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Feasibility of Ultrasonic Sensors in Development of Real-Time Plant Canopy Measurement System †

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Abstract: A real-time approach based on IoT sensors to detect and measure the canopy size of trees in orchards for plant data collection has been proposed. This work discusses the issues related to sensors, particularly ultrasonic sensors for canopy size measurement. Other core issues related to sound cone measurement, angle error, crosstalk error, and measurement accuracy have also been investigated in depth. Keeping these aspects in mind, this work focused on the usability of these sensors while providing information about environmental structures. The feasibility of this research was tested in a laboratory. The results showed that for large sensor spacings, the interference errors are minimal, and the sensors' field distance measurements are accurate.

Keywords: IoT; digital agriculture; precision agriculture; ultrasonic sensor; plant canopy measurement; error reductions

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1. Introduction

Numeral and visual research of top of the plant arrangements has massive efficacy for phenotypical findings. In such studies, users can automatically obtain information with pragmatic measurements. The improved capacity of techniques in computer processing and the reduced size of recent data measurement devices has supported an exponential increase in plant canopy measurements [1]. Different IoT sensors are used for estimating plant qualities [2]. Traditional application of pesticides has resulted in a drift due to the employment of continuous and non-selective spraying methods without adequate control mechanisms. To counter this drift, Precise Variable Spraying Technology is employed to lessen the effect of pesticide waste and environmental pollution. As mentioned, technology supports automatically adjustable nozzle flow rate, the volume of air supplied, and variable nozzle—tree distances depending upon the canopy characteristics [3–5]. This effective use of precision technology results in an increased productivity and reduced costs of inputs. Electronic sensors have different advantages and drawbacks that depend upon their acquiring cost, processing speed, and data size.

In [6], plant reconstruction was estimated with sonar intensity to measured plant volume density. A cylindrical leaf-distribution canopy model based upon the experimental results was proposed in [7]. Apart from ultrasonic sensor-based detection and estimation systems, researchers have shown interest in and have applied methods for tree canopy detection, using laser sensors and LIDAR. In comparison, LIDAR provides better estimates of the crop variables than ultrasonic sensors. The researchers in [8,9] suggested a real-time canopy quantity recognition system by applying a field laser sensor and inferred the undergrowth external base from top capacity evidence and statistics. Evidently, detection technologies are different in terms of their various inherent characteristics. For example, LIDAR-based detection systems demand high initial costs, are intrinsically complex, and result in large datasets that require large computational resources [10]. Conversely, ultrasonic sensor-based detection mechanisms have a low initial cost, are simple in terms of application, and are more practical in various environments. This paper discusses the general process of canopy reconstruction of plants. Then, the technical defects and reasons for low accuracy are outlined. The sensor's applicability in terms of sound-cone measurement, angle error reduction, crosstalk error reduction, and field measurement accuracy are also assessed in this study.

2. System Model

Ultrasonic sensors involve two modules, one acting as the transmitter and the other acting as the receiver. The transmitter will transform the electrical signal into a high-frequency ultrasonic pulse and the receiver is responsible for receiving the signal that bounces back. When the receiver detects the sonar pulse, it will generate an output signal that is proportional to the magnitude of the distance of the object. The pulses are triggered using microcontrollers; as a result, the ultrasonic transmitter emits a burst of pulses having a frequency of about 40,000 Hz as shown in Figure 1. After transmitting the signal, the receiver is activated for a certain time (38 milliseconds in this study). The calculation of the distance between the object and the sensor is carried out with a microcontroller using following Equation [11].

$$s = txv \quad (1)$$

where 's' is the distance of the object, 't' is the time or width of the pulse sensed by the receiver, and 'v' is the speed of sound. Equation (1) calculates the complete distance traveled by the pulse after transmission and reception at the receiver, which is double the distance between the sensor and object. To find the exact distance of the object, Equation (1) can be written as:

$$s = (txv)/2 \quad (2)$$

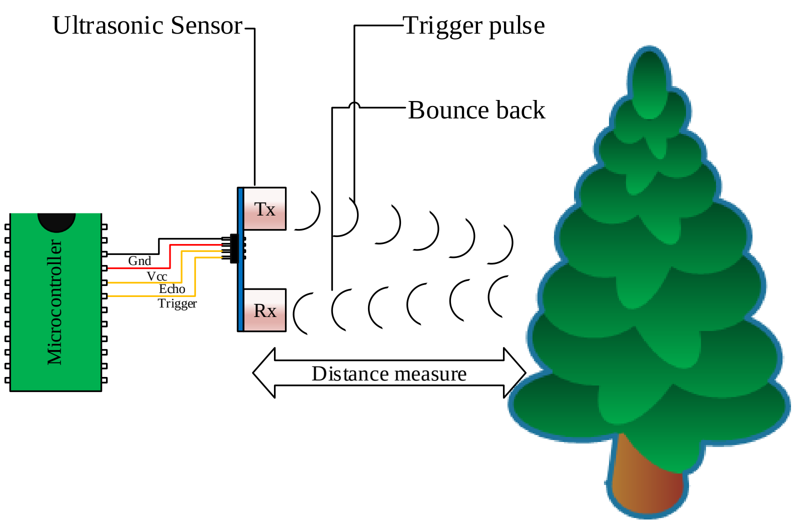

Figure 1. Working principle of the ultrasonic sensor.

Using this feature the plant/tree canopy is recognized using an array of ultrasonic sensors. Multiple sensors are used to gather samples of plant depth at different heights. The microcontroller is continuously reading the data from the sensors so the data from each ultrasonic sensor 'A_A' at the given instance is averaged to determine the cross-sectional canopy of the plants [12].

$$P_c = 2\sum_{j=1}^{j=10} \left(0.5A_R - \overline{A}_{Aj}\right) A_s \quad (3)$$

In Equation (3), 'P_c' is the plant canopy in square meters, A_R is the reference distance, $\overline{A}_{Aj}$ is the jth average distance for a specific time interval, and A_s is the displacement between the ultrasonic sensors. Equation (3) calculates the single cross-section of a plant at a certain instance. The overall canopy of plants is calculated using:

$$v_{PC} = \sum_{j=1}^{j=i} tW_j P_{cj} \quad (4)$$

where v_{PC} is the plant canopy in cubic meters, i is the number of scans or instances in which multiple plant scans are carried out, 't' is the time interval for one scan, W_j is the jth scan for canopy calculation, and P_{cj} is the jth cross section of the plant. The canopy of the plants in our prototype is calculated using Equation (4). Whereas some variables must be set directly, GPS and wheel transponders can be changed in later versions. This paper's research objective was to assess the viability of using a sensor module to calculate the canopy.

3. Results and Discussion

The accuracy of ultrasonic sensors is recognized in this study. Multiple tests related to ultrasonic sensors was conducted to examine their accuracy, which is dependent on distance and the angle of obstacles and sensors. Increasing the number of sensors will decrease the spacing between the adjacent sensors and as a result, interfacing will occur. Table 1 shows the comparison between different sensor spacing distances for the ultrasonic sensors.

Table 1. Comparison between multiple ultrasonic sensors spacing distances.

Object Distance (cm)	Sensor Spacing (cm)			
	30	60	75	90
25	NI	NI	NI	NI
43	I	NI	NI	NI
73	I	I	NI	NI
84	I	I	I	NI
98	I	I	I	I

NI = No Interference and I = Interference.

This method of signal sensing will not obtain accurate information at a given point. The thickness of the ultrasonic signal increases as the signal travels a long distance. As the beam widens, it will bounce back off the first surface that it contacts as shown in Figure 2. This error is dependent upon the shape of obstacle and the distance from sensor.

The sensor angle is also an important parameter for consideration in canopy measurements. This parameter was also tested by changing the spacing of the object and sensor placement angle as shown in Table 2. It was observed that the chosen sensor has satisfactory performance up to 15 degrees at any distance.

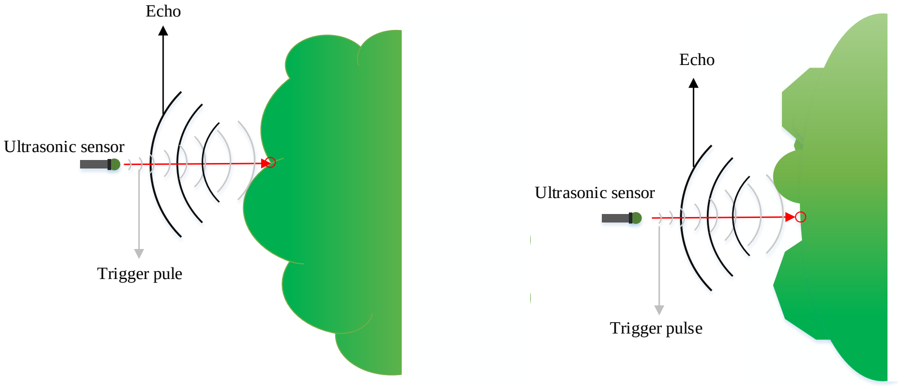

Figure 2. Beam widening of the ultrasonic sensor.

Table 2. Comparison of ultrasonic sensors angle of detection.

Angle	Actual Distance (cm)	Measure Distance (cm)	Error (cm)
0°	55	52	2
	105	108	3
	150	156	6
10°	55	52	2
	105	108	3
	150	155	5
15°	55	53	3
	105	109	4
	150	158	8
20°	55	Out of range	Out of range
	105	Out of range	Out of range
	150	Out of range	Out of range

4. Conclusions

Agriculture has advanced using IoTs for crop management and optimization. In such studies, users can automatically obtain information with pragmatic measurements. The improved capacity of techniques in computer processing has supported an exponential increase in plant canopy measurements and reconstruction studies. Ultrasonic sensor-based detection mechanisms have a low initial cost, are simple in terms of application, and are more practical in various environments. These sensors' applicability in terms of sound-cone measurement, angle error, crosstalk error, and field measurement accuracy are important parameters to observed.

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References

1. Vázquez-Arellano, M.; Griepentrog, H.W.; Reiser, D.; Paraforos, D.S. 3-D imaging systems for agricultural applications—A review. *Sensors* **2016**, *16*, 618. [CrossRef] [PubMed]
2. Blais, F. Review of 20 years of range sensor development. *J. Electron. Imaging* **2004**, *13*, 231–240. [CrossRef]
3. Nan, Y.; Zhang, H.; Xu, Y.; Jiao, X.; Zheng, J.; Liu, D. Research progress on profiling target spray and its control technology in agriculture and forestry. *World For. Res.* **2018**, *31*, 54–58.
4. Jeon, H.Y.; Zhu, H. Development of a variable-rate sprayer for nursery liner applications. *Trans. ASABE* **2012**, *55*, 303–312. [CrossRef]
5. Gil, E.; Escolà, A.; Rosell, J.R.; Planas, S.; Val, L. Variable rate application of plant protection products in vineyard using ultrasonic sensors. *Crop Prot.* **2007**, *26*, 1287–1297. [CrossRef]
6. Palleja, T.; Landers, A.J. Real time canopy density validation using ultrasonic envelope signals and point quadrat analysis. *Comput. Electron. Agric.* **2017**, *134*, 43–50. [CrossRef]
7. Nan, Y.; Zhang, H.; Zheng, J.; Bian, L. Estimating leaf area density of Osmanthus trees using ultrasonic sensing ScienceDirect Estimating leaf area density of Osmanthus trees using ultrasonic sensing. *Biosyst. Eng.* **2019**, *186*, 60–70. [CrossRef]
8. Palacín, J.; Pallejà, T.; Tresanchez, M.; Sanz, R.; Llorens, J.; Ribes-Dasi, M.; Masip, J.; Arno, J.; Escola, A.; Rosell, J.R. Real-time tree-foliage surface estimation using a ground laser scanner. *IEEE Trans. Instrum. Meas.* **2007**, *56*, 1377–1383. [CrossRef]
9. Palacin, J.; Palleja, T.; Tresanchez, M.; Teixido, M.; Sanz, R.; Llorens, J.; Arno, J.; Rosell, J.R. Difficulties on tree volume measurement from a ground laser scanner. In Proceedings of the 2008 IEEE Instrumentation and Measurement Technology Conference, Victoria, BC, Canada, 12–15 May 2008; pp. 1997–2002.
10. Deepak, B.B.V.L.; Bahubalendruni, M.V.A.R.; Biswal, B.B. Development of in-pipe robots for inspection and cleaning tasks: Survey, classification and comparison. *Int. J. Intell. Unmanned Syst.* **2016**, *4*, 182–210. [CrossRef]
11. Morgan, E.J. HC—SR04 Ultrasonic Sensor Datasheet. Available online: https://docplayer.net/23967545-Hc-sr04-ultrasonic-sensor-elijah-j-morgan-nov.html (accessed on 20 December 2022).
12. Schumann, A.W.; Zaman, Q.U. Software development for real-time ultrasonic mapping of tree canopy size. *Comput. Electron. Agric.* **2005**, *47*, 25–40. [CrossRef]