Performance of Ultrasonic and Infrared Sensors for Detection of the Target for Development of Orchard Sprayer

ABSTRACT

Detection of plant canopy is one of the main tasks in achieving the variable rate spraying. Two types of sensors, namely ultrasonic and infrared sensors were studied for the parameters *viz*., error, range of detection and response time at different distances from the sensor. The error of the sensors was found to be 5.6, -11, -10.5 and 15.4, 26.4, 32.3 mm at a distance of 500, 1000 and 1500 mm from the sensor for ultrasonic and infrared respectively. The range of detection was found to be 147.33, 343.67, 430.66 and 50.66, 67.00, 83.67 mm at a distance 500, 1000 and 1500 mm from the sensor for ultrasonic and infrared sensor respectively. The response time was found to be 0.20, 0.24, 0.28 and 0.25, 0.27, 0.29 s at 500, 1000 and 1500 mm from the sensor for ultrasonic and infrared sensor respectively. The ultrasonic sensor was found to be superior to the infrared sensor in terms of error, range of measurement and response time. The ultrasonic sensor can be better suited for target detection for development of target based sprayer.

Key words: Sensor, Ultrasonic, Infrared, Error, Response time and Range of detection

1. Introduction

Plant protection products (PPPs) are often constantly applied in large volumes without any relation to canopy density of the plant or tree. Also, the spray solution is being sprayed in the absence of canopy causing wastage of pesticides and environmental pollution. Efficient chemical application on plant canopies is a challenge because of their complex structure and wide plant spacing. Public opinion, environment degradation concerns and demands for healthy fruits, have stimulated researchers for more sustainable spraying techniques, by optimizing the spray treatments in orchards and preventing spray losses towards environment degradation.

A number of systems for adjusting the applied dose of plant protection products according to orchard structure have been developed in the past decades. Tree Row Volume (TRV) system (Byers *et al.,* 1971) varies the spray dose by varying the spray volume at TRV proportional constant pesticide concentration. Contrary to TRV, leaf area measurements was used to correlate spray deposits with different spraying equipment and hedgerow vineyards. However, the continuous calculation of TRV for different tree canopies, even in the same orchards, required continuous adjustments and interventions to optimize the spray application efficiency (Pergher *et al.,*1997).

A sensor based target spraying approach is necessary as it saves chemicals and minimizes environmental risk. Environmentally safe spray techniques were developed to reduce the use of PPPs through target applications for reduced environment losses (Doruchowski and Holownicki, 2000). Many techniques as well as computational processing were employed to calculate a wide range of parameters based on light interception characteristics of the crop (Walklate *et al.,* 2002). The techniques include use of sensors and radar. But radar-based system was very expensive for implementation. The use of ultrasonic sensors and proportional electro-valves with software and automation, allowed real time spray modification as per the orchard crop structure and considerably reduced the spray and pesticide application amount (Gil *et al.,* 2007). A programmable ultrasonic sensing system for targeted spraying in orchards employed ultrasonic sensing processed in LPC1343 microcontroller and spray using electromagnetic valves reduced the spray amount up to 37.7% as it abstained from spraying within gaps (Stajnko *et al.*,2012*)*. Also, the studies conducted for the distance measurement for the detection of target using ultrasonic and infrared sensors, results found to be successful with an accuracy ranging from 95 to 99% (Mustapha *et al*., 2013). The study was taken up to compare the performance of the infrared and ultrasonic sensors to detect the target for the development of sprayer that can spray the pesticide based on the target.

2. MATERIALS AND METHODS

The evaluation of the sensors was conducted in the laboratory condition. The study was taken up at college of Agricultural Engineering, Raichur. The types of sensors considered were the ultrasonic sensor of type HC SR04 and infrared sensor of type SHARP GP2Y0A02YK0F. The specifications of the sensors (data sheets of respective sensors) were given in the Table 1. Before evaluation the sensors were calibrated to get the accurate results.

Table 1. Specifications of the sensors used for the study

S.No	Parameters	Specifications	
		Infrared sensor	**Ultrasonic sensor**
1	Model	SHARP GP2Y0A02YK0F	HC SR04
2	Measuring range	200 to 1500 mm	20 to 4000 mm
3	Output voltage	0.25 to 0.55 V	0 to 5 V
4	Power consumption	0.033 A	0.015 A
5	Operating temperature	-10 to 60 ºC	-15 to 70 ºC
6	Voltage requirement	4.5- 5.5 V	3.3-5 V
7	Measuring angle	Upto 10 º	Upto 15 º
8	Operating frequency	25 Hz	40 KHz

2.1 Error

Error is the difference of the distance measured by the sensor and the actual physical distance between the sensor and the target. An artificial target was set at a pre determined distance from the sensor with the help of measuring tape. The distance measured by the sensors was read with the help of a Light Emitting Diode (LED) display connected to the aurdino board. The aurdino was programmed to read the distance by converting the voltage to the distance as shown in Fig. 1. The distance was measured at different distances of 500, 1000 and 1500 mm from the sensor. The formula used for measuring the error was given by the equation (Anghel and Dumitrescu, 2017)

Error (mm) = Measured value (mm) - Actual value (mm) …(1)

Fig.1: Measurement of distance by the sensor

2.2 Range of detection

The range of detection was measured in vertical plane. The Mild Steel (MS) bar which was hang up with the help of two square shafts was kept at the same height as that of the sensor from the ground and can be moved up and down. The MS bar was moved upwards from the original position until the distance was measured by the sensor and the movement of the bar was stopped once the detection by the sensor stops. The distance in the upward direction was measured from the original point. Again, the MS bar was moved downwards from the original position until the detection by the sensor stops (Smallwood, 2018). The distance from the original point to the MS bar was measured. The range of detection is the total upward and the downward distance detected by the sensor.

2.3 Response time

The setup for measurement of response time consists of the sensor, micro controller board, solenoid valve, pump and nozzle. The sensor was connected to the micro controller board and the solenoid valves were used to regulate the pesticide solution based on the input signals from the micro controller board. The DC pump was used to supply the pesticide solution to the nozzle.

For determining the response time, an artificial target was set. A laser projector was placed on the sensor and the sensor was moved towards the target at a fixed distance from the target. The laser projector will point on the artificial target will be considered as seeing of the target by the sensor. The action is recorded by a high speed camera and the frames of the video were analyzed to get the response time (Wandkar, 2016). The response time was the time taken from seeing of the sensor to the start of flow of liquid from the nozzle.

2.4 Analysis

The experiments were conducted as per the general factorial design. The results of the experiment were analyzed using Design expert software (version 7.00). The ANOVA was studied to analyze the effect of type of sensor and distance from the target on the error, range of detection and response time.

3. Results and discussion

3.1 Error

The maximum error was 33.5 mm obtained for infrared sensor at a distance of 1500 mm from the target. The minimum error was 2.85 mm obtained for ultrasonic sensor at a distance of 500 mm from the target. The error ranged from -13.7 to 33.5 mm. The error range of the sensors was found within the limits mentioned in the data sheets. The results obtained were in similar trends as reported by Anghel and Dumitrescu, (2017).

The effect of type of sensor and distance from the target on error was presented in Fig. 2. As the distance from the target increased, the error was from positive to negative for ultrasonic sensor might be due to the wind that might have diffracted the ultrasonic waves. For infrared sensor, as the distance increased the error increased may be due to environmental factors such as sun light that affecting the IR light.

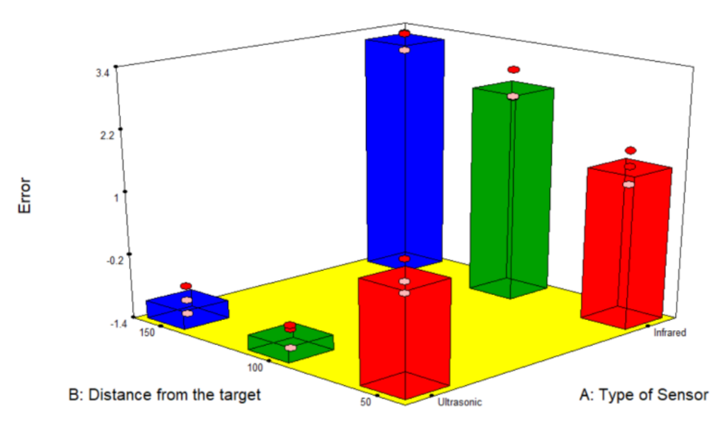

Fig. 2. Error as a function of type of sensor and distance from the target

The model was found to be significant at 1% level of significance. The main effect, type of sensor (A) and the interaction of AB had significant effect on the error at 1 % level of significance. The mean value of the error was observed to be about 9.7 mm with a standard deviation of 0.28 and coefficient of variation was about 28.47 % as shown in Table 2.

Table 2. Analysis of variance for error of sensor

Source	Sum of squares	DF	Means quare	F-value	p-value
Model	50.44	5	10.09	132.69	<0.001**
A- Type of Sensor	40.65	1	40.65	534.76	<0.001**
B- Distance from target	0.38	2	0.19	2.47	0.1265

AB	9.41	2	4.70	61.87	<0.001**
Pure error	0.91	12	0.076		
Cor total	51.35	17			

Mean	0.97	**C.V.%**	28.47
Std.Dev.	0.28	**R-Squared**	0.9822

DF: Degrees of freedom; **Significant at 1%level

The model coefficient of determination (R^2) was obtained to be 0.9822 and the predicted R^2 value of 0.9600 was in reasonable agreement with adjusted R^2 value of 0.9748.The signal to noise ratio which was measured by adequate precision was about 27.255 and it was greater than 4, which indicates an adequate signal and the model can be used to navigate the design space. The model (Eq.2) was developed to determine the relationship between the error and selected sensor parameters.

$$\text{Error} = 0.97+1.50A+0.084B-0.20B^2-1.01AB+0.37AB^2 \qquad \ldots (2)$$

3.2 Range of target detection

The range of target detection for different types of sensors and different distances from the target was determined. The maximum range was 434 mm obtained for ultrasonic sensor at a distance of 1500 mm from the target. The minimum range was 49 mm obtained for infrared sensor at a distance of 500 mm from the target. The range of detection ranged from 49 to 434 mm. The results were in similar trend that was specified by Adarsh *et al*., (2016).

The effect of type of sensor and distance from the target on range of target detection was presented in Fig. 3. It was observed that as the distance from the target increased, the range of canopy detection increased for ultrasonic sensor. This might be due to the wide beam angle of ultrasonic waves emitted by the sensor. For infrared sensor, as the distance increased there is very slight increase in range of target detection. This may be due to narrow beam angle of the infrared sensor.

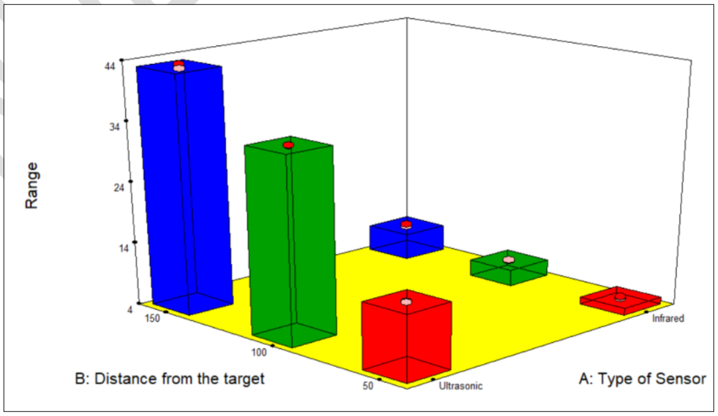

Fig. 3. Range of detection as a function of type of sensor and distance from the target

The statistical analysis of the experimental results was presented in Table 3. The model was found to be significant at 1% level of significance. The main effects of type of sensor (A) and distance from the target (B) and the interaction of AB had significant effect on the range at 1 % level of significance. The mean value of the range was observed to be about 18.72 cm with a standard deviation of 0.20 and coefficient of variation was about 1.08 %.

Table 3. Analysis of variance for range of detection of sensor

Source	**Sum of squares**	**DF**	**Means quare**	**F-value**	**p-value**
Model	3874.67	5	774.93	18849.75	<0.001**
A- Type of Sensor	2594.40	1	2594.40	63107.14	<0.001**
B- Distance from target	780.20	2	390.10	9488.96	<0.001**
AB	500.07	2	250.03	6081.91	<0.001**
Pure error	0.49	12	0.041		
Cor total	3875.17	17			

Mean	18.72	**C.V.%**	1.08
Std.Dev.	0.20	**R-Squared**	0.999

DF: Degrees of freedom; **Significant at 1%level

The model coefficient of determination (R^2) was obtained to be 0.999 and the predicted R^2 value of 0.9997 was in reasonable agreement with adjusted R^2 value of 0.998.The signal to noise ratio which was measured by adequate precision was about 324.612 and it was greater than 4. The model (Eq.3) was developed to determine the relationship between the range and selected sensor parameters.

$$\text{Range of detection} = 18.72-12.01A-8.82B+1.82B^2+7.17AB-1.83AB^2 \qquad \ldots(3)$$

3.3 Response time

The maximum response time was 0.30 s obtained for infrared sensor at a distance of 1500 mm from the target. The minimum response time was 0.20 s obtained for ultrasonic sensor at a distance of 500 mm from the target. The response time ranged from 0.20 to 0.30 s.

The effect of type of sensor and distance from the target on response time was presented in Fig. 4. It was observed that as the distance from the target from the sensor increased, there is very slight increase in response time for both the sensors. This might be due to the time required for the travel of light and sound waves. But both the sensors response time was found to be on par with each other. The very slight less response time of the ultrasonic sensor is due to its ability to emit sound waves in the horizontal plane and wide beam angle. The slight higher response time of the infrared sensor was due to narrow beam angle and the response time depends upon the surface of reflectance.

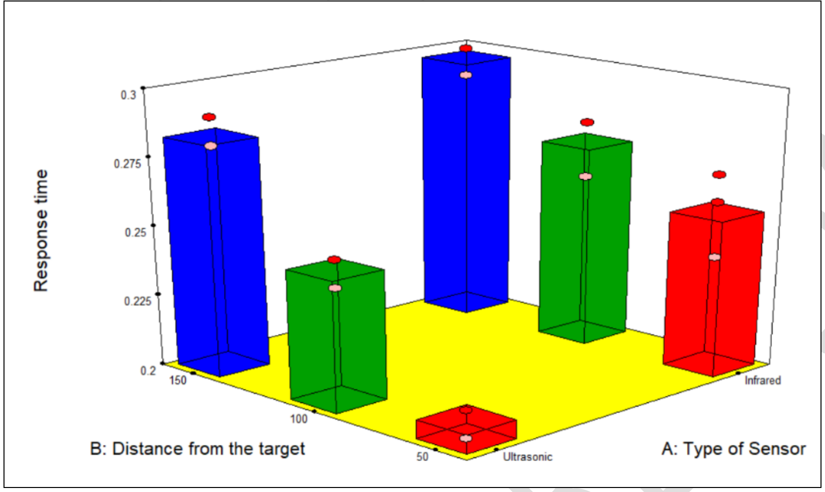

Fig. 4. Response time as a function of type of sensor and distance from the target

The statistical analysis of the experimental results was performed and presented in Table 4. The model was found to be significant at 1% level of significance. The main effects type of sensor (A), distance from the target (B) and the interaction of AB had significant effect on the response time at 1 % level of significance. The mean value of the response time was observed to be about 0.26 s with a standard deviation of 9.129E-003 and coefficient of variation was about 3.50 %.

Table 4. Analysis of variance for response time of sensor

Source	Sum of squares	DF	Mean square	F-value	p-value
Model	0.15	5	3.059E-003	36.71	<0.001**
A- Type of Sensor	4.050E-003	1	4.050E-003	48.60	<0.001**
B- Distance from target	0.10	2	5.106E-003	61.27	<0.001**
AB	1.033E-003	2	5.167E-004	6.20	0.041**
Pure error	1.000E-003	12	8.333E-005		
Cor total	0.016	17			

Mean	0.26	**C.V.%**	3.50
Std.Dev.	9.129E-003	**R-Squared**	0.9386

DF: Degrees of freedom; **Significant at 1%level

The model coefficient of determination (R^2) was obtained to be 0.9386 and the predicted R^2 value of 0.8619 was in reasonable agreement with adjusted R^2 value of 0.9131.The signal to noise ratio which was measured by adequate precision was about 17.076 and it was greater than 4, which indicates an adequate signal and the model can be used to navigate the design space. The model (Eq.4) was developed to determine the relationship between response time and selected sensor parameters.

Response time =0.26+0.015A-0.029B-5.556E-004B^2+1.00E-002AB-1.667E-003AB^2…(4)

4. Conclusion

The different parameters of the sensors were studies and analyzed. The error was found to be less with ultrasonic sensor than the infrared. The range of detection also found to be more for ultrasonic sensor than infrared. The response time was found to be on par with each other for both the sensors, but it is slightly less for the ultrasonic sensor than infrared. The ultrasonic sensor was a better option for the detection of the target for variable rate spraying compared to the infrared sensor.

References

1. Adarsh, S., Kaleemuddin, M., Bose, D. and Ramchandran, K.I., (2016), Performance comparison of Infrared and ultrasonic sensors for obstacles of different materials in vehicle/robot navigation applications. IOP conference series: material science and Engineering.,149:1-8. (10.1088/1757-899X/149/1/012141)

2. Anghel, I. and Dumitrescu, C., (2017), performance comparison of infrared and ultrasonic sensors in distance measuring. JEECCS.,3(10):9-14.

3. Byers, R. E., Hickey, K. D. and Hill, C. H., (1971), Base gallon age per acre. Virginia Fruit., 60:19–23.

4. Data sheet of HC SR04 Sensor

5. Data sheet of SHARP GP2Y0A02YK0F Sensor

6. Doruchowski, G. and Holownicki, R., (2000), Environmentally friendly spray techniques for tree crops. Crop Prot., 19: 617–622.(10.1016/S0261-2194(00)00081-8)

7. Gil, E., Escola, A., Rosell, J. R., Planas, S. and Val, L., (2007), Variable rate application of plant protection products in vineyard using ultrasonic sensors. Crop Prot., 26:1287–1297. (10.1016/j.cropro.2006.11.003)

8. Mustapha. B., Zayegh. A. and Begg. R. K., (2013), Ultrasonic and infrared sensors performance in a wireless obstacle detection system. IEEE- Computer system., 487-492. (10.1109/AIMS.2013.89)

9. Pergher, G., Gubiani, R. and Tonetto, G., (1997), Foliar deposition and pesticide losses from three air-assisted sprayers in a hedgerow vineyard. Crop Prot., 16(1): 25-33. (10.1016/S0261-2194(96)00054-3)

10. Smallwood. J., (2018), ultrasonic field of view test. https://www.arxterra.com/ultrasonic-field-of-view-test/?form=MG0AV3

10. Stajnko, D., Berk, P., Lesnik, M., Jejcic, V., Lakota, M., Strancar, A., Hocevar, M. and Rakun, J., (2012), Programmable ultrasonic sensing system for targeted spraying in orchards. Sensors., 12(11): 15500–15519. (10.3390/s121115500)

11. Wandkar, S., (2016), Unpublished thesis submitted to Maharana Pratap University of Agriculture and Technology. PP 41-43.

12. Walklate, P. J., Cross, J. V., Richardson, G. M., Murray, R. A. and Baker, D. E., (2002), Comparison of different spray volume deposition models using LIDAR measurements of apple orchards. Biosyst. Eng., 82: 253–267. (10.1006/bioe.2002.0082)