Journal of Applied Horticulture, 17(2): 96-100, 2015

Evaluation of sensors for sensing characteristics and field of view for variable rate technology in grape vineyards in North Dakota

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Abstract

Sensors have been used to detect tree sizes for agrochemical and fertilizer applications in grape vineyards. Rugged and reliable sensors are required to measure the size and quality of tree canopy volume for variable rate fertilizer application. Real time sensing is important as size of the tree changes with time due to biological factors and management practices. This study evaluated ultrasonic sensor, optical sensor and a laser sensor for their sensing characteristics and field of view (FoV) in a range of conditions. The FoV was established by moving targets perpendicular to the centerline on both sides. The maximum sensig range of sensors varied from 6 to 8 m with ultrasonic sensor having the highest range. The beam widths for ultrasonic sensors were found to be wide (maximum 950 mm) whereas optical sensor has a narrow maximum beam width of 70 mm. The laser sensor has a sharp beam and did not work well in outdoor environment with plant materials. Statistical analysis was also done for sensors and found that P value is lower than 0.001 and R^2 value closer to 1.0 which indicates significant better result in the vineyard for sensing characteristics.

Key words: Vineyards, sensors, variable rate technology (VRT), tree-sensing

Introduction

Precision farming allows one to manage crops in a site specific manner. Recently various aspects of precision farming are getting popular among the farmers due to its beneficial effects on crops. One of the precision agriculture technologies is variable rate technology (VRT) which allows differential application of fertilizer throughout the field based on the requirement. Therefore, primary goal of using VRT is to maximize profit to its fullest potential, create efficiencies in input application, and ensure sustainability and environmental safety. There are different kinds of variable rate technologies available which can be used with or without a GPS system. The two basic technologies are either map-based or sensor-based. A sensor based VRT system mainly detects heights or determine canopy volume of trees to apply different pre- determined variable rates of fertilizer with no prior mapping or data collection involved.

VRT fertilization in vineyards has potential economic and environmental benefit. Real time sensors measure the desired properties like growth of the trees by measuring heights. Measurements made by such a system are then processed and used immediately to control a variable-rate applicator (VRA Tools). The disadvantage of using tree height is that there may be absence of leaves in some trees or presence of damaged leaves. Due to this steps are being taken to quantify the tree canopy volume for variable rate fertilization (Zaman *et al*., 2005b). It has been noted that, yield also has direct relationship with tree canopy volume (Wheaton *et al*., 1995 and Whitney *et al*., 1999). Zaman *et al*. (2005a) suggested incorporating temperature compensation system in the sensor while quantifying the sources of error including different environmental factors like air temperature in ultrasonic measurement.

Most of the commercially available sensors like ultrasonic, photoelectric, optical and laser sensors are basically developed for industrial purposes and indoor environment. However, recently they are being used in the agricultural sectors also because of their potential for use in sensing, detecting and profiling trees. Wei and Salyani (2005) studied a laser scanning system to quantify foliage density of citrus trees and density. Tumbo *et al*. (2001) compared citrus tree canopy volume measurements by manual, laser and by ultrasonic sensors. Schumann and Zaman (2005) used ultrasonic sensor and photoelectric sensor to measure tree canopy volume and tree heights to apply pre-determined amounts of fertilizer to a single tree. Escola *et al*. (2011) checked the overall performance of ultrasonic sensor in apple tree canopies. Jeon *et al*. (2011) also tested ultrasonic sensors for accuracy in measuring distances to simulated canopies of field crops. Miller *et al*. (2003) tested a variable rate granular fertilizer spreader with both GPS-guided prescription mapping and real-time tree size measurement with photoelectric sensors in citrus groves.

The main focus of this study was to evaluate and compare different sensors that are available in the market and verify whether they are suitable for sensing grapevines for use in variable rate fertilizer application.

Materials and methods

Three different types of sensors (Ultrasonic, optical, laser) namely Banner Ultrasonic sensor, Banner optical sensor and Balluff laser sensor were tested for this study according to their specifications. The sensors were mainly selected to check their performance in terms of their sensing range, field of view and their sensing characteristics in the vineyards. The field of view or beam pattern is the angle over which objects are detected by the sensor. In some cases FoV is also presented as angle of view which describes the angular extend of area covered by the sensor. The FoV of the sensors were established by measuring the sensing width at different distances. The experiment was done in both indoor and outdoor environment to assess any difference. For the indoor experiment, the sensor was mounted on a stand and a tall 2-inch diameter white PVC pipe was moved towards the center line perpendicularly and marked on the ground when the target was detected. Similar points were established on the other side of the center line. The beams were detected both sides of the center line to document the field of view; also, known as beam pattern. After the sensor is excited by 12V battery, signal was transmitted. A circular white PVC pipe (2 in dia) was used to detect the signal. The pipe was moved both side of the center line, till the voltage was recorded. The voltage on the center line at different distance was also recorded. The schematic of experimental set-up is shown in Fig. 1. Care was taken for engaging proper dip switches in the ultrasonic sensors and the output wirings in all the sensors. The indoor experiment helps to verify the specifications of the sensors by the manufacturer.

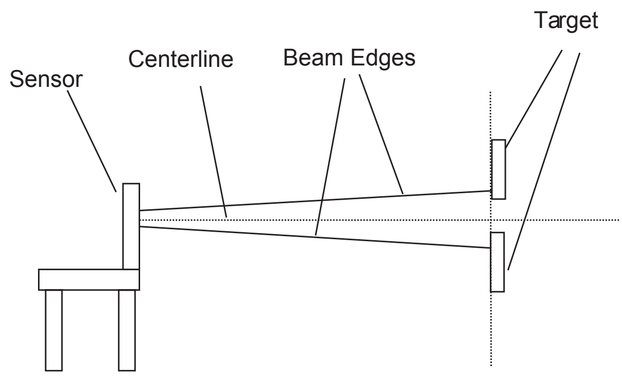

Fig. 1. Experimental set up

Fig. 2. Set-up for lab test

Lab test: A 2.03 m high and 1.30 m wide portable screen was used as a moving target shown in Fig. 2. When the sensor signals hit the target, the distance was measured and the corresponding output voltage was recorded. The procedure was repeated in indoor and outdoor environments. Water was sprayed at the sensor to see if moisture affected performance.

Field test: The outdoor experiment was conducted in the Red trail Vineyard which is in the south central North Dakota (46° 54' 09" N, 97° 29' 42" W). The three sensors were placed at vineyards rows with some changes for the sensor placement. The same experiment set-up was established in the field conditions as shown in Fig. 3. The field test was repeated three times to get better results.

Fig. 3. Set-up for field test

Statistical analysis was done for the output of ultrasonic sensor. The coefficient of determinations (R^2) of the linear output along with coefficient of variation (CV) and root mean square error (RMSE) were observed. CV, expressed in percentage, is the statistical measure of deviation of a variable from its mean and is calculated by dividing standard deviation by the mean value. RMSE is the root mean square deviation from the average.

Ultrasonic Sensor: Banner Ultrasonic Sensor (U-GAGE QT50ULBQ6), is from Banner Engineering Corp. (Minneapolis, Minn.) and is a waterproof, compact, long range, temperature compensated with operating condition range of -20 °C to 70 °C (-4 to 158 °F) and sensing range from 200 mm (8 in) to 8m (26 ft) with 1 mm resolution. The signal frequency is 75 kHz and supply

Table 1. Manufacturers' sensor specifications

Specifications	Photoelectric	Ultrasonic	Laser
Sensing range	6 m (20 ft)	8 m (26 ft)	6 m (20 ft)
Supply voltage	10-30 VDC	10-30 VDC	15-30 VDC
Output response time	1 ms	100 ms	5 ms
Operating frequency		75 kHz	
Wave lengths	Infrared (880 nm)		Red light Laser (650…670 nm)
Output	Discrete	Analog (0-10V)	Analog (0-10V)
Operating temperature	-20 to 55 °C (-4 to 131 °F)	-20 to 70 °C (-4 to 158 °F)	-10 to 55 °C (12 to 131 °F)

voltage is 10 to 30 VDC. It has a scalable analog output with adjustable minimum and maximum limits and output can be selected 0-10 VDC or 4-20 mA via DIP switches. For this test, the output was set for 0-10 VDC. The sensor has 9 m (30 ft) long color coded 5-wire cable with shield.

Optical Sensors: The diffuse reflectance photoelectric/ optical sensors are from Banner Engineering Corp. (Minneapolis, Minn.) and are commonly known as Banner eyes. These are compact, self contained sensors in metal die cast housing and have an infrared sensing beam (880 nm) with supply voltage of 10-30 VDC at less than 40 mA. The sensor has an output response time of 1 ms (on & off) and works at a temperature range of -20 °C to 55 °C (-4 to 131 °F). Its output type is discrete (NPN) and has a sensing range of 6m (20 ft). The sensor has two status LEDs; yellow for signal and green for power. This is currently used in VRT spreaders available in Florida to detect heights of citrus trees.

Laser Sensor: The BOD 63M is a photoelectric sensor for distance measurement with laser as emitter light source and is marketed by Balluff Inc., Florence, KY. The sensor is basically used for industrial purpose and provides output voltage that is directly proportional to distances between targets and the sensor. It is a compact rugged metal-housed sensor with a class II red light laser (650…670 nm) sensing beam. The sensing range is 500 mm (1.6 ft) to 6 m (20 ft) and has analog and discrete output. The supply voltage is 15-30 VDC with current consumption of less than 100 mA. The light spot diameter is 5 mm at 3 m and 10 mm at 6 m sensing distance. The working temperature range is -10°C to 55 °C (14 °F to 131 °F). It has three status LEDs, green – supply voltage indicator, yellow – output indicator, and the red – stability indicator. During this test, 24 V were supplied from a battery and the analog output (voltage) was measured at different sensing distances using terminals three and five to record the output voltage from the voltmeter which ranged 0-10V.

Results

Ultrasonic Sensor: The data were recorded for both outdoor and indoor environment. Although according to the manufacturers it was rated that the sensor can sense up to 8 m, actually it only sensed up to 7.2 m. Hence, the maximum limit was set at that point while data were recorded in the outdoor environment. The voltage output from the sensor was similar in outdoor and indoor. But it was different, when the sensor was wet with water. Water was added to it because; the manufacturer claimed that it will work in rain. The sensor provided reliable signal in the wet condition. The experiment was conducted by 2 inch PVC pipe which was used as the target in order to find out the field of view. The manufacturer did it with 1 inch pipe and 500 mm plate. The experiment was done with 2 inch pipe, because larger target like tree crop is being used. The beam widths for ultrasonic sensors were found to be wide with a maximum of 950 mm. Although, the manufacturer specified the maximum width would be around 1600 mm. the actual maximum angle (17 degees) was smaller than the specified maximum beam angle of 45 degrees. The sensor provided better result in the vineyard (outdoor) for sensing characteristics. The graph illustrating the field of view, angle of view and sensing range of the sensor was found to be quite similar with the manufacturer's specifications which are shown in Fig. 4, 5 and 6, respectively. SAS program procglm was administered to analyze the output and found that there was no significant difference in all conditions. R^2 value of the linear output along with CV and RMSE in given in Table 2. The sensor signal stabilizes during the period of testing and repeatability was great.

Optical Sensors: The Banner optical sensor was tested for its sensing range and FoV in different light detection conditions. The sensor has two indicators; a green LED shows power that the sensor is on and the yellow LED indicates that the sensor is detecting a target. If the yellow indicator flashes, there is marginal excess gain in light condition. The FoV is established by finding the beam width of the sensor in both conditions and is shown in Fig. 7. When light is sensed, it could detect a target till the sensing range of 4.9 m with highest beam width of 47 mm. With marginal excess gain (yellow indicator flashing) the range was 5.97 m, which was similar to the manufacturer's specification of

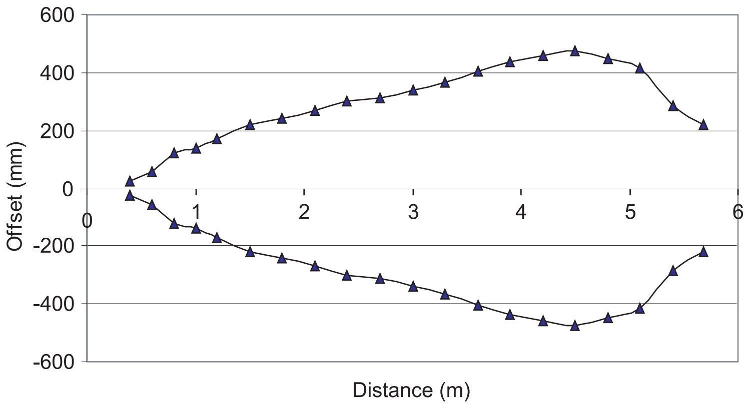

Fig. 4. Ultrasonic Sensor. Field of View from Experiment

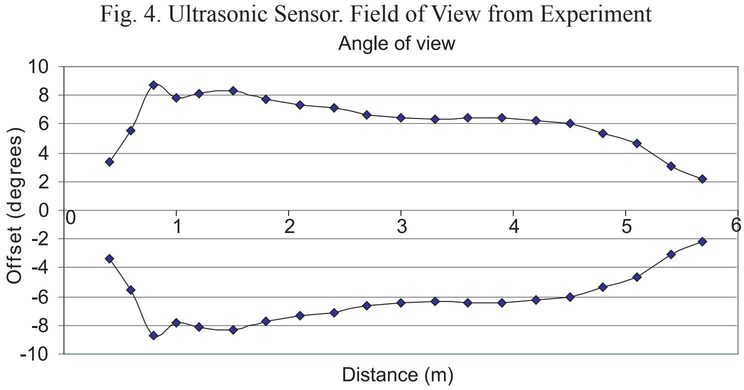

Fig. 5. Angle of view for the Banner ultrasonic sensor

Table 2. Statistical analysis of output of Banner ultrasonic sensor

Environment	R^2	Rep to Rep CV (%)	RMSE	*P* value
Indoor	0.9999	1.14	0.0447	<.001
Outdoor	0.9999	0.53	0.0211	<.001
Wet	0.9998	1.95	0.0829	<.001
All together	0.9969	5.41	0.2185	<.001

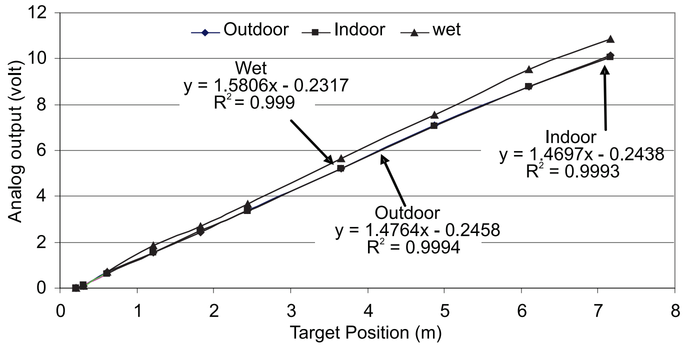

Fig. 6. Ultrasonic Sensor characteristics-Sensing range vs. voltage output in different conditions

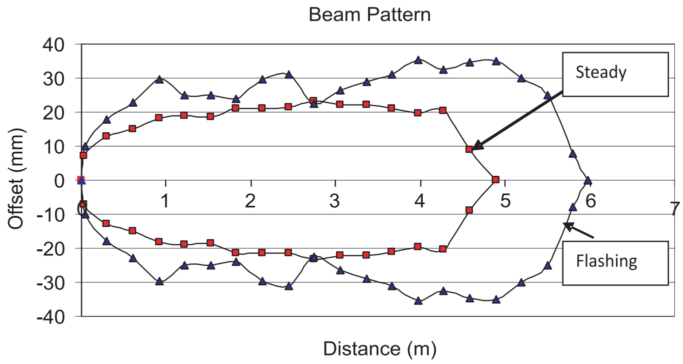

Fig. 7. Optical Sensor. Field of View from Experiment

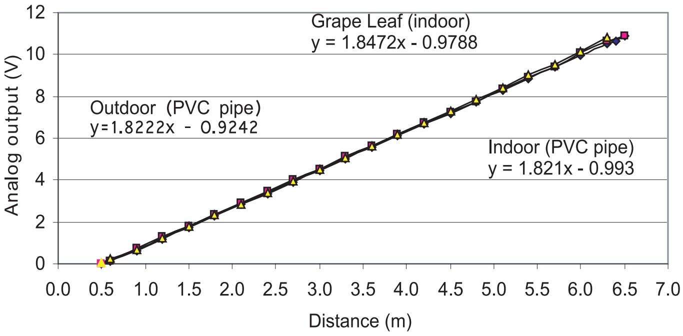

Fig. 8. Trend of output for the Balluff laser sensor

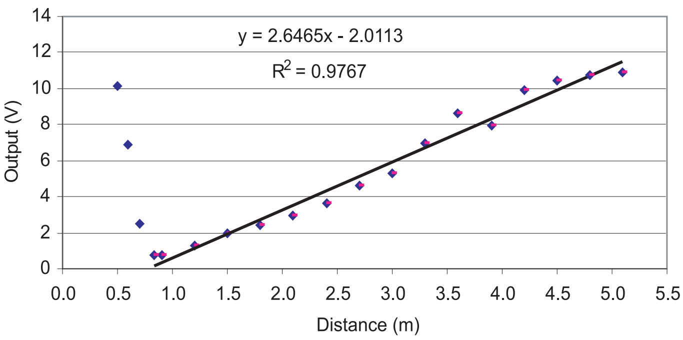

Fig. 9. Trend of analog output of Balluff laser sensor with leaf as target in an outdoor environment

6 m. The maximum beam width was 70 mm in comparison to the manufacturer's specification of 60 mm with is an elliptical shape. The beam width was narrow compared to the ultrasonic sensor.

Laser sensor: The evaluation test was conducted in an outdoor and indoor environment. The sensing range was different for differed colored target and also for indoor and outdoor environment as shown in Table 3 and Fig. 8. The statistical analysis of the signal output is presented in Table 4. The sensing range for grape leaf as target in indoor environment is shown in Fig. 8 and in the outdoor environment is shown in Fig. 9. The laser sensor did not work well in the vineyards. Signal from laser sensor was erratic due to its conflict with sun-shine. It did not detect any object with plant leaves as the laser beam gets reflect and refract by the leaves.

Table 3. Sensing ranges of Balluff Laser Sensor for different colored targets

Target color	Sensing range (m)	
	Indoor	Outdoor
White	6.46	6.42
Black	6.29	6.20
Green	6.43	6.34
Brown	6.46	6.47
Gray	6.40	6.22
Yellow	6.45	6.51

Discussion

Banner Optical Sensors and ultrasonic sensor worked well in vineyards and gave reliable results. Optical sensor has narrow FoV whereas the ultrasonic has a wide FoV. The beam widths were maximum 950 mm and 70 mm for ultrasonic and optical sensor respectively. So, both of them are suitable for detecting a tree. There were problem with the laser sensor and thus a reliable output cannot be determined. Both optical and ultrasonic sensor can be used to find the canopy volume of the vineyard based on distances and eventually predetermined amount of fertilizer can be applied according to the height of each tree. Here, the ultrasonic sensor has a higher sensing range of 7.2 m (Li *et al.*, 2002).

Therefore, it can be said from this study that: (i)Ultrasonic sensor and optical sensor worked well and can be used for VRT of tree crops (vineyards); (ii) The Banner ultrasonic sensor is waterproof and provides reliable signal even in wet condition (iii) Pre-determined amount of fertilizer according to canopy volume or height for each tree (iv) FoV and sensing range should be calibrated for individual tree crop; (v) The laser sensor did not perform at outdoor environment (beam passed through leaves).

Table 4. Statistical analysis of analog output of Balluff Laser Sensor

Environment	R^2	CV (%)	RMSE	P-value
PVC pipe (Indoor)	0.999985	0.30	0.016681	<0.001
PVC pipe (Outdoor)	0.999903	0.89	0.047697	<0.001
PVC pipe (Both Environment)	0.999810	0.96	0.053896	<0.001
Leaf (Indoor)	0.999967	0.46	0.023469	<0.001
All together	0.999646	1.30	0.066358	<0.001

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Submitted: October, 2014; Revised: January, 2015; Accepted: January, 2015