrument are presented. Moreover, a DGPS was used for the measurement of the vehicle position. The performance of the DGPS was also presented in this paper.

MATERIAL AND METHOD

1.Experimental equipment

Figure 1 shows the appearance of the ultrasonic measuring instrument developed in this research. The instrument is driven by a DC12V battery. The ultrasonic sensors are transmitter T40-16P and receiver R40-16P (Frequency 40kHz ±1.0kHz, input voltage 60 V_{p-p}), which are made by Nicera (Nippon Ceramic Co. Ltd.). Three couples of the transmitters and receivers are installed on an L-shape aluminum at the distance of 30 cm. They are assigned the number CH1, CH2 and CH3 from top to bottom.

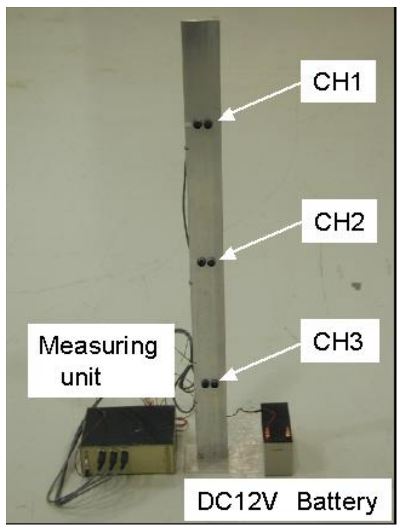

Figure 1. Ultrasonic instrument for the measurement of tree canopy.

Figure 2 shows the schematic diagram of the single channel ultrasonic measuring instrument. In the ultrasonic measuring instrument, a short acoustic pulse is first emitted from the transmitter. This acoustic pulse is a tone burst wave of 18.5 Hz with carriers of 40 kHz. A timer IC (NE555) generates timing clocks of 18.5Hz. It hits an object and then is reflected. The receiver waits for the return echo. The time, t [s], is measured from emitting to receiving by a counter and a clock. If the return echo is detected, the distance, D [m], can be found by multiplying the speed of sound, v_s [m/s], by one half the time measured as shown in Eq. (1).

$$D = \frac{v_s t}{2} \quad (1)$$

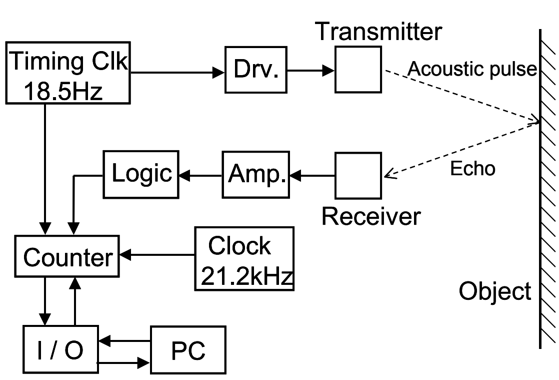

Figure 2. Single channel ultrasonic measuring instrument.

The time is halved since the time measured includes the time taken to strike the object, and then return to the receiver. The speed of sound is compensated by temperature, T [ºC], as follows.

$$v_s = 331.5 + 0.61T \quad (2)$$

The time is measured using a clock with the basic frequency of 21.2 kHz.

Each ultrasonic sensor can measure the distance, D_i [m] (i=1, 2, 3), every 54 ms sequentially. In addition, the ultrasonic measuring instrument can measure from CH1 to CH3 at the period of 216 ms.

The measuring instrument is installed on an ATV (All Terrain Vehicle) as shown in Fig. 3. The vehicle is a 6-wheel ATV made by Polaris. The heights of the ultrasonic sensors are 0.9, 1.2 and 1.5 m from ground, respectively.

A DGPS, which is StarFire SF-2000R made by John Deere, is installed on a roll bar of the ATV. This DGPS obtains a free differential GPS signal called WAAS (Wide-Area Augmentation System) in order to correct the position data. Moreover, it is low-cost, update rate of 5 Hz and real-time accuracy better than 1 ft (by technical specification sheet of the maker).

The data from the ultrasonic instrument and DGPS is recorded with a computer (Gateway 2000, Pentium 166 MHz, OS : RedHat Linux 7.1J). The data from the ultrasonic instrument is acquired through an I/O board (Measurement Computing, CIO-DAS08-AOL). The DGPS is connected with the computer through a serial port. The electricity of the devices is supplied from an electric generator (Honda, EU1000I) and an uninterrupted power system (CyberPower, CPS900AVR).

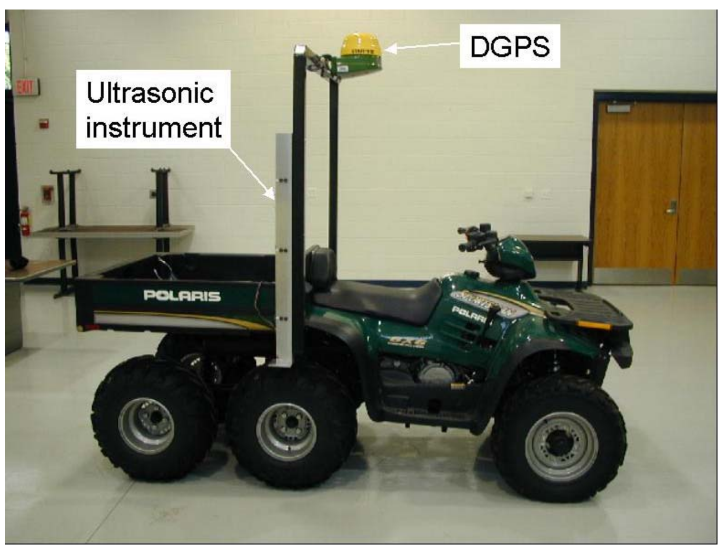

Figure 3. 6-wheel ATV with the ultrasonic instrument and the DGPS.

2.Method

a) Calibration of ultrasonic sensors

Calibration tests were conducted in a room that was controlled temperature. The temperature of the room is kept at 25 ºC. The distances between ultrasonic instrument and concrete wall are measured by ultrasonic sensors and manually with a tape measure. The measured distance is from 0.5 to 4.5 m. The means of 100 data measured by the ultrasonic instrument are used as a representation of the measured data.

b) Ultrasonic measurement of tree canopy

Tests of the measurement of the tree canopy were done in the campus of University of Florida on 29 August in 2001. Four trees were used for the tests (Fig. 4). The distances of each tree were about 4.5 m. The dimension of the trees was measured based on the method by Tumbo (2001). Figure 5 shows a schematic diagram of parameters measured by sensors and manually. Table 1 shows the dimensions of the trees. The numbers of trees were assigned from south to north.

Figure 4. Four trees used for measuring test.

The vehicle first stopped as the ultrasonic sensors faced with each tree. The relative distances between the sensor and the tree canopy were measured by ultrasonic instrument. The position of the vehicle was measured by the DGPS at the same time. In addition, the distances between the sensor and the canopy were manually measured with a tape measure. After the tests, the accuracy of the ultrasonic instrument was estimated by comparing the ultrasonic data with the manual data.

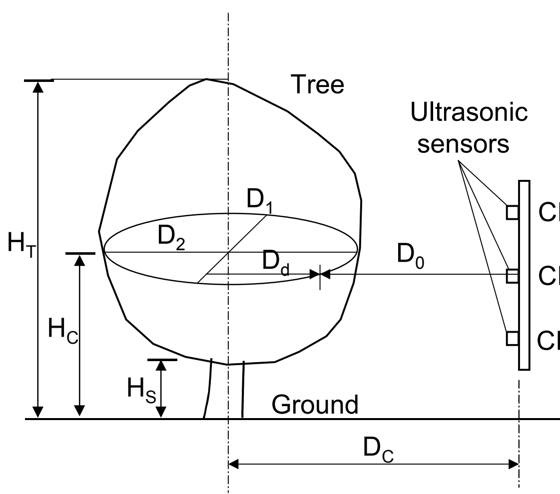

Figure 5. Schematic drawing showing tree, ultrasonic sensors and dimensions used to measure tree canopy manually and by ultrasonic sensors.

Table 1 Dimensions of four tree canopies.

Tree	H_T	H_c	H_S	D_C	D_1	D_2
1	2.50	1.40	0.86	2.84	1.70	1.50
2	3.30	1.50	0.35	2.75	1.65	1.55
3	2.35	1.20	0.70	2.81	1.00	0.95
4	2.00	1.40	0.60	2.65	1.10	1.55

[unit : m]

Finally, the ultrasonic instrument measured the distances between the sensor and the tree canopy while the vehicle was running at the constant speed of 1.00, 1.25, 1.50 and 1.75 m/s. The vehicle traveled on a straight path of 20 m long. The position of the vehicle was measured by the DGPS in the same way.

c) Accuracy of DGPS

Since the vehicle was equipped with the DGPS, the tracks of the vehicle were obtained from the GPS data after the tests. The GPS data was GGA format and included the latitude, longitude and altitude on the WGS84 (World Geodetic System in 1984). The GGA format data was transformed to the latitude, longitude and altitude on the NAD83 (North America Datum in 1983). After that they are transformed by the UTM (Universal Transverse Mercator) projection in order to convert into the Cartesian coordinate frame system (refered to *Map Projection – A Working Manual*). The accuracy of the DGPS used in this research was estimated by the tracks of the vehicle.

RESULT AND DISCUSSION

1. Calibration of ultrasonic sensors

Figure 6 shows the calibration results of the ultrasonic instrument. The ultrasonic instrument could measure the distances from 0.5 m to 4.5 m. The RMS of each sensor were 1.0, 1.3 and 3.1 cm, respectively. Since the resolution of the ultrasonic sensor was 0.8 cm when the temperature was 30 ºC, the performance of the ultrasonic instrument seemed to be good enough to detect the tree canopy. The detailed results of each ultrasonic sensor are shown in Table 2.

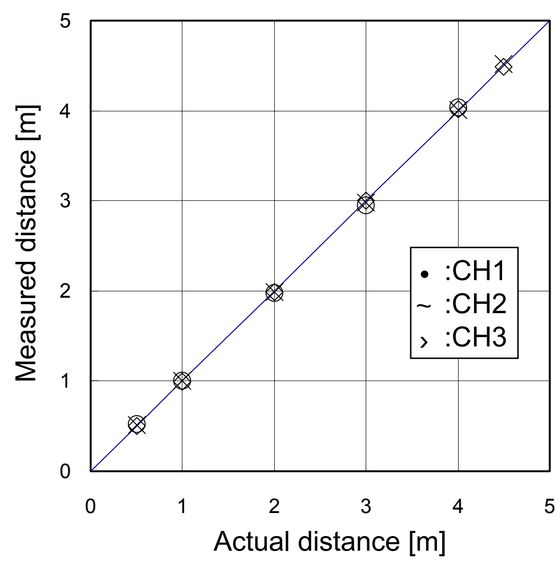

Figure 6. Calibration curve of the ultrasonic sensors.

Table 2. Calibration coefficients of ultrasonic sensors.

	CH1	CH2	CH3
a ($\times10^{-5}$)	2.2803	2.3621	2.2373
b	0.17070	0.17697	0.18736
r	0.99998	0.99996	0.99970

(r : correlation coefficient)

$Y = aE v_s EX + b$
X : Count value [pulses]
Y : Distance [m]
v_s: Speed of sound (=331.5 + 0.61 T)
T : Temperature [•]

2. Ultrasonic measurement of tree canopy

Figure 7 shows a test scene of the ultrasonic measurement of the tree canopy. Table 3 is measured distances between the sensor and the canopy with the vehicle is still. Table 4 shows the maximal error and RMS of the data measured by the ultrasonic instrument. The error means the value obtained by subtracting the manual measured data from the ultrasonic measured data. The ultrasonic instrument could measure the distances successfully in the tests. In addition it could detect the distance between the sensor and the tree stem of 10 cm in diameter. Every sensor could measure the distances precisely. However, since the density of the tree canopy was not uniform, there were some cases where the error was more than 20 cm according to location.

Figure 7. Test scene of the measurement of the distance between tree canopy and ultrasonic sensor.

Table 3. Results of the manual and ultrasonic measurement of the distance between tree canopy and sensor while the vehicle is still.

		Manual			Sensors		
No	Tree	CH1	CH2	CH3	CH1	CH2	CH3
1	1	0.80	0.80	1.38	0.81	1.01	1.46
2	1	0.80	0.80	1.38	0.81	0.94	1.46
3	1	0.80	0.80	1.38	0.82	0.97	1.49
4	2	0.92	1.20	1.30	0.92	1.20	1.47
5	2	0.92	1.20	1.30	0.92	1.23	1.46
6	2	0.92	1.20	1.30	0.91	1.23	1.52
7	3	1.10	1.10	1.26	1.13	1.35	1.45
8	3	1.10	1.10	1.26	1.13	1.29	1.45
9	3	1.10	1.10	1.26	1.17	1.38	1.40
10	4	0.85	0.60	0.70	0.79	0.58	0.85
11	4	0.85	0.60	0.70	0.88	0.60	0.80
12	4	0.85	0.60	0.70	0.83	0.59	0.84

[unit: m]

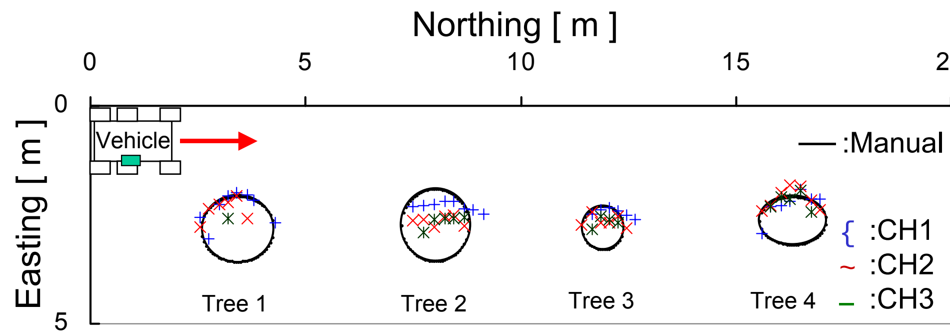

Figure 8. Tree canopy measured by three ultrasonic sensors while the vehicle is running (1 m/s).

Table 4. Maximal errors and RMS of ultrasonic measurements (1 m/s).

Error	CH1	CH2	CH3
Maximum	0.07	0.28	0.22
RMS	0.03	0.15	0.15

[unit : m]

Figure 8 shows a result of the ultrasonic measurement of the tree canopy while the vehicle is running. The vehicle ran straight at the speed of 1 m/s. Circles in solid line means the outlines of the tree canopies based on the manual measurement. Table 4 shows the maximal errors and RMS of the ultrasonic measurement of each sensor. As the result, it was proved that the ultrasonic instrument could detect four tree canopies precisely.

Table 5 shows the RMS of the ultrasonic measurement versus the speed of vehicle. The ultrasonic instrument could measure the tree canopies at the speed of 1.8 m/s. In the case that the vehicle was running at the speed of 1.8 m/s, the RMS of the ultrasonic measurement was about 0.2 m.

Table 5. RMS of the ultrasonic measurement while the vehicle running at various speeds.

Average speed [m/s]	RMS [m] CH1	CH2	CH3
1.08 (1.00)	0.13	0.12	0.07
1.27 (1.25)	0.07	0.14	0.12
1.55 (1.50)	0.13	0.15	0.10
1.84 (1.75)	0.18	0.21	0.19

( ): desired speed

In addition it was difficult to detect the thin stem of tree by the ultrasonic instrument even though the vehicle was running at the low speed. The reason is that the sampling rate of the ultrasonic instrument is low and the vehicle travels less than 22 cm in the case that the speed is 1.0 m/s. Similarly, the higher speed of vehicle is, the rougher lateral distance sampled by the ultrasonic instrument is. Therefore, the accuracy of the ultrasonic measurement tends to be high in the case of the low speed of vehicle.

Figure 9 shows a graph that is plotted the means of the data measured by three ultrasonic sensors. The means of the data measured by three ultrasonic sensors corresponded approximately to the outlines of four tree canopies. It can be thought that it is useful to determine the means of the data measured in three different heights in order to detect the outline of the tree canopy.

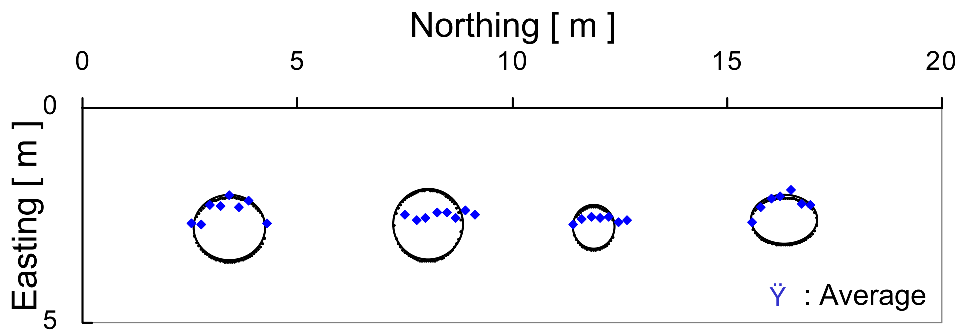

Figure 9. Means of the measurement by three ultrasonic sensors while the vehicle is running

(1 m/s).

3. Accuracy of DGPS

Figure 10 shows a track of the vehicle while measuring the tree canopy by the ultrasonic instrument. It was proved that the vehicle had traveled on the straight path from south to north. Table 6 is the xy-coordinates of the start and stop position of the vehicle measured by the GPS. As the result, the GPS could measure the position of vehicle within the standard deviation of 0.07 m.

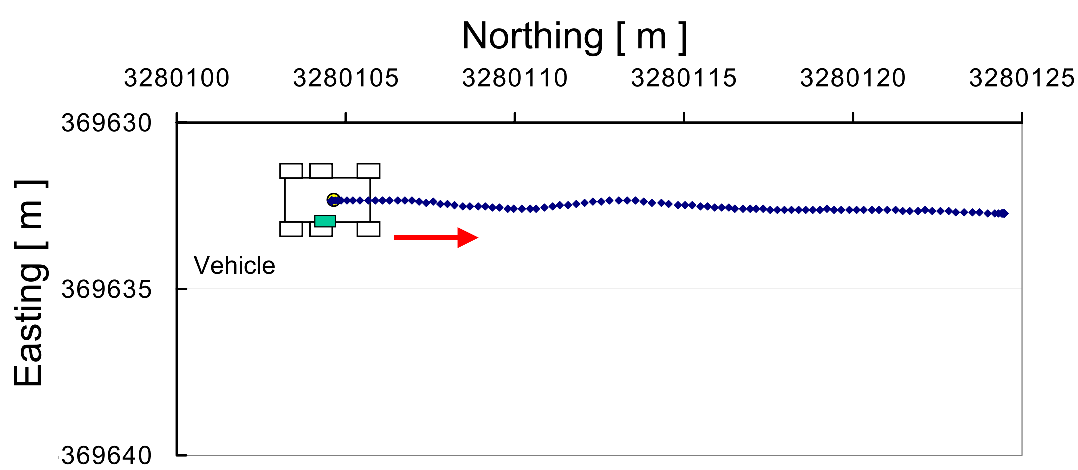

Figure 10. Track of vehicle measured by DGPS (1 m/s).

Table 6. Coordinates of the start and stop position of the vehicle measured by GPS.

Start

No.	Easting [m]	Northing [m]	Altitude [m]
1	369632.368	3280104.605	39.440
2	369632.368	3280104.568	39.320
3	369632.368	3280104.586	39.240
4	399632.335	3280104.531	39.280
5	369632.414	3280104.420	39.320
6	369632.382	3280104.420	39.380
7	369632.399	3280104.475	39.470
8	369632.383	3280104.475	39.390
9	369632.366	3280104.439	39.380
10	369632.431	3280104.493	39.410
11	369632.414	3280104.420	39.440
12	369632.382	3280104.401	39.420
Mean	369632.384	3280104.486	39.374
STD	0.027	0.000	0.070

Goal

No.	Easting [m]	Northing [m]	Altitude [m]
1	369632.729	3280124.514	39.990
2	369632.728	3280124.421	39.860
3	369632.679	3280124.403	39.860
4	399632.695	3280124.403	39.900
5	369632.727	3280124.366	39.930
6	369632.694	3280124.311	39.970
7	369632.726	3280124.310	39.950
8	369632.759	3280124.328	39.880
9	369632.727	3280124.329	39.900
10	369632.710	3280124.274	40.010
11	369632.726	3280124.310	40.010
12	369632.694	3280124.274	40.020
Mean	369632.716	3280124.354	39.940
STD	0.023	0.038	0.060

CONCLUSION

In this research the development and estimation of the ultrasonic instrument for the automatic steering system of the tractor working in the orchard were done. At the same time, the performance of the DGPS based on the differential signal of the WAAS was estimated. The main results of this research are summarized as follows.

1. The ultrasonic instrument consisted of three ultrasonic sensors had been developed in order to measure the tree canopy.
2. The ultrasonic instrument can measure the distance between the ultrasonic sensor and object within the range of 0.5 – 4.5 m at the period of 216 ms. The resolution of the measurement is 0.8 cm at the temperature of 30 ºC. The RMS of each sensor are 1.0, 1.3 and 3.1 cm, respectively.
3. The ultrasonic instrument could measure the tree canopy while the vehicle running at the speed of 1.0 – 1.8 m/s.
4. The GPS used in this research could measure the tracks of vehicle in the real time.

Therefore, It can be thought that the ultrasonic instrument developed is useful for the navigation of the tractor working in the orchard.

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