Plant Archives Vol. 24, No. 1, 2024 pp. 411-418 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2024.v24.no.1.057

DEVELOPMENT OF AUTOMATED PESTICIDE APPLICATION SYSTEM

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(Date of Receiving-15-10-2023; Date of Acceptance-24-01-2024)

ABSTRACT

Over an extended duration, concerns have been mounting due to the excessive use of pesticides in crop management. Conventional spraying techniques, which utilize sprayers with a consistent application rate, lead to each plant receiving an identical dosage of pesticides. This inefficiency becomes particularly evident when applying pesticides between rows, resulting in significant chemical waste. To address this challenge, an innovative real-time robotic spraying system has been developed to ensure precise and targeted pesticide application. System is composed of robotic unmanned vehicle, ultrasonic wave-based sensor, microcontroller board, electronic pump, nozzle for dispensing pesticides and a solenoid valve unit. The time interval between sensing and solenoid actuation exhibited variations ranging from 0.42 to 0.63 seconds. The performance was assessed based on parameters such as droplet size, density and uniformity coefficient and spray deposition across different plant positions. Utilizing deposit scan software, the droplet size recorded for Gerbera plants ranged from 227.56 μm to 241.65 μm. Meanwhile, droplet density, uniformity coefficient, and spray deposition ranged from 27.50 to 31.20 drops/cm^2, 1.67 to 2.17 and 0.81 to 0.87, respectively. Notably, the observed liquid savings in Gerbera plants ranged from 25.77% to 31.73%. Consequently, the crop-specific robotic sprayer demonstrated a significant reduction in pesticide losses compared to conventional spraying methods.

Key words : Droplet size, Robotic unmanned vehicle, Solenoid valve, Sprayer.

Introduction

The predominant challenge confronting humanity in meeting the demands of a growing population lies in the simultaneous increase in population and the constrained availability of arable land. This urgent issue has prompted researchers worldwide to shift away from conventional agricultural approaches toward automation and robotics. The judicious use of chemicals assumes a vital role in the agricultural production process, serving to protect crops and enhance overall yield. Pests, including insects, weeds and diseases, contribute to substantial losses, accounting for 35 to 45 % of crop production. Additionally, approximately 35% of crop productivity is compromised during storage (Anonymous, 2022). It is essential, in order to achieve higher crop yields, to provide protection for plants against diseases, pests, and insects. Controlling the damage caused by insects, weeds and diseases can be accomplished by a variety of approaches, including biological control, host resistance, cultural control, physical and mechanical control. Among all the existing methods chemical method is most popular because of ease of operation and wider approach.

A substantial portion of insecticide applied through conventional sprayers is lost due to off-target factors like airborne drift, runoff and evaporation. Traditional sprayers lack the flexibility to adjust spray output once activated; a fixed amount of liquid is dispensed irrespective of the presence, height, width, or shape of the target tree. Significantly, pesticides are wasted in inter-tree spaces, above smaller plants and around tree trunks beneath canopies. Consequently, excessive pesticide use not only leads to financial losses for farmers, but also heightens the environmental pollution risk and jeopardizes the health of workers and residents in the vicinity.

In the existing pesticide spraying setup, the manual spraying method exposes farmers to potential health risks, particularly airborne and waterborne infections. Many countries currently face a shortage of skilled labor in the agricultural sector, thereby impeding the progress of developing nations. Until now the technologies used in farms are outdated and the present farming needs revolutionary technique of farming (Vikram, 2020). Farmers must therefore employ updated technologies for farming activities (spraying, digging, fertilization, seed sowing, etc.) (Abdulrahman, 2017; Pawase *et al*., 2023a). It is now necessary to automate the sector in order to solve this problem, which will also reduce labor demand and also helpful for environment.

In recent times, robotics has solidified its role as a vital tool for precision application of agricultural inputs. Advanced agricultural robotics are introducing a new era in farming practices, displaying increased intelligence, the ability to identify field variability, reduced energy consumption and adaptability for more versatile tasks. This is entirely due to the advancement of agricultural robotics (Gatkal *et al.*, 2022). The usage of robots is widespread in other countries despite the fact that this technology is still relatively new. Considering the shortage of labor, health risk and extreme environmental conditions has stressed for precise application of chemicals by unmanned vehicle. In light of this an attempt has been made to develop an automated vehicle for on target chemical dispensing.

Materials and Methods

This section outlines the methodology employed in the creation of an automated robotic vehicle designed for targeted pesticide dispensing in agriculture. It details the development process, validation procedures and the performance evaluation conducted on crops. Automated robotic vehicle for dispensing on target pesticides in agriculture was developed at the Dr. ASCAET, MPKV, Rahuri. Plant from an institutional farm of Gerbera (*Transvaal daisy*). The performance was evaluated in same laboratory with latitude 19°34’92’’ N and longitude 74°64’61’’E.

Development of robotic vehicle

The robotic car is a prime mower of the sensor based sprayer. Robotic car consists of a microcontroller (Node MCU ESP8266), motor driver module (L298N), battery (3.7 V, 2200 m Ah), motors (300 rpm BO) and wheels. Circuit diagram of robotic car is shown in Fig. 1.

Programming of robotic car was done using Arduino IDE software in C^{++} language. For varying the speed of the motor from 0.55 to 1.11 m/s, the PWM capability was used. The node MCU car is operating using ESP 8266 mobile software.

Development of sensor based spraying system

The primary objective of the robotic spraying system was to reduce pesticide usage by activating the spraying system only when the plant canopy is present. The developed robotic spraying system comprises a robotic platform for mounting the sprayer, a sensing unit to detect the target, a data processing unit (microcontroller unit) to receive and process data from the sensing unit, and a Spray control unit for dispensing chemicals through spray nozzles at the desired flow rate.

Algorithm of spraying unit

The signals to be sent for actuation of solenoid valves after detecting the plant canopy was developed for on target chemical dispensing. The programming written in embedded C using Arduino Uno integrated development environment (version 1.8.19, Arduino, USA). The initial sketch of the program was written in arduino IDE and was uploaded in Adriano microcontroller board for execution. The flow chart of the developed program is shown in Fig. 2.

Development of controller system

The controller system received a signal from the ultrasonic sensor via Arduino UNO microcontroller board. Based on the algorithm, the signal was activated in presence of plant canopy, which intern actuated the solenoid value to allow the atomization and transfer of spray liquid from nozzle to the surface of plant canopy. The controller system consisted of Arduino microcontroller board (Arduino Uno ATMega328p), Relay module (5V DC), Ultrasonic sensor (4 m range, 5V DC), Solenoid valve (12 VDC, ½”), Battery (12V, 7Ah) and Pump (4 l/min, 12 VDC).

Control unit

The control was responsible for receiving data from the Ultrasonic sensor, and actuating the solenoid valve to dispense the liquid on the plant canopy. The schematic diagram of control unit (Fig. 3) shows how the opening of solenoid valve is controlled. To achieve the required flow rate of nozzle, a solenoid valve was used. Solenoid valve was controlled by the microcontroller based on the input from the ultrasonic sensor. The 5 V DC Relay modules were used to on/off the solenoid valve.

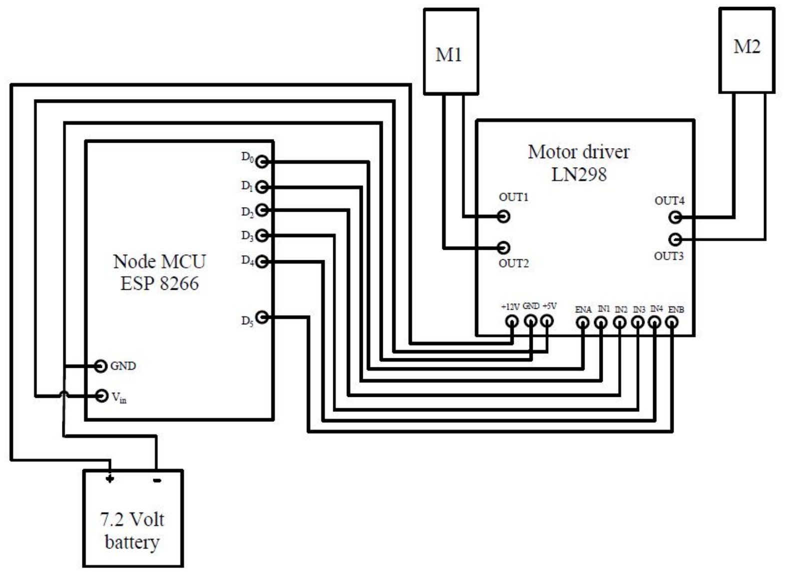

Fig. 1 : Circuit diagram of robotic car.

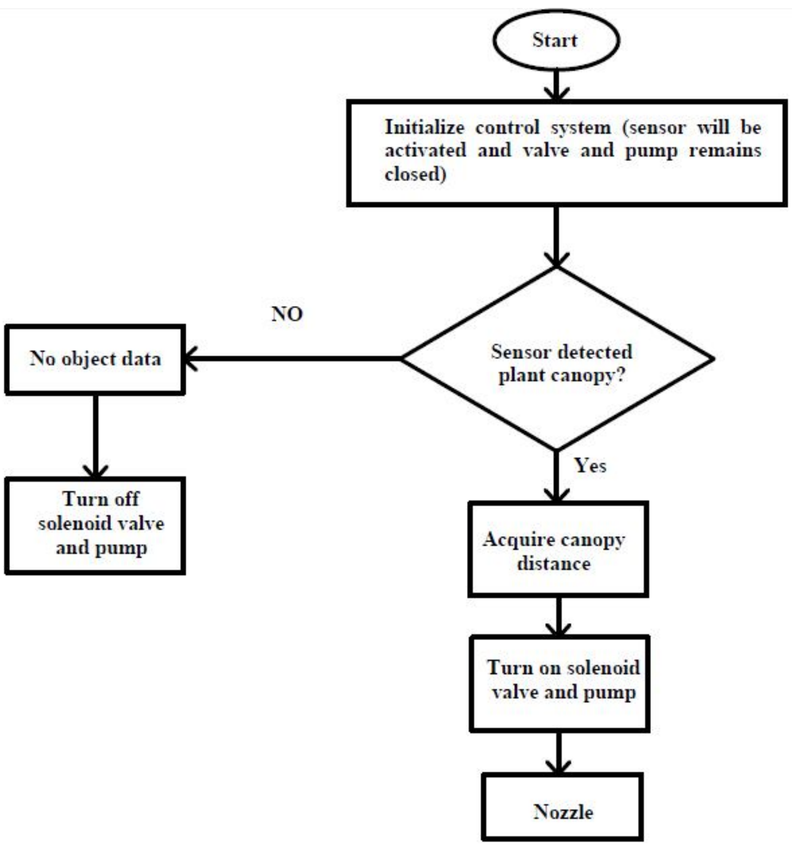

Fig. 2 : Flow chart for functioning of microcontroller unit.

Sensing unit

In the real-time spraying technique, accurate detection of the target canopy is of utmost importance. The selected sensor must possess the capability to provide data swiftly and precisely. In order to determine the canopy of the plant that was being studied, a high-speed ultrasonic sensor with the model number HC SR-04 was utilized. Since, the newly developed spraying system only has capacity for a single nozzle, only a single ultrasonic sensor has been installed. An ultrasonic sensor performs its function by first sending out ultrasonic waves from its sensor head and then collecting those same ultrasonic waves that are reflected from an object (Fig. 4). It determines the location of the object by measuring how long it takes for the sonic wave to travel from its source to its destination and measuring that interval of time. Through the use of the built-in teach-in feature, the ultrasonic sensors that were chosen can be trained to detect things at distances of up to 4 meters. The sensors were configured to detect the items within a range of 50 cm, taking into consideration the other factors that were included in this study. The sensor was generating an analogue voltage output of 5 V for the range that was selected. The output of the sensor was designed to decrease with increasing range, so that it would give the maximum voltage reading for the object that was closest to it. The microcontroller was used to manage the sensor, which received a supply of 12 volt (DC) through a PVC cable with a four-pin connector. During operation, after initialization of sensor, sensor starts to detect the object and after detecting the object it measures the distance of surface of the object from its tip. This data was then processed through algorithm in data processing unit to deliver amount of spray to be sprayed. The developed robotic spraying system is illustrated in Fig. 5.

Spray delivery and control unit

Spray delivery system consisted of a pesticide tank, electronic pump, flow control panel, solenoid valves and nozzles. During operation, pump and nozzles were controlled via solenoid valves which were controlled by micro-controller board based on sensor output.

Solenoid valve

The normally closed solenoid valves (12V DC) of 1/2" size having maximum operating pressure of 0.8 M Pa were used to control the flow rate of nozzles. As the developed system had one nozzle, the solenoid valve was connected to nozzle, to control that nozzle output in a fast and reliable manner. The valve was supplied with 5 V

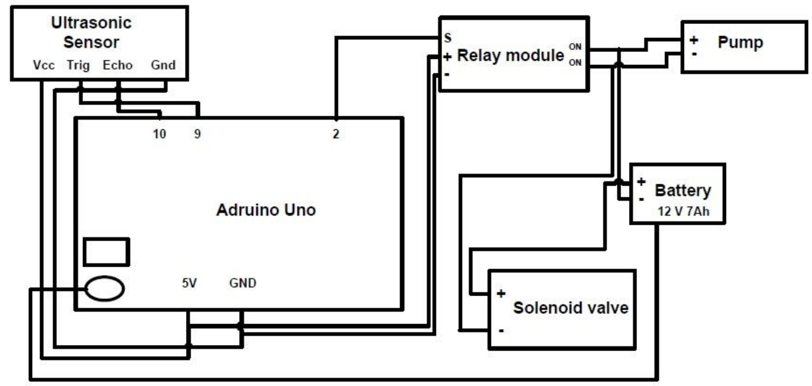

Fig. 3 : Control unit circuit.

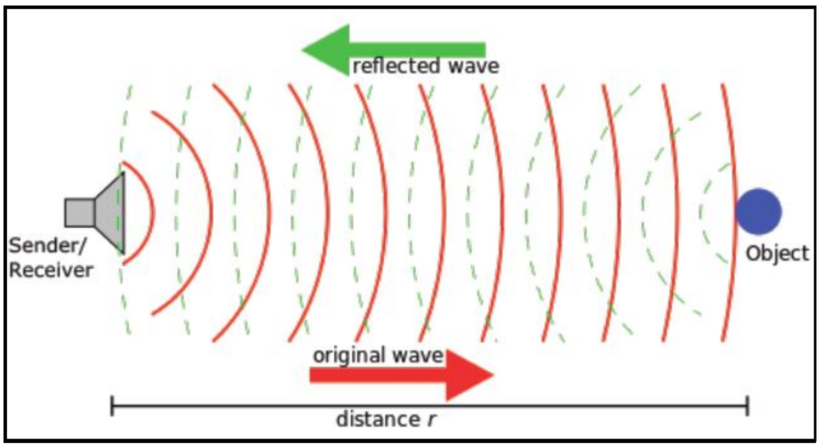

Fig. 4 : Working principle of ultrasonic sensor.

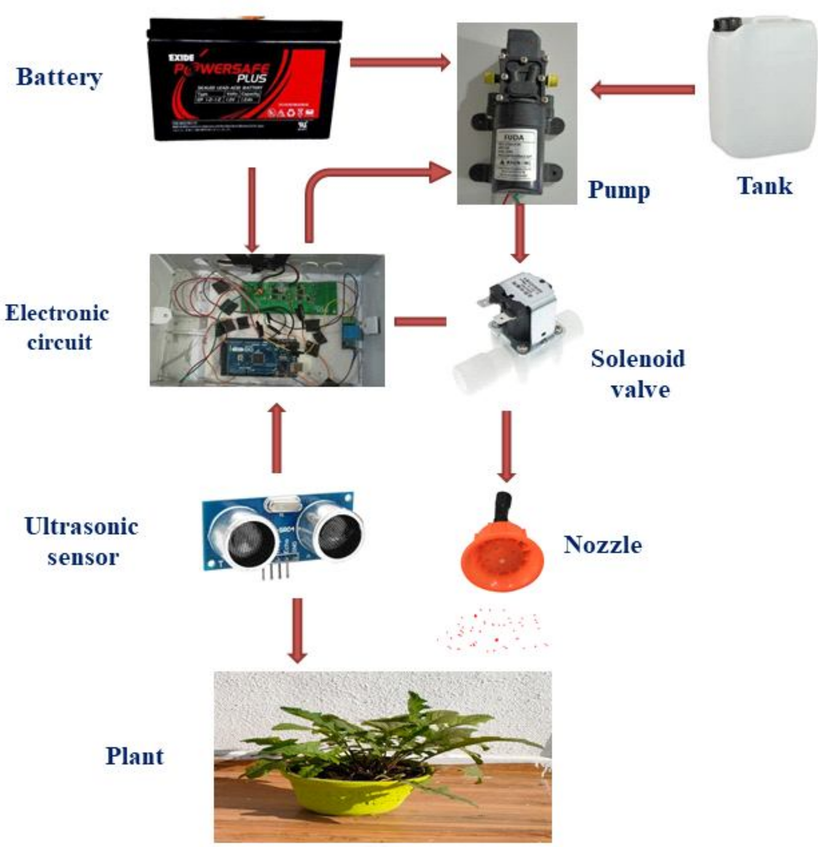

Fig. 5 : Robotic spraying system.

(DC) supply.

Pesticide tank

A plastic tank of capacity 1 liter was used as a pesticide tank. To avoid entry of dust and debris in pumping system, a fluid filter was provided, which had MS mesh screen to filter any debris from spraying fluid.

Pump

An electronic pump was used to generate pressure on the spray fluid, which worked in the oil bath and produced maximum discharge of 4 l/min at the maximum operating pressure of 7 kg/ cm^2. The output of the pump was connected to inlet of solenoid valve.

Nozzles and spray delivery hoses

The hollow cone and flat fan nozzles were selected for study, which has spray angle, flow rate and operating pressure 43-180°, 0.19-1.2 l pm and up to 7 kg/ cm^2, respectively.

Development of robotic sprayer

Based on electronic control system for on-the-go application, a complete robotic sprayer was developed. The sprayer consisted of two main systems namely; spray delivery system with electronic system and robotic vehicle. The whole assembly of sprayer was mounted on the frame. The developed robotic sprayer is shown in Fig. 6.

Performance evaluation of developed robotic sprayer

Laboratory tests were conducted to evaluate the performance of the developed robotic sprayer for selected dependent variables at different levels of independent variables. This study was carried out on Gerbera (*Transvaal daisy*) plant.

Variables of the study

Independent variables

Following independent variables were selected to study their effect upon the dependent variables.

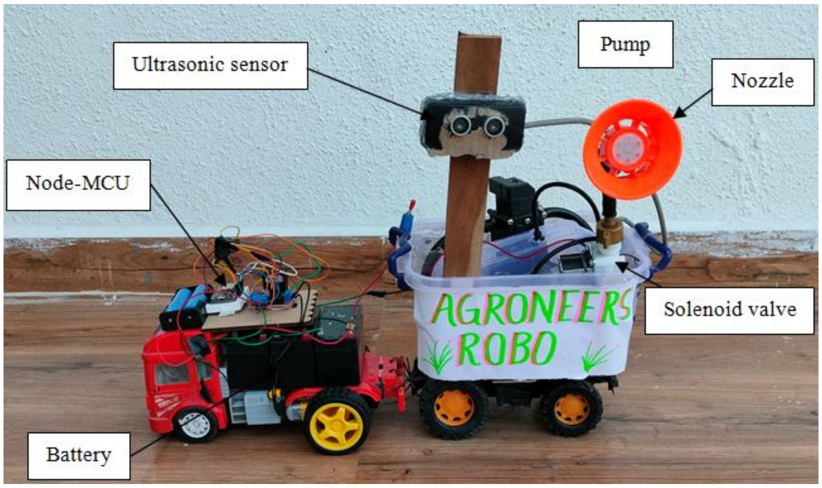

Fig. 6 : Developed robotic sprayer.

S. no.	Variable	Unit	Levels
1.	Forward speed	m/s	0.55, 0.83 and 1.11
2.	Type of nozzle	—	Hollow cone and Flat fan nozzle

As per the BIS test code IS 15191:2012, Equipment for crop protection – test methods for sprayers for field crops (Anonymous, 2012), speed of operation of sprayer for dynamic test should be up to 4 km/h (1.11 m/s), considering this, three levels of forward speed were selected as 0.55, 0.83 and 1.11 m/s to signify different forward speed requirements in crops.

Selection of proper nozzle is very essential for effective pesticide application. Hollow cone nozzles are commonly used in India for pesticide application. Also use of flat fan nozzle is more popular for orchard pesticide application. Considering this, both nozzles were selected for study for their significance on selected dependent variables.

Fig. 7 : Gerbera plant with water sensitive paper.

Dependent variables

In agricultural spraying, droplet size and droplet density have significant effect upon effectiveness of spraying operation (Pawase *et al.*, 2023 (b)). Droplets within optimum range needed to be applied to achieve greater uniformity. Following are the dependent variables were selected for the study.

1. Droplet size, µm
2. Droplet density, no. of droplets/cm^2
3. Uniformity coefficient
4. Spray deposition, µl/cm^2

Droplet size

Droplet size is defined by the diameter of an equivalent sphere having the same property (such as volume or mass) as the analyzed droplet. It is measured in µm.

Uniformity coefficient

Uniformity coefficient is ratio of volume mean diameter (VMD) to number mean diameter (NMD).

$$Uniformity\ coefficient = \frac{VMD}{NMD} \quad (1)$$

Droplet density

The droplet density is important parameter along with droplet size for the quality of the spray. The number of droplets per unit area was termed as droplet density.

Spray deposition

Spray deposition is ratio of volume of spared liquid to total area. It is measured in µl/cm^2.

Measurement of droplet depositions

The laboratory experiment was carried out to investigate the effect of various experimental parameters on spray deposition at various positions on the plant. To collect droplets and analyze droplet sizes, 26×76 mm water sensitive papers (WSP) were used (Abdullah *et al.*, 2017; Pawase *et al.*, 2024). The purpose of these cards is to highlight areas, where droplets fall. During experiment, WSP were mounted at different locations on plant (Fig. 7). Testing of developed robotic sprayer on gerbera plant is shown in Fig. 8.

Spray data acquisition and processing

The water sensitive paper (WSP) samples were collected carefully by wearing gloves after drying, and

Fig. 8 : Testing of developed robotic sprayer on gerbera plant.

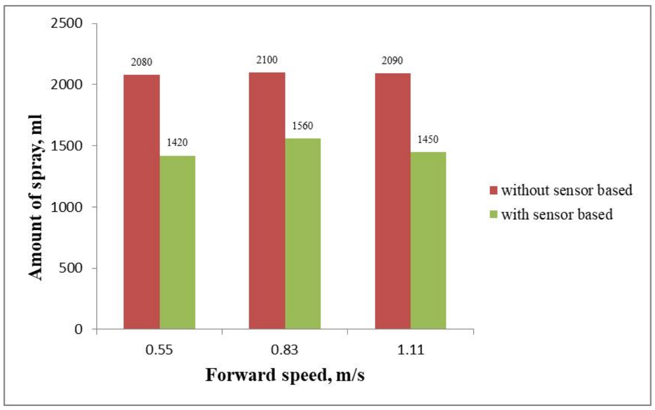

Fig. 9 : Spray liquid consumption obtained in gerbera plant.

they were then sealed and labeled in zip lock bags. These samples were then placed in a dry insulated box for safe transport into the laboratory for further processing. The scanning process was carried out for each individual WSP sampler using a high-density lab scanner with a 600 dpi image resolution. Using industry-leading WSP image scanning and processing software (Deposit Scan software version 1, USDA ARS, Wooster, OH, USA), from the scanned WSP was calculated in accordance with the researcher's recommended technique (Ahmad *et al.*, 2020; Zhu, *et al.*, 2011). The deposition, droplet density, droplet coverage, and the variation in droplet sizes can all be measured using the Deposit Scan software. Uniformity coefficient was calculated by taking the ratio of volume median diameter and number median diameter.

Calculation of liquid consumption

One of the major goal of this study was to determine if the developed robotic sprayer operation would result in considerable reductions in pesticide consumption by better targeting application. To determine this, tests were conducted to document the savings in spray, when using the robotic sprayer. For the test, water was used as spray fluid. The test was performed by making number of spray runs through the test sections of the plant row. The test was conducted over Gerbera plant. Test row of 20 m length was selected for testing (Pawase *et al.*, 2024).

A starting line was positioned at the beginning of the test row section. Before each run, the sprayer was positioned with the axle directly above and parallel with the starting line. Two tests were performed, spraying with developed robotic sprayer with sensor based control turned on and spraying with same sprayer without sensor based rate control. Each test was replicated three times. During the test, sprayer was operated at three different forward speeds *i.e.* 0.55, 0.83 and 1.11 m/s. For each run, spray delivered was collected in collecting jar and then, it was measured with measuring cylinder. Spray volume savings then calculated using the no control output as a basis for savings calculations.

Results and Discussion

The results and discussion from the laboratory testing of robotic rate sprayer and laboratory evaluation of robotic sprayer for on Gerbera plant are discuss below.

Robotic real time spraying system response time

This time represents lag between the time when the ultrasonic sensor detected the target and the time when liquid discharged from the nozzle. Obtained lag time included software computation time, electronic response time and hydraulic-mechanical response time. Obtained lag time was then used to determine the distance between ultrasonic sensor and nozzle outlet on the sprayer so that nozzle should start spraying exactly when it comes in front of the target. The sprayer was operated at a forward speed of 0.55 m/s, the sensor and nozzle were placed at 50 cm distance from the plant. The response time between the sensing and discharging fell within the range of 0.42 to 0.63 s.

Performance Evaluation on gerbera plant

As per the procedure explained in materials and methods section, the sprayer was tested at three forward speeds (0.55, 0.83 and 1.11 m/s) and two type of nozzles (hollow cone and flat fan nozzle) inside gerbera plant. The results on droplet size, droplet density and uniformity coefficient and spray deposition for different levels of independent variables are discussed below. The obtained results are presented in Table 1.

Effect on droplet size

The analysis of water sensitive papers (WSP) revealed droplet size in volume median diameter (VMD) at different plant positions as an effect of the selected variables independently and in combination thereof. The droplet size was found to increase with increase in forward speed from 0.55 to 1.11 m/s. Due to variable

Table 1 : Mean droplet size, droplet density, uniformity coefficient and spray deposition observed for combined effect of forward speed and type of nozzle.

Independent variables		Dependent variables			
Forward speed	**Type of nozzle**	**Droplet size µm**	**Droplet density drops/cm²**	**UC**	**Spray deposition µl/cm²**
0.55	Flat fan	228.53	28.9	2.17	0.82
	Hollow cone	227.56	30.20	1.67	0.86
0.83	Flat fan	235.56	27.50	2.11	0.82
	Hollow cone	234.89	31.20	1.77	0.87
1.11	Flat fan	241.65	28.54	2.13	0.81
	Hollow cone	240.89	30.89	1.70	0.85

rate function of the sprayer, discharge of nozzle increased with increase in speed of operation. Thus, increased discharge of nozzle increased droplet size. The maximum droplet size of 241.65 µm was observed with 0.83 m/s forward speed for flat fan nozzle whereas minimum droplet size of 227.56 µm was observed with 0.55 m/s forward speed for hollow cone nozzle. The combination of forward speed and nozzle type had very less effect on droplet size. The results reveals that droplet size values observed with hollow cone nozzle were significantly lower than the values observed with flat fan nozzle at all plant positions. It is well known fact that hollow cone nozzle produces finer droplets as compared to flat fan nozzle and obtained data follows that trend.

Effect on droplet density

The analysis of WSP revealed droplet density in number of droplets per square centimeter on leaf surfaces as an effect of selected variables independently and in combination thereof. The result shows that forward speed had non-significant effect on droplet density. Type of nozzle individually had significant effect on droplet density. Hollow cone nozzle deposited more number of droplets than flat fan nozzle. Because of internal swirl plate, hollow cone nozzle produces finer droplets as compared to flat fan nozzle; it also helps to produce more number of droplets than flat fan nozzle. The maximum droplet density of 31.20 drops/cm^2 was observed at 0.83 m/s speed and hollow cone nozzle whereas minimum droplet density of 27.50 drops/cm^2 was observed at 0.83 m/s speed and flat fan nozzle. The droplet density values observed at leaf with hollow cone nozzle and flat fan nozzle were within recommended limit (*i.e.* 20 to 50 drops/cm^2).

Effect on uniformity coefficient

The results shows that forward speed had less significant effect on uniformity coefficient. The effect of two types of nozzles on uniformity coefficient was found significant. The UC values with hollow cone nozzle were significantly lower than flat fan nozzle. The maximum uniformity coefficient value of 2.17 was observed at 0.55 m/s speed and flat fan nozzle whereas minimum uniformity coefficient value 1.67 was observed at 0.55 m/s speed and hollow cone nozzle. The recommended values of uniformity coefficient (*i.e.* near unity) were observed with hollow cone nozzle.

Effect on spray deposition

The effect of selected variables *i.e.* forwards speed and type of nozzle on spray deposition at different plant positions was studied. The effect of forward speed on spray deposition was studied and the results shows that forward speed individually had non-significant effect on spray deposition. The analysis of the data presented in Table 1 shows that type of nozzle individually had significant effect on spray deposition. The mean spray deposition observed with hollow cone nozzle was significantly higher than the values observed with flat fan nozzle. The maximum mean spray deposition of 0.87 µl/cm^2 was observed at 0.83 m/s speed with hollow cone nozzle whereas minimum mean spray deposition of 0.81 µl/cm^2 was observed at 1.11 m/s forward speed with flat fan nozzle.

Liquid Saving

The average liquid consumption observed when spraying at forward speed of 0.55, 0.83 and 1.11 m/s. spraying with sensor based control significantly reduced quantity of sprayed liquid with average savings of about 25.77 to 31.73% in gerbera plant. The maximum saving of 31.73% was observed at 0.83 m/s forward speed. The similar kind of result also found by Wandkar *et al.* (2018). The past study of several researchers reported pesticide savings of up to 50-70%, when spraying with variable rate control. Spray liquid consumption obtained in gerbera plant for with and without sensor based control is shown in Fig. 9. The saving achieved with developed sensor based robotic sprayer was lower as compared to past results as developed sprayer was spraying on only one side with two nozzles. These findings demonstrated that the sensor based spraying system made substantial savings in spray mixture consumption compared to spraying without sensor based function, although the savings decreased as the plant to plant spacing decreased and foliage density increased. The quantity of liquid consumed with conventional method was more as compared to robotic sprayer. This is because, in conventional method continuously rate of spray in agriculture field by the way in field no accurate plant to plant spacing available and in robotic sprayer plant canopy sense by the sensor and electric circuit fulfill the spray cycle. These findings demonstrated that the sensor based robotic spraying system made substantial savings in spray consumption compared to spraying without sensor based function, although the savings decreased as the plant to plant spacing decreased.

Summary and Conclusion

Traditional pesticide applicators lack flexibility and the quality of spray deposition varies significantly under different plant spacing conditions. Users of these sprayers typically apply a constant rate across the entire field. Excessive pesticide usage not only leads to economic losses but also poses a potential risk of environmental contamination, impacting the safety and health of applicators, workers and nearby residents. By using deposit scan software droplet size obtained at different plant positions are ranging from 227.56 µm and 241.65 µm for Gerbera plant. The droplet density, uniformity coefficient and spray deposition are ranging from 27.50 to 31.20 drops/cm^2, 1.67 to 2.17 and 0.81 to 0.87, respectively. The percentage liquid saving observed in gerbera plant was 25.77 to 31.73%. This developed automated sprayer is viable option for saving of input cost and minimizing environmental hazards from pesticide.

Acknowledgement

We would like thanks to Chhatrapati Shahu Maharaj Research, Training and Human Development Institute (SARTHI), Pune for giving national fellowship for Ph.D. research work. We would also like thanks to CAAST-CSAWM, MPKV, Rahuri for providing research facility.

Conflict of interest : Authors have no conflict of interest.

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