Evaluation of Spatial Application Accuracy of Sensing-Spraying System for Variable Rate Application of Oil Palm Trees

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ABSTRACT

Precious agricultural agents are lost during conventional spraying systems. The use of sensing and spraying system to spray according to the plant size reduces spray losses which reduces farming costs significantly and contributes to environmentally friendly crop farming. The continuous change in the size of the plant canopy requires an accurate adjustment of the quantity of liquid. The objectives of this study are examining, analyzing and improving the ability of the sensing and spraying system in detecting and spraying the plants under higher speed conditions. In this paper, two different ultrasonic sensors WRA1 and EZ0 were used to investigate the effect of sensor response time on detecting different distances and spatial application accuracy (SAA) of VR spraying system at different driving speeds. The results of the first assessment of an electronic control system for proportional spray application to the canopy length showed there was no significant effect of driving speed from 1.1 to 3.3 m/s on ultrasonic detected distance measurements. Sensor EZ0 gave a shortest response time at driving speed range of 1.1-3.3 m/s with error in range of 11-15 cm. The use of VR sprayer with the ultrasonic detection system was fast and accurate enough to spray at the correct positions above the plant with a maximum SAA of 97.7%.

INTRODUCTION

The ultimate goal of spray technologies is to put the correct amount of agrochemical, on the correct place, at the correct time to reduce the amount of chemical wasted per unit area. In younger linear groves and row crop fields, a lot of agrochemical agents are lost in the wide gaps between the plants because of using conventional spraying systems. However, management and use of precision agriculture (PA) helps in reducing agrochemical used in fields by using the suitable and correct spraying applications. Over the last years, band spraying system (spraying of chemical materials in parallel bands and area between the bands is left free of chemical) was used instead of broadcasting spraying to reduce spray losses [1]. Band spraying is more economical as compared to broadcast spraying [2] because it targets a specific area of the field such as rows or strips. In fact, conventional band spraying is still characterized by considerable inefficiency because an entire band is sprayed regardless of whether there are targets in the line or band not.

The use of a VR sprayer to adjust spray volume according to the sensed canopy size is anticipated to control the optimal amount of spray to target plants and stop spraying between trees. Several sprayer models are in the markets that are able to turn off the spray when there is a gap between trees [3]. The continuous growth and change in the size of the plant require accurate measurements of canopy size and continuous adjustment of the applied dose. Measuring canopy size is one of the challenges faced by sprayers due to the complicated structures and irregular shapes of trees [4]. The analysis of the echo signals from ultrasonic sensors make it is possible to assess the presence and absence of the plant by a technique already in use. Ultrasonic sensors have been used to estimate the size of the plant by several researchers. In general, the use of ultrasound sensors has optimized the performance of sprayers [5-9] but there are some limitations which need further research. According to Molto et al [10] ultrasonic sensors can measure the distance of the tree canopy with an error of 11.40 cm. It has been noted that the accuracy of ultrasonic measurement was lower than manual measurement at a driven speeds of 1.0–1.5ms⁻¹ [11]. Sensing-controlled spraying system used in current targeted spraying typically has a chronological gap between the detection of the target and spraying application, resulting in application errors.

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The primary problem with sensor-controlled variable rate sprayer is that there is always a long response time in the sensing-spraying system which is a function of the sprayer speed and the distance between sensor and spray nozzle above the plant. The driving speed of the sprayer is primarily determined by the period between target detection and spraying. By increasing the driving speed, the response time for one operation period decreases. If the total response time is greater than the maximal time limit, there will be misapplication [12]. Much of the studies thus far have focused on plant sensing and on the overall performance of the sprayer while relatively little has focused on the effect of the control system on SAA [13]. Smart sprayers have not yet achieved wide acceptance because they do not fulfill the requirements of optimal spraying at high driving speed with the spatial application accuracy (SAA) compared to typical linear methods. In order to overcome the above problems, the objectives of this study are examining, analyzing and improving the ability of the sensing and spraying system in detecting and spraying the plants under higher speed conditions.

**MATERIALS AND METHODS**

*Electronic control system:*

The electronic control system consists of an ultrasonic sensor (SN-XL-MaxSonar-WRA1 and LV-MaxSonar-EZ0 Maxbotix Inc, USA), the main control unit (Arduino Mega 2560) and the spray nozzle (AA250AUH automatic nozzle model, flat fan Teejet TP9503E, spraying system CO, USA). A laptop computer is interfaced with the prototype for data acquisition. The system is powered by 24 V DC which provided using two 12 V batteries. Different ultrasonic sensors are used to compare the performance of industrial standard sensor like WRA1 with ultra high speed sensor like EZ0 under same driving speeds. Part of the sensing and spraying system is tested in the laboratory to insure that it worked by detecting the presence and absence of the plant. The spraying actuator is enabled when the spraying is in the vicinity of the plant.

*Ultrasonic sensor calibration:*

A set of tests was carried out in the lab with the aim to assess the ability of the sensors to detect the targets. A single sensor was positioned on a vertical support mounted on a slide frame at different distances from a piece of flat wood as shown in Figure 1. The distances from sensor and the flat wood were measured manually with a measuring tape. The measured distances and the measurements by the sensor were compared using linear regression using SPSS software to examine the accuracy of the ultrasonic sensor in measuring the distance and calibrated them. The analog output voltage of the sensor was also recorded and correlated with the actual distance.

*Detection accuracy testing:*

To evaluate detection accuracy in a range of high driving speeds, the system was mounted on experimental carriage which was driven over a 15 m rail by an electrical motor. The sensor was mounted on a boom and moved at three speeds of 1.1, 2.2 and 3.3 m/s. The detecting target distance height was 0.5m high and 0.58m long artificial plant where placed at 0.50m distance under the sensor. The algorithm calculated the ultrasonic distance length when the vertical ultrasonic scan line hit the leftmost edge of the artificial plant (i=1). A timer in the program was used to measure the time till it detected the rightmost edge (i=n). The artificial plant canopy length \( L_p \) was calculated using the time measured by the timer \( (T_{i=n} - T_{i=1}) \) and the driving speed of carriage \( S \) using the following equation [14].

\[
L_p = (T_{i=n} - T_{i=1}) \times S
\]
Calculation of total response time:

The response time of control system is the delay between the time when the plant is detected and the nozzle begins spraying. The following equation was used to calculate the total response time.

\[ T_{RS\text{max}} = T_{RSS\text{max}} + T_{RSC\text{max}} + T_{RSN\text{max}} \]  

Where:

- \( T_{RS\text{max}} \) = Maximum total response time of the whole control system (s)
- \( T_{RSS\text{max}} \) = Maximum response time of the sensor (s)
- \( T_{RSC\text{max}} \) = Maximum response time of the controller (s)
- \( T_{RSN\text{max}} \) = Maximum response time of the spray nozzle valve (s)

Calculation of the distance between sensor and the nozzle:

The sensor was put in front of the nozzle at a specific distance \( L_s \). This distance was adjusted depending on the driving speed of the sprayer \( S \) and the total response time of the whole control system. The following equation is used to measure the specific distance:

\[ D = S \times T_{RS\text{max}} \]  

Where:

- \( D \) = Distance between sensor and the nozzle (m)
- \( S \) = Driving speed (m s\(^{-1}\))
- \( T_{RS\text{max}} \) = Maximum total response time of the control system (s)

The algorithm used to control the system is represented in Figuer2.

**Fig. 2**: Flow chart of an algorithm running the control system.

**VR Sprayer prototype test**:  
The sensing and control system was fitted to the spraying system equipped with a pressurized water tank, air pressure gauge, filter, water pressure gauge, and spray nozzle. The stationary supply tank was used to supply the spraying liquid to the moving carriage. The spray liquid was tap water. The ultrasonic sensor EZ0 and automatic nozzle were mounted on the boom. The ultrasonic sensor was placed in front of the spray nozzle at some specific distance; this distance was adjusted by moving the sensor on a linear slide according to the driving speed of the sprayer. The target was 1m high and 0.87m long oil palm tree was placed in the middle of the distance between beginning and ending of the track. The sensing and spraying system was aligned with the oil palm tree as shown in Figure3. A series of spraying tests were carried out to check the performance of the sprayer prototype. To assess the influence of the driving speed of the sprayer and sensor on SAA, the sensing and spraying system was tested at three driving speeds average 1.1, 2.2 and 3.3m/s. Spatial application accuracy above the plant was investigated using a high speed camera technique V710 to record spray line. The spray line begins from the rightmost edge of the tree and ends at the leftmost edge. An average temperature 30°C and relative humidity 70% was recorded on the test day. The SAA of VR sprayer above the plant was calculated by the following equation.

\[ SAA\% = 100 \left( \frac{L_{SD}}{L_P} \right) \]  

\( SAA \) = Spatial application accuracy (%)
\( L_{SD} \) = Length of spraying distance above the plant (m)
\( L_P \) = Length of plant (m)
RESULTS AND DISCUSSION

Ultrasonic Sensor Calibration:

The sensing and control system (sensors and controller) of the VR sprayer was successfully tested in the lab. The sensors were calibrated for distance measurement and the linear calibration model showed that the distance measured from sensor to the wood was highly correlated with the distance measured manually for both sensors. Both sensors WRA1 and EZ0 gave an $R^2 = 0.999$ and 0.998 respectively with $P < 0.001$. The relationship between the measured and actual distance is illustrated in figure 1. In order to correlate the measurements, the potential difference indicated by each sensor at different distances was also analysed with an $R^2 = 0.987$ and 0.999; respectively at $P < 0.001$. Figure 2 illustrates the relationships.

Effect of sensor type and driving speed on detection distance:

Table 1 below shows the averages of three replications of the 0.58m long artificial plant measurements by ultrasonic system by both sensors WRA1 and EZ0. The sensor detected distances were compared to actual length of the plant. The difference between ultrasonic and actual lengths was used to evaluate the performance of the ultrasonic system. In this study, sensor EZ0 generally showed acceptable performance for detecting the plant within the speed range 1.1–3.3 m/s. Random distance-detecting errors were observed during sensor tests. The difference between ultrasonic and manual volumes ranged from 16 to 21cm for sensor WRA1 and from 11.66–15 cm for sensor EZ0 at average traveling speeds of 1.1–3.3 m/s. The tests indicate that a relative mean difference of 19 cm for WRA1 and 11.66cm for EZ0 existed at a carriage speed of 3.3 m/s. Similar to the results

Fig. 3: Scheme of an experimental carriage set up.

Fig. 4: Relationship between distance obtained from ultrasonic sensors WRA1 and EZ0 and actual distance measured from sensor to target.
reported by [15] and [6], our test results indicated that no significant differences existed in detected distance results at travel speed range from 1.1–3.3 m/s. According to Zaman and Salyani [6], sensing variation along the driving speeds might be caused from target scanning frequency and plant canopy variability. However, in our study, the detecting error might have resulted from two reasons; multi-return path effects because of the acoustic wave bouncing between angled plant leaves until the wave returned to the sensor’s receiver due to leaf orientations [16]. It was observed that the accuracy of the width measurement is based on the ultrasound scanning frequency and the accuracy of the driving speed. When the speed was constant, the accuracy of measurement depended on response time per cycle. The ultrasonic sensor EZ0 with frequency 20 HZ achieved higher detection accuracy with less difference of tree length measurements at all driving speeds.

![Image: Relationship between voltage obtained from ultrasonic sensors WRA1 and EZ0 and the distance from sensor to the target measured manually.](image)

**Fig. 5:** Relationship between voltage obtained from ultrasonic sensors WRA1 and EZ0 and the distance from sensor to the target measured manually.

**Table 1:** Ultrasonic detection distance of the 0.58 m length of the artificial plant for two types of ultrasonic sensors WRA1 and EZ0 under three driving speeds conditions 1.1, 2.2 and 3.3 m/s.

<table>
<thead>
<tr>
<th>Average driving Speed (m/s)</th>
<th>Ultrasonic detection distance (m)</th>
<th>Sensor WRA1</th>
<th>Sensor EZ0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (cm)</td>
<td>SD (cm)</td>
<td>Difference</td>
</tr>
<tr>
<td>1.1</td>
<td>0.4166</td>
<td>0.1106</td>
<td>0.1633</td>
</tr>
<tr>
<td>2.2</td>
<td>0.3666</td>
<td>0.0750</td>
<td>0.2133</td>
</tr>
<tr>
<td>3.3</td>
<td>0.3900</td>
<td>0.1014</td>
<td>0.1900</td>
</tr>
</tbody>
</table>

SD: standard deviation of the mean

Difference: absolute value of the difference between actual and ultrasonic detection distance

Different letters indicate that the mean difference is significant between sensors at the .05 level

Similar letters indicate that the mean difference is not significant between speeds at the .05 level

**Effect of driving speed on Spatial Application Accuracy:**

Results of SAA indicated that VR sprayer was fast and accurate enough to open and close the nozzle with a short response time after receiving the sensor target detection information as shown in Table 2. The VR sprayer was able to spray the targeted location with no significant differences of sprayed distance above the plant while travelling at driving speed range from 1.1–3.3 m/s. The spatial application accuracy reached 97.67%.

**Table 2:** Average spraying distance and spatial application accuracy of the 0.87 m oil palm tree length for VR sprayer with ultrasonic sensor EZ0 under effect three driving speeds conditions 1.1, 2.2 and 3.3 m/s.

<table>
<thead>
<tr>
<th>Driving speed (m/s)</th>
<th>Spraying distance $L_{SP}$ (m)</th>
<th>SAA (%)</th>
<th>Mean</th>
<th>SD</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>0.840**</td>
<td>97.67**</td>
<td>0.03464</td>
<td>4.02990</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.2</td>
<td>0.790</td>
<td>91.84</td>
<td>0.03000</td>
<td>3.46503</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.3</td>
<td>0.835</td>
<td>97.09</td>
<td>0.02500</td>
<td>2.91000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$L_{SP}$: Spraying distance length above the oil palm tree
SAA: Spatial application accuracy=$L_{SP}/L_{TP}$, $L_{TP}$: Oil palm tree length(m)
SD: Standard deviation of the mean
**The mean difference is not significant between speeds at the .05 level**
**Conclusions:**

The result concluded that by using fast ultrasonic sensors, the spraying system can adequately detect and spray when the target is in the range, reducing the chances of spray loss during plant detection, as seen by other low speed sensors. The results indicated a high R^2 indicating that the system is indeed a promising solution. The high special accuracy strongly suggests the efficiency of the system is better than conventional methods will less loss of the precious spraying agents. However by using even better and faster sensors, the results can be improved further.

**ACKNOWLEDGMENT**

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**REFERENCE**

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