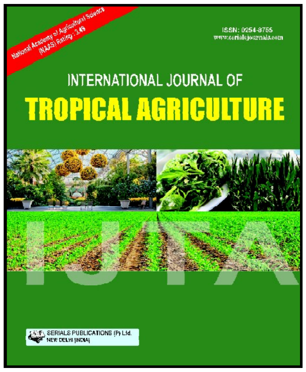

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Sensors and Controller for Efficient Utilization of Agricultural Sprayers a Review

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Abstract: Agriculture plays major role in the Indian economy. In order to achieve higher crop production protection of plants from insects, pest and diseases, sprayers are very important. The different shapes of trees crops even during the same growing season requires a continuous adjustment of the applied spraying dose to optimize the spray application efficiency and to reduce environmental contamination utilization of different sensors and electronic controller is the need of efficient spraying system in this era. For the detection of target very advanced system such as vision systems , laser scanning, or with ultrasonic and spectral systems are being used. Ultrasonic sensor, laser sensor showed better prediction of canopy volume due to high resolution. Ultrasonic sensor and light detection and ranging (LIDAR) sensor used for detection of crop height, width and volume with manual and destructive canopy measurement method. Result indicated that both ultrasonic sensor and light detection and ranging (LIDAR) had good correlation with manual methods, ultrasonic sensor is an appropriate tool for canopy characterisation but LIDAR proved to be a more accurate method.

The sensor based system with microcontroller variable rate spraying system saves the liquid from 70% to 28% for different crops like olive, pear and apple orchards compared to a conventional application.

INTRODUCTION

Agriculture sprayer is an equipment used to apply herbicides, pesticides, and water soluble fertilizers on agricultural crops. Sprayers range in size from manually operated that is backpack with spray gun to tractor operated to self-propelled units similar to tractors with boom.

A pest has been defined as a living organism which causes damage or illness to man or his possession or is otherwise in some sense 'not wanted' (Convay, 1976). Row crops like cotton, different food grain crops are susceptible to large number of pest and diseases right from seedling stage till harvest. In bushy crops like cotton the spray distribution and coverage of spray volume are difficult. Broadly on the basis of application of pesticide, the sprayers are classified as hydraulic and air assisted. Hydraulic sprayers have been used for application of pesticides as spray diluted in water. Air assisted sprayer uses air as a vehicle to carry fine atomized droplets to the target. It employs blower to generate an air blast of sufficient discharge and velocity. The spray fluid is introduced in to air blast in the form of fine droplets. The turbulence in the air blast causes thorough blending of air and spray fluid. This air ladden with spray fluid then proceeds from the sprayer and displaces the original air in the plant canopy, and spay liquid contained in the air is effectively deposited on leaves of the plant. Thus, the small quantity of pesticide is effectively distributed over the target. Air carrier spraying is advantages over conventional hydraulic spraying as 1. These are designed for the concentrate spaying, less amount of water is required and this cuts the time consumed in the frequent refilling of the pesticide tank, 2. It allows pesticide spraying at the faster rate, 3. The plant leaves are ruffled by the spray ladden air stream which penetrates to the dense leaf growth, causing the droplets to deposit on the both surfaces of the leaves. 3. The optimum use of pesticide formulation minimizes the drip loss from the leaves and thereon soil contamination is substantially reduced.

For the row crop like cotton, pesticide sprays are to be taken at different stages from seedling stage to harvest. At seedling stage, there is more spacing between plants which reduces as plant groves. In order to precisely use the pesticide, the empty space between two plants along the row should not be sprayed. In conventional hydraulic boom sprayers multi rows are sprayed, the spraying being commencing continuously, causing loss of pesticide and additional soil contamination. The spraying of farms with overdose of pesticides will result in farmers incurring huge financial losses due to wastage and phytotoxicity, which will decrease the yield. However, the major risk of overdose or under dose is the increased likelihood for the pests to develop resistance against pesticides, which can have devastating large-scale effects on cocoa production (Meijden, 1998). Excessive use of chemicals such as pesticides, fungicide and herbicide expectedly resulted in wastes and residues in foods and emission to the air and soil, which had potential adverse effects on human health and environment (Gil & Sinfort, 2005; Pimentel *et al*, 1992)., Hence, it is necessary to use the sensor based intermittent spraying system which can sense the plant along row, to make the spraying system operate and put off as soon as the empty space between two plants commerce.

1. Smart Spraying System

Thus, a smart spraying system generally consists of target detecting system with chemical spraying system.

There are two core technologies for autonomous chemical spray system.

1. Sensing technology for target detection (machine vision, spectral detection) : Target detection sensing technology includes targeted detection sensors, data processing and decision making system
2. Spraying systems includes spraying control unit and sprayer (nozzle): Robotics for spray execution (micro-spray, cutting, thermal, electrocution)

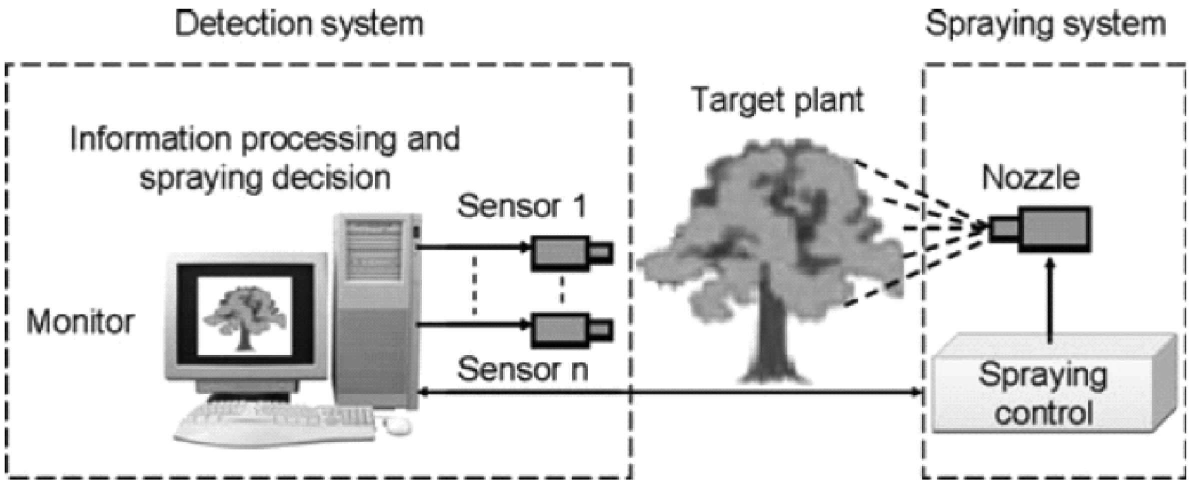

Figure 1

1.1. Application of spraying with technology

1.1.1 Broadcast spraying is traditional method applied with great inefficiency, it often resulted in up to 60–70% off-target losses (Edward Law, 2001).

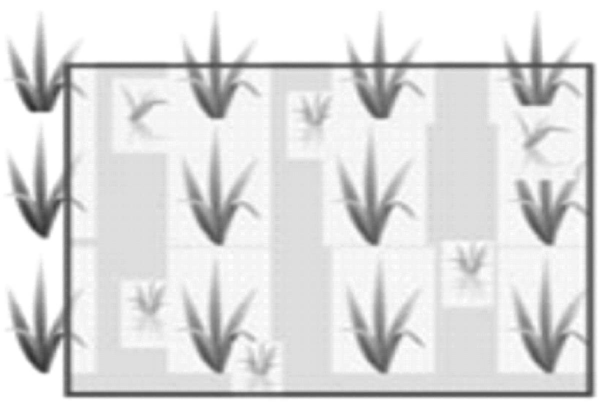

Figure 2

1.1.2 Band spraying :In Band pattern spray application is on selected region instead of all of broad area. Band application and mechanical practice not only showed that reductions in chemical use but that subsequent careful selection of chemicals can also lead to minimal environmental impact. (Giles & Slaughter, 1997; Netland, Balvoll, & Holmøy, 1993; Niazmand, Shaker, & Zakerin, 2008; Wijnands, 1997).

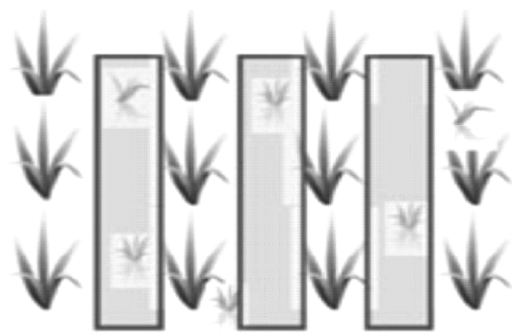

Figure 3

1.1.3.Targeted spray In targeted spraying system the detection of target in the field and then control the spraying operation accordingly depending upon the canopy of the crop . Research showed that with targeted spraying system 41% reduction in ground deposition and reduced pesticide concentration in surface water runoff by 44%.

(Brown, Giles, Oliver, and Klassen, 2008)

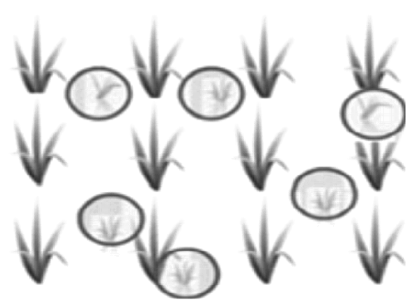

Figure 4

1.2. Target Detecting System

For efficient and low-labor production in agriculture, the target detection focuses on weed classification and position detection, infected plant detection and severity estimation in the field. In weed control, weeds, crops or trees are basic detected objects.

There are currently two research directions: One is weed identification, in which all plants are detected, and weeds are identified; the other one is crop detection, in which the crop plants are detected and all other plants are considered as weeds.

In pesticide management, plant growth status, which related to disease incidence and severity level, were usually measured and analyzed. In orchard chemical spraying, the target detection general focuses on plant position, canopy volume, disease incidence and severity level.

A sensors used for the target detection are generally based on spectrum technology which includes absorption of electromagnetic wavelength from 10^{-3} nm to 10^{9} nm According to the spectrum range, image could be divided into color image (RGB image in visible band) and spectral image (visible and NIR band). Color image is a most familiar descriptor by human scene, which includes RGB (red 600–700°nm /green 490–600° nm / blue 400–490°nm) color information for each pixel. The spectral image is generally indicated to the image, which presents information not only in visible band but also near-infrared band. All sensor works on the spectrum technology for detection of target Image sensor, Spectrometer, Remote sensing, Thermograph, ultrasonic and laser sensor

1.2.1. Spectrometer is an instrument spectral reflectance of light over a specific portion of the electromagnetic spectrum Green plants typically display low reflectance in a visible region of the spectrum due to strong absorptance by photosynthetic and accessory plant pigments.

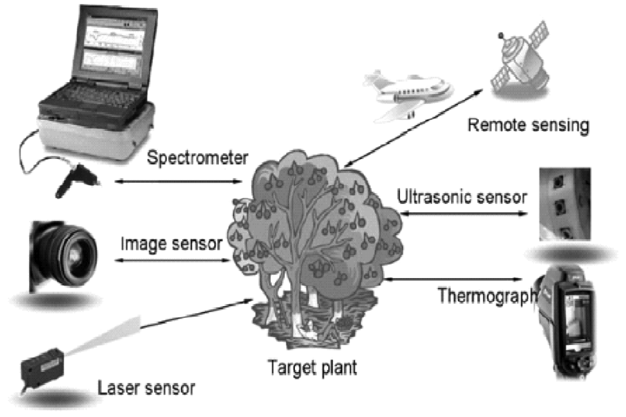

Figure 5

Vrindts, De Baerdemaeker and Ramon (2002), measured canopy reûectance of sugar beet, maize and weed with a line spectrograph (480–820nm). Three wavelengths (511.1 nm, 588.1nm and700.3nm) were analyzed for the classiûcation of maize and weed; The results showed that broadleaved plants.(sugarbeet) were easily distinguished from weeds. According to the spectral characteristics of stems and leaves of various crop and weed species, ûve wavelengths (496 nm, 546nm, 614nm, 676nm, and 752nm) within the visible and NIR wavebands were selected to build colour indices in the form of normalized difference.

Figure 6

1.2.2. An image sensor is an electronic device that converts an optical image into an electronic signal. It is used in digital cameras and imaging devices to convert the light received on the camera or imaging device lens into a digital image.

1.2.3. Thermograph An instrument that produces a trace or image representing a record of the varying temperature or infrared radiation over an area or during a period of time. The thermographic camera detects radiation in the infrared range of the electromagnetic spectrum (900–1400° nm) and produces images of the radiation. Lenthe, Oerke, and Dehne (2007) used an image infrared thermography system, with high spatial resolution, to monitor the microclimatic conditions promoting incidence and severity of disease within wheat fields. The results indicated that the potential of thermography for detecting plant health was highest with regards to water status.

1.2.4. Ultrasonic sensor Ultrasonic sensor is used for the measurement of distance it emits the ultrasonic wave and and receive the wave reflected back from the target. It measures the distance to the target by measuring the time between the emission and reception. Distance L is calculated by following formula

$$\text{Distance } L = 1/2 \times T \times C$$

where L is the distance,

T is the time between the emission and reception, and C is the sonic speed.

(The value is multiplied by 1/2 because T is the time for go-and-return distance.)

1.2.5. Laser scanning system Laser scanning, also known as LIDAR, is a surveying technique for collecting a three-dimensional (3-D) point cloud of the reflected objects that uses laser ranging and detection, scanning, positioning and orientation measurement techniques. Several types of laser scanning systems currently exist, such as: airborne laser scanning (ALS), terrestrial laser scanning (TLS) and mobile laser scanning (MLS).

- A laser generates an optical pulse that is shaped and expanded to reduce its divergence.
- It is then directed toward the scene to be interrogated by a scanner.
- The backscattered light is directed into a collector (e.g., a telescope), where it is focused onto a photosensitive element.
- The resulting electronic signal is filtered to remove noise and analyzed to determine the time of arrival of the reflected optical signal.
- The distance to the scene at the point where the transmitted light was reflected is determined by the round-trip time of the radiation.
- The scanner repositions the interrogation point and the process is repeated.

1.3. **Target detection system**: from all of above sensor most commonly sensor used for the target detection is Ultrasonic sensor and Laser sensor following review explain how this sensor work in the field for

1.3.1. **Ultrasonic sensor** : Ultrasonic waves are relatively affordable robust during outdoor conditions, and capable of estimating the canopy volume of trees satisfactorily have been used by several researchers .advantages of using ultrasonic sensors are waves can reflect off a glass or liquid surface and return to the sensor head, even transparent targets can be detected. Detection is not affected by accumulation of dust or dirt. Presence detection is stable even for targets such as mesh trays or springs. Also it is capable of estimating the canopy volume of trees satisfactorily therefore it has been used by several researchers.

Zamahhn and Salyani (2004) used ultrasonic sensors with microprocessor to quantify and map tree canopy volume. In his experiment, he used ten ultrasonic sensor with the microprocessor which were mounted on vertical mast.

The sensor spacing was 0.46m. The system was moved to three ground speed 1.6,3.4 and 4.7Km/h to quantify half canopy volume of selected tree. He took fifteen densely foliated (dense) and 15 partially defoliated (light) citrus trees. The measurements were compared to those calculated from manual measurements of the tree dimensions. Result indicated that ground speed had no significant effect on ultrasonic measurements.

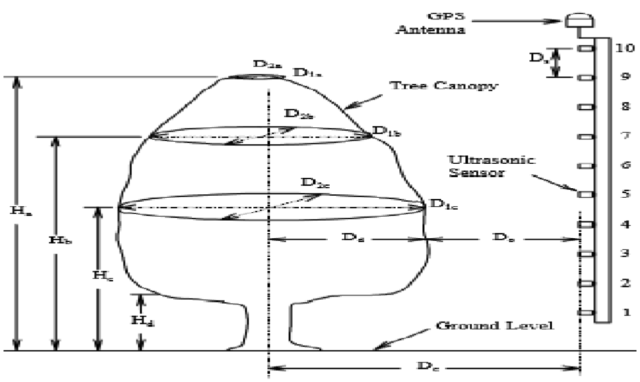

Figure 7

Giles *et al.* (2007) used a commercially available ultrasonic sensor to detect apple trees and developed, an electronic control system to allow measurement of changes in the crop structure and modification of the total applied volume according to those changes. A mast was fitted on its left side with three ultrasonic sensors and three solenoid electro-valves. These were at the same level of each nozzle set. All three sets were connected to the central control unit with the corresponding software and automation placed on the top rear of the sprayer.

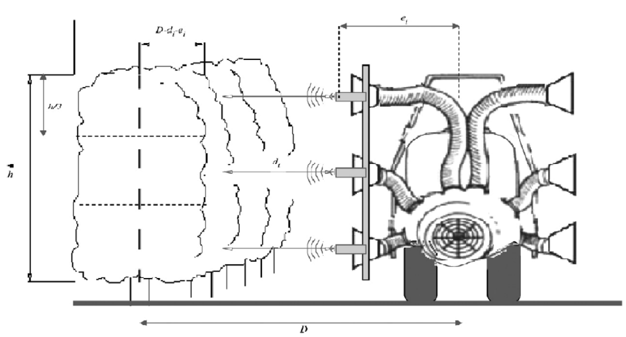

Figure 8

Field tests reported that the sensor was relatively precise in measuring tree width (with less than 10% average error).

Percentage of saving at different height

	Left	*Right*	*Total*
Top	86.9	32.7	59.8
Bottom	48.7	48.0	48.4
Middle	52.2	83.9	68.1
Total	62.6	54.9	58.7

The total flow rate sprayed by the nozzles was modified according to the variations of crop width measured by the ultrasonic sensors. On average 58% less liquid was applied compared to the constant rate application, with similar deposition on leaves with both treatments.

Jeon *et al.*(2011),studied the durability of ultrasonic sensor for measurement of canopy size by evaluating it in simulated field condition ,changing travel speed had no significant effect on sensor detection but increase in ambient temperature from 16.7 to 41.6 degree reduced the distance by 5 cm. They used, water proof ultrasound sensor (LV-MaxSonar WR1, Maxbotix Inc, Brainerd, MN, USA). The sensor was rated as IP (ingress protection) 67 which refers to dust tight and 1-m water immersion protection (CENELEC, 2000). The sensing resolution was 3.82 mV/cm with an approximate beam angle of 10°. The sensor body was constructed with a pipe connector and cable grip to protect the sensor under the outdoor conditions (Fig. 2). Sensor IP67 rated sensor because of its fast detecting frequency (20 Hz), necessary for higher travel speeds, and the acceptable minimum detecting range (30.48 cm) for tree liner application. In addition, due to sensing signal interference, the DW sensors were unable to simultaneously detect canopy range, which is a critical issue for dense liner field conditions. 2.2. Data acquisition system To acquire data from sensors, a custom-designed data acquisition system was built with a peripheral interface controller (PIC) (PIC18F4523, Microchip technology Inc., Chandler, AZ, USA). The PIC triggered the sensor and received analog signals from the sensor. By using the embedded 12-bit analog-to-digital (AD) converter module of the PIC, the signal was converted to a discrete digital number ranging from 1 to 4096. The data acquisition and sensor system resolution in measuring distance was 0.32 cm. After the AD conversion, the digital information was sent to a laptop computer via serial communication. To acquire the data, a user interface was written using Visual Basic.NET

Wandkar *et al.* (2016) developed air assisted variable rate sprayer with three main systems an electronic variable rate control system, spray supply system and air delivery system.

The sprayer consisted of two nozzles mounted on a vertical boom. Two ultrasonic sensors were used for canopy size detection. Pulse width modulated (PWM) proportional solenoid valves were used for spray modulation. A micro controller based on Arduino software was fabricated to control the ultrasonic sensors and proportional solenoid valves. Determined discharge through nozzles. Result showed that increase in air velocity increased spray deposition at all selected plant positions whereas forward speed had the non-significant effect on spray deposition. The higher spray deposition was observed on upper leaf surface at the top, middle and bottom plant position.

1.3.2. Laser scanning system Laser scanning, also known as LIDAR, is a surveying technique for collecting a three-dimensional (3-D) point cloud of the reflected objects that uses laser ranging and detection, scanning, positioning and orientation measurement techniques. Several types of laser scanning systems currently exist, such as: airborne laser scanning (ALS), terrestrial laser scanning (TLS) and mobile laser scanning (MLS).

Figure 9

Tumbo *et al.*, (2002) conducted a study on comparison of ultrasonic and Laser measurement of citrus canopy volume with manual measurement in comparison with the ultrasonic sensor, laser sensor showed better prediction of canopy volume due to high resolution.

Wei and Salyani (2004 and 2005) used a laser scanner with an offline processing algorithm to scan the citrus canopy. Based on the scanning data they calculated the canopy characteristics such as tree height, width, canopy volume, foliage density and tree boundary profile. An artificial target was tested and the results showed an accuracy of 97% for the length measurement. The density estimation was found to have good correlation with the visual assessments.

Rosell *et al.* (2009) used a laser scanner mounted on a tractor to scan selected trees of a vineyard and a pear orchard several times before and after defoliation. The scanned data was then used to build

Figure 10

3D images to determine geometrical and structural parameters of the vegetation such as volume and leaf area of trees. These geometrical and structural parameters were compared with crop leaf surface values obtained by manual measurements.

Results have shown a good linear correlation between the canopy volume calculated from the laser measurement and the total foliage area from the manual measurement.

Figure 11

Liorens *et al.*, (2011) compared ultrasonic sensor and light detection and ranging (LIDAR) sensor for crop height, width and volume with manual and destructive canopy measurement method result indicated both ultrasonic sensor and light detection and ranging (LIDAR) had good correlation with manual methods, also they concluded ultrasonic sensor is an appropriate tool for canopy characterisation but LIDAR proved to be a more accurate method.

CONCLUSIONS

1) Smart sprayer with controlled spraying should be designed for special applications
2) The sensors most commonly used to measure tree canopy characteristics are ultrasonic sensors or laser scanners.
3) Ultrasonic sensors have the advantage of being simple to use and low cost; however, due to the divergence angle of sound waves, its error increases with the increases in distance measured. Also, their accuracy can be affected by the ambient temperature, humidity and even the tractor ground speed.
4) Laser scanning is relatively more expensive but has advantages such as higher accuracy, scanning mode rather than the single point measurement as is the case when using ultrasonic sensors.
5) The average 58% less liquid was applied compared to the constant rate application, with similar deposition on leaves with air assisted spraying.
6) Result showed that with targeted spraying system 41% reduction in ground deposition and reduced pesticide concentration in surface water runoff by 44%.

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