Design and development of a sensor-based precision crop protection autonomous system for orchard sprayer

Rasool Khodabakhshian[1*], Seyed Morteza Javadpour[2]

(1. Department of Biosystems Engineering, Ferdowsi University of Mashhad, Mashhad, Iran;
2. Department of Mechanical Engineering, University of Gonabad, Iran)

Abstract: Recent years have shown enthusiastic research interest to reduce pollution of non-target such as sensitive environmental areas, human and non-targeted crops. In this way, the most important issue is that intermittent spraying on the trees simply needs a detection system to apply the spray only to the target trees, allowing the sprayer to turn off between trees or in areas where trees are missing. So, in this study, we present a low-cost sensing system that can apply a variable amount of liquid according to detection of the tree canopy for plant protection products applications in orchards. Target detecting system was implemented on a 2000 liter conventional towed air-blast orchard sprayer. In this study, the target detecting system was designed on the basis of "sensor-equipped spraying'. Generally, the optical sensors were used to detect the tree canopy, then send signal to PLC until which solenoid ON/OFF valves is opened. Laboratory and field experiments were conducted to evaluate its performance. During laboratory experiments, delay time to start and stop spraying, spatial lag were investigated. During field experiments, evaluation of water sensitive paper and evaluation of pesticide consumption were studied. In the laboratory test, forward speed did not show any significant effect on delay times of starting or stopping the spraying. Variance analysis of data of sprayed area on water sensitive paper (WSP) indicated that the effects of forward speed, vertical and horizontal place of water sensitive papers on the area of WSPs covered by sprayed liquid were significant at the 1% of probability level. The results of measuring the amount of sprayed liquid at studied forward speed levels showed about 50% saving in pesticide consumption implementing variable rate in comparison with the conventional spraying.

Keywords: air-blast orchard sprayer, optical sensor, precision horticulture, target detection

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[*] 1 Introduction

In recent decades, research on agrochemicals, and more specifically, application techniques of Plant Protection Products (PPP) have progressed significantly due to the economic and environmental costs derived from their use (Escolà et al. 2013; Song et al., 2015; Gonzalez-de-Soto et al., 2016; Hołownicki et al., 2017; and Asaeia et al., 2019). Particularly noteworthy is the improvement in sprayer performance and pollution hazards minimization by combining sprayer with target detecting system. Nevertheless, many of these researches have concentrated uniquely on analyzing and developing dosage models for orchards, groves, and vineyards (Fox et al., 1973; Peterson and Hogmire, 1994; Pierce and Nowak, 1999; Planas et al., 2006; Siegfried et al., 2007; Pergher and Petris, 2008; Gil and Escolà, 2009; Planas et al., 2011; Walklate and Cross, 2012). These efforts revealed a need to reduce pollution of non-target such as sensitive environmental areas, human and non-targeted crops. Zhu et al. (2006) reported that just 30% of the sprayed pesticide achieved the tree canopy and the 70% is wasted and cause damage. The wasted pesticide outside

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[*] **Corresponding author: Rasool Khodabakhshian,** Ph.D., Associate Professor of Department of biosystem engineering, Ferdowsi University of Mashhad, zipcode: 91775-1163, Iran. Email: khodabakhshian@um.ac.ir. Tel: +985138805832, Fax: 985138805832.

of the target region may be spread over a wide area between the trees and/or over and under the tree canopies (Derksen et al., 2007).

Adapting precision agriculture and site-specific management practices with spraying technologies, which is the integration of target detected sensor, analytical methods, atomization spraying devices and control system, is developed rapidly over the last 20 years and plays an important role in solving these issues but its application in horticulture lags behind (Slaughter et al., 2008; Escolà et al., 2013; Song et al., 2015; Asaeia et al., 2019). According to the preceding research studies, many different types of detecting technologies such as machine vision, spectral reflectance, remote sensing, ultrasonic sensor and lase sensor have been attempted for use in agricultural sprayers (Song et al., 2015). But, this technique could not decrease the air-drifted quantity of pesticide (Asaeia et al., 2019). Later as early as 1990s, the tunnel sprayers were applied (Peterson and Hogmire, 1994). This method was then used by Planas et al. (2011). Along with advancing in electronics and information technology, electronic implements were increasingly applied to measure some apparent characteristics of the tree canopy. For example, ultrasonic sensor and lase sensor application to measure canopy or stem position and position detection for orchard spraying management were reported by some researchers (Wei and Salyani, 2004; Schumann and Zaman, 2005; Chueca et al., 2008; Brown et al., 2008; Perry et al., 2010). The pesticide consumption was saved in the amount of 28% to 52% by this technique. Recent research studies have investigated canopy variability and adjusting the amount of sprayed PPP using machine vision (Hocevar et al., 2010; Asaeia et al., 2019), spectral analysis (Scotford and Miller, 2005; Naidu et al., 2009) and remote sensing (Du et al., 2008; Oberti et al., 2016).

According to the bibliography, the newest development is the use of fleets of robots, for outdoor applications such as applications that are related to agriculture, to perform tasks collaboratively (Gonzalez-de-Soto et al., 2016; Ivić et al., 2019). However, problems associated with outdoor field technology conditions such as variable light, distorted or blurred image due to vibrations imply leading to dosage errors (Asaeia et al., 2019). So researchers applied additional components and methods to solve it. For example, Bietresato et al. (2016) used a LIDAR 3D stereoscopic vision system to reconstruct the tree canopy. Therefore, as it was found from bibliography, expensive components in the system were duplicated. In addition, the majority of sprayers currently applied in fruit growing were developed many years ago and it was very hard to adapt precision system with them. Thus, a need to simplify systems and to develop integrated autonomous agricultural sprayer is essential. Therefore, manufacturers and researchers are seeking to introduce the simple solutions to enable the control of spraying parameters with tree canopy variability. In this way, the most important issue is that intermittent spraying on the trees simply needs a detection system to sense the two ends of the tree canopy hence, the need for this study to supply a low-cost and robust sensor-based sprayer. This study aimed to develop a low-cost sensing system that can apply a variable amount of liquid according to detection of the tree canopy for PPP applications in orchards.

2 Materials and methods

2.1 General system

This study entailed a detailed description of the electronic system for canopy detection and the calculation of the adapted flow rate; and a comparison of the performance of the variable application technique over the conventional technique. For this purpose, an orchard sprayer manufactured by Talaye Sepide Shargh Company was used to conduct the test. The tests included laboratory tests (delay time to start and stop spraying, spatial lag) and field tests (evaluation of water sensitive paper, evaluation of pesticide consumption).

An all-purpose autonomous agrochemicals spray device fundamentally comprises two main systems: Sensing system for target detecting (machine vision, ultrasonic sensor, remote sensing, spectral detection and laser sensor) and automation for spray implementation (micro-spray, cutting, thermal, electrocution) (Song et al., 2015). Thus, a precision spraying system usually includes target detecting system and agrochemicals spraying system. The target detection system integrates target detected sensors, analytical methods (data processing and decision making algorithm); spraying systems consist of valve control unit and nozzles.

2.2 Target detecting system

In this study, the target detecting system was designed on the basis of "sensor-equipped spraying'. The optical sensors and components are listed and detailed in Table 1.

Table 1 Technical specifications of the components used in the sensor-equipped spraying system sensor-equipped spraying system

Components	Manufacturer/model	Characteristics	Signal characteristics
Pressure sensor	Autonics	0-10bar	4-20mA
Optical sensor	Autonics	3m	0-10VDC
Laser sensor	Autonics	5m	
Flowmeter	Autonics	1000 lit hr^{-1}	4-20mA
PLC	Siemens 1214		24VDC
Analog input module			
Analog output module			
HMI			
Solenoid Valve		ON/OFF	12VDC

Generally, the optical sensors are used to detect the tree canopy, then send signal to Programmable logic controller (PLC) until which solenoid ON/OFF valves is opened. Additionally, pressure sensor is used to control minimum pressure from behind of nozzle. In other words, stop injection when pressure goes below 1.5 bar. The nozzle pressure was set at 172 kPa (25 psi) to achieve a flow rate of 1.8 L min^{-1}. The simplified schematic diagram of the sensor-equipped spraying system is shown in Figure 1.

This sensor-equipped spraying system was constructed with six solenoid valves, which were mounted on a stainless steel boom at a 2 m from trees and height of 0.5 m above ground (Figure 4). The boom sprayer was divided into five sections, each containing one solenoid valve. Each valve was supplied by a 12-Vdc source to depending on the height of the tree, was controlled the number of valves to open. The human machine interface (HMI) indicated when the solenoid was open.

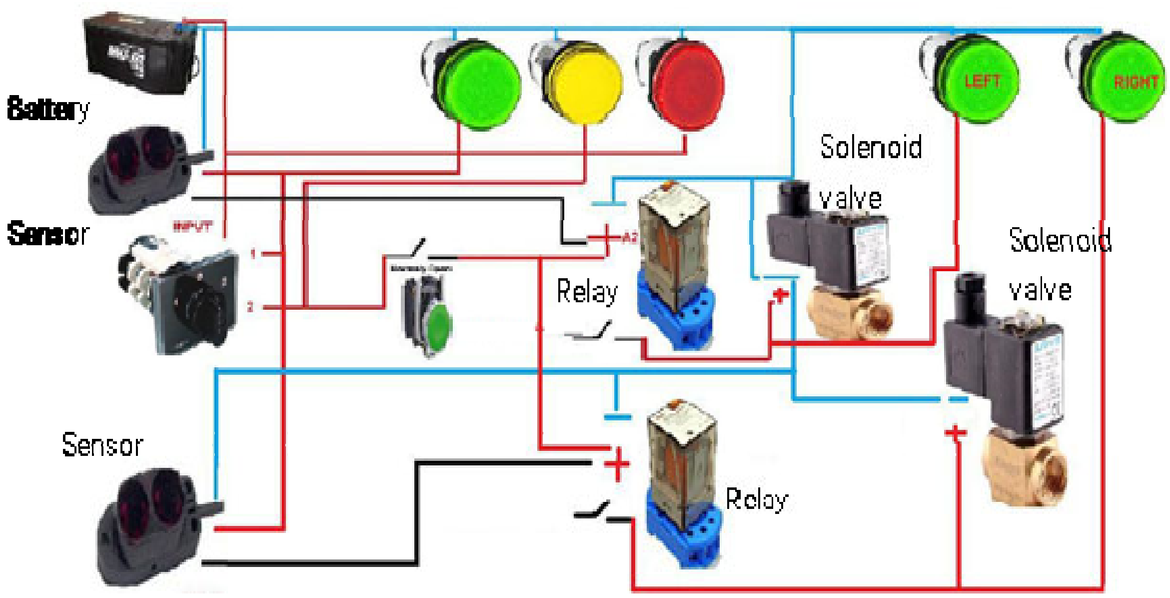

Figure 1 Simplified schematic diagram of the sensor-equipped spraying system

To relate the Field of view (FOV) of the optical sensors to the spraying area, a real-time/multi-task control system has to be used. As it can be stated earlier the aim of this project is to develop a low-cost sensing system that can apply a variable amount of liquid according to detection of the tree canopy for PPP applications in orchards. So a low-cost PLC (serve as system timer and nozzle controller) in conjunction with a software of the controller that was programmed according to the flow chart shown in Figure 2 were combined together to form a sensor-equipped spraying.

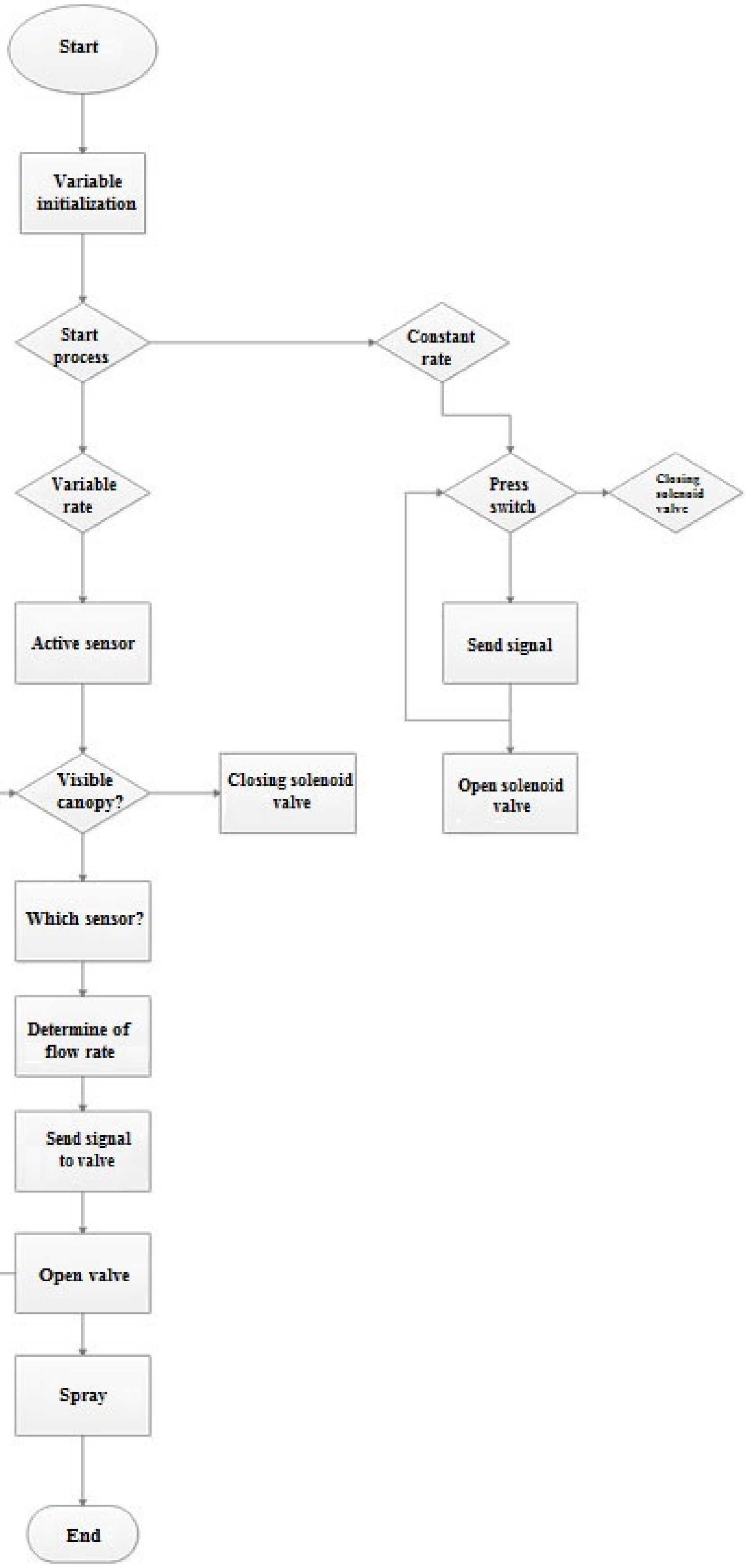

Figure 2 Flow chart of the program to control the sprayer prototype

2.3 Spraying system

To consider the performance of the target detecting system and quantitatively assess the usage rate of reduced agrochemicals, applications for conventional air-blast spraying and target detection (sensor-equipped) were accomplished with the similar sprayer configuration. The only difference was that the target detecting system was enabled for "sensor-equipped spraying'' and disabled for conventional spraying.

Target detecting system was implemented on a 2000 liter conventional towed air-blast orchard sprayer (Omega Model, Talaye Sepide Shargh Co., Ltd., Mashhad, Khorasan Razavi, Iran) in such a way that both of the sides were able to spray in variable- rate mode. It consists of a frame, tank (Three pieces including main called tank "sprayer tank", hand washing tank and system washing tank), pump, hose, pressure reducing valve, axial flow fan having a 950-mm external diameter and 900-mm inner diameter, filter, agitator, cardan shaft, wheeled jack, tank opening screen and cover, booms and sixteen turbo twin ceramic nozzles. Figure 3 shows the front and back view of the conventional towed air-blast orchard sprayer. Massey Ferguson 285 (MF 285) tractor was applied for giving mobility and power to the studied sprayer system. This tractor has a 75-hp (55.92 kW) engine and an approximate mass of 3114 kg. The operator cabin was picked up in order to build a more compact vehicle that housed subsystems of target detecting system.

Figure 3 The used conventional towed air-blast orchard sprayer

The necessary modifications in the studied sprayer and attached new components stated were constructed such as optical sensors, controller with its specific software, on/off switches, relays, guide lamps and the electromagnetic valves (Figure 4). Consequently, the modified sprayer (the precision sprayer) includes three subsystems: a tree canopy detection system (optical sensors), an autonomous system (electronic controller with its monitoring sensors) to perform the control algorithm, and actuating system (solenoid valves) to fittingly spray the predetermined volume usage rate. As previously mentioned, both of the sides were able to spray in variable- rate mode. Firstly, the presence or absence of tree canopy were assessed from the optical sensors. Secondly, a control signal was calculated and sent to the solenoid valves to spray flow rate on a specific location.

2.4 Laboratory validation experiments

One of the most important issues in precision assessment of the sensor-equipped orchard sprayers is response time, which specifies the working frequency and minimum distance for numerous actuations. The method for determining the response time consisted of measuring temporal and spatial delays at the beginning and end of spraying at different forward speeds, the data were analyzed. Spraying delay time is the time duration that the nozzle passes the leading edge of a paper to the moment it starts spraying. The assessment of the sprayer precision in the laboratory was accomplished in accordance with Asaeia et al. (2019) with slight modifications. 600×300 mm papers were mounted on parallel ropes at a height of 2m off the ground level and different spacing ranging from 0.5 to 2 m. The sprayer moved along the experiment path such that papers were within the field of view of the sensor. Laboratory experiments were conducted at Biosystems Department in Ferdowsi University of Mashhad in Aug 2019 at three forward speeds (3, 5 and 6 km h^{-1}) with 35 replications at each speed, while the air temperature was 20℃–25℃, relative humidity at 20%-30% and wind speed was 5–8 km h^{-1} during the experiments.

2.5 Field validation experiments

The field validation experiments comprised two applications of pure water in a 60-ha apple orchard in Iran with 14,000 six to eight years old trees, in Khorasan Razavi (Figure 5). During the experiments, wind velocity was 4–6 kmh^{-1} with an air temperature of 18℃–23℃ and relative humidity of 18%-25%. The first treatment was performed in a conventional application procedure at a constant application volume rate (L ha^{-1}), while the second was a variable application volume rate using the modified sprayer. The variable application and the conventional procedure were accomplished using the same Tractor (MF 285) and sprayer (Omega Model) for the two studied spraying modes since the device installed on the control system enables the sprayer to work at two modes selected by related switch installed on the sprayer control system. The measuring of amount of discharged water from nozzles were carried out at constant pressure, three forward speeds (3, 5 and 6 km h^{-1}) and two studied spraying modes (sensor-equipped and conventional) with five replications and then the mean (±S.E.) values reported while the results were compared using a F-test.

Figure 4 Sensor-equipped orchard sprayer prototype implemented with two optical sensors (1), controller (2), on/off switches (3), guide lamps (4) and the electromagnetic valve (5).

Figure 5 The top (a) and back (b) view of field evaluation experiment

The spray deposition on the canopy was carefully assessed during field experiments. The protocol developed for measuring the spray deposition on the canopy was based on Asaeia et al. (2019) with slight modifications. Briefly, 35×70 mm rectangular water sensitive papers were placed on the trial trees vacant spaces between them to assess the precision of target spraying. These papers were positioned along the spraying path so that 9 papers were placed with a matrix pattern as shown in Figure 6.

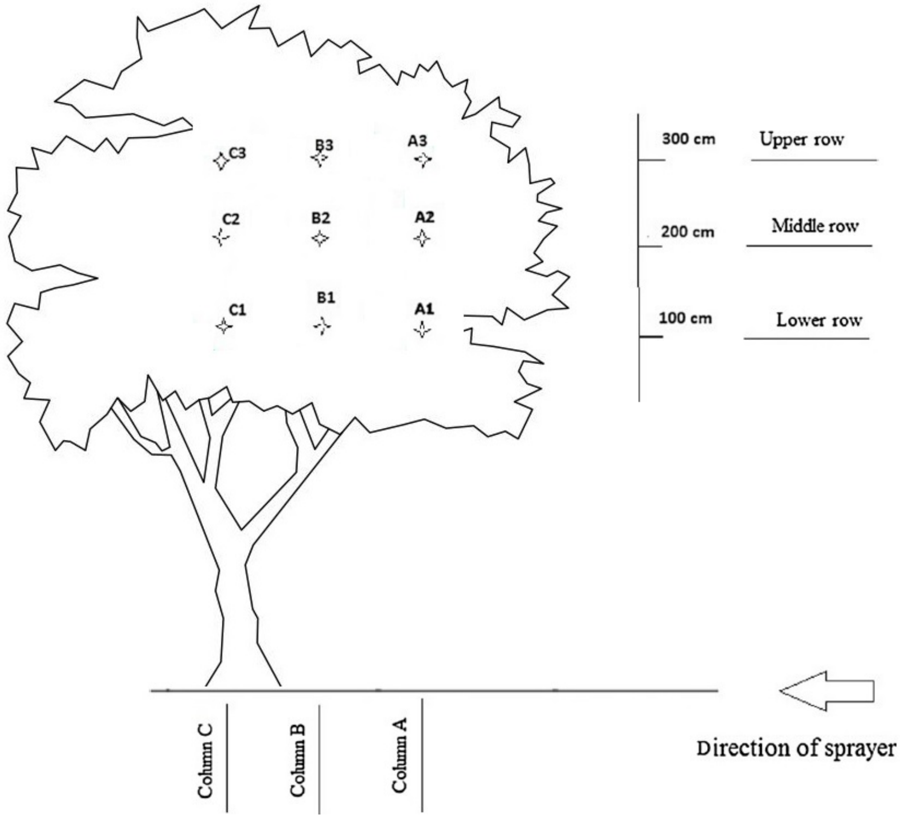

Figure 6 Water sensitive papers positions on tree canopy and sprayer direction of travel

To evaluate performance of the sprayer at different points of areas where trees are missing or between trees, nine papers were also located in each vacant space between the trees. After spraying, the papers were immediately collected from the trees and spaces between trees, preserved in airtight bags to keep them from absorbing moisture from the experiment field environment and transported to the Biosystems Departmental laboratory in the Ferdowsi University of Mashhad for analysis. The concentration of sprayed water on water sensitive papers was measured according to the flow chart shown in Figure 7. The percent of paper surface received sprayed droplets was calculated using image processing toolbox of Matlab (2013) (The MathWorks Inc., Natick, MA). Also, the effects investigation on vertical or horizontal place of water sensitive papers on spray concentration and sprayer forward speed was studied.

3 Results and discussion

3.1 Laboratory validation experiments

The precision assessment of the sprayer in on-target spraying is subjected by determining the response time consisted of measuring temporal and spatial delays at the beginning and end of spraying. The results of the laboratory experiments were analyzed as follow.

3.1.1. Delay time to start spraying

The results of variance analysis carried out to examine the effect of sprayer forward speed on delay time to start spraying is reported in Table 2. It was obtained that the effect of forward speed on the delay time of nozzles to start the spraying was not significant at the 5% of significance level. This implies that optical sensors and actuators work independently with respect to sprayer forward speed, similar trend was reported by Asaeia et al. (2019) for site-specific orchard sprayer equipped with machine vision for chemical usage management. It was reported that using machine vision technology for site-specific orchard sprayer make another source of delay, which is due to the threshold set for greenness value in the machine vision, except the inherent delay due to the processing time needed for machine vision as well as actuating the solenoid valves. The threshold value of greenness throughout this study was set to 10% of the image in the algorithm .Also, Song et al. (2015) reported other types of detecting technologies such as spectral reflectance, remote sensing, ultrasonic sensor and lase sensor demonstrating more delays when used in agricultural sprayers. Therefore, it is concluded that in the comparison of other target technology, optical sensors make low delays in the target detection during spraying. As solenoid activation signal was sent only after the target was detected by the optical sensors, there was not any lead in the spray triggering.

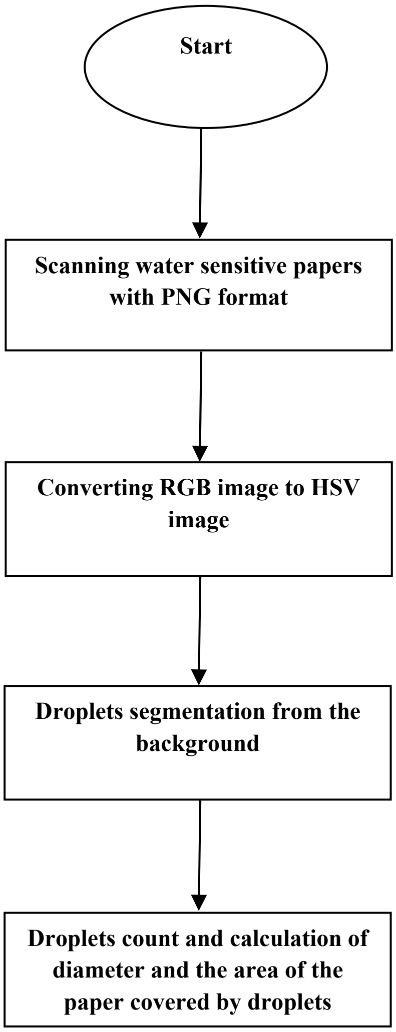

Figure 7 Flow chart the used image processing to determine the percent of paper surface received sprayed droplets

Table 2 Analysis of the variance showing the effect of forward speed on the delay time of nozzles to start the spraying

Variation Source	Degree of freedom	Sum of squares	Mean squares	$F_{calculated}$
Forward speed	2	0.04	0.02	1.03^{ns}
Error	102	1.98	0.02	
Total	104	2.02		

Note: not significant at 5% level.

3.1.2 Delay time to stop spraying

The results of variance analysis which was carried out to examine the effect of sprayer forward speed on delay time to spraying cutoff is seen in Table 3. Considering the values presented in Table 3, the effect of forward speed on the delay time of spraying cutoff was not significant (p<0.05),this implies that the cut off delay mainly attributed to the residual pressure in the pipes from the solenoid to the nozzles. This justification can be proved by the fact that while the cut off happened almost immediately after the solenoid received the signal from the controller, the time needed for the pressure to drop produced the delay in stopping the spraying. Similar result was reported by Asaeia et al. (2019) who also reported that the other sources of the delay in their research such as processing time of the vision system, the delay of triggering the solenoid valve by the microcontroller, and closing the flow by the solenoid valve were independent of the forward speed. Consequently it was expected that the delay of stop spraying would not be subjected by the forward speed.

Table 3 Analysis of the variance showing the effect of forward speed on the delay time of spraying cutoff

Variation Source	Degree of freedom	Sum of squares	Mean squares	$F_{calculated}$
Forward speed	2	0.06	0.03	1.21^{ns}
Error	102	2.52	0.02	
Total	104	2.58		

Note: not significant at 5% level.

3.1.3 Spatial lag

Generally, delay in the system makes a spatial lag, which can be perceived as off-target spraying. In this study, spatial lag is the result of two parameters including sprayer timing delay and forward speed. So, this state that the spatial lags were changed at different levels of forward speed even there was no significant difference between the delay times. The spatial lags at different forward speed levels were considered by using the average value of delay time from the results of laboratory experiments and sprayer forward speed. These results are shown in Table 4.

Table 4 Analysis of the variance showing the effect of forward speed on the delay time of spraying cutoff

Sprayer forward speed (km h^{-1})	3	5	6
Average spatial lag at the start of spraying (m)	0.21	0.43	0.68
Average spatial lag at the stop of spraying (m)	0.41	0.83	1.01

Considering the values presented in this Table, the proportionally increased with forward speed while the delay time was approximately constant. The spatial lag made by sprayer timing delay and forward speed was also investigated by Asaeia et al. (2019). They found the values of spatial lag in the ranges of 0.3-0.87 and 0.55-1.32 for average spatial lag at the start of spraying and average spatial lag at the stop of spraying respectively.

3.2 Field validation experiments

3.2.1 Evaluation of water sensitive paper

Variance analysis of data of sprayed area on water sensitive paper (WSP) indicated that the effects of forward speed, vertical and horizontal place of water sensitive papers on the area of WSPs covered by sprayed liquid were significant at the 1% of probability level (Table 5). Stepwise analysis of the obtained results revealed that among studied variables namely horizontal row, vertical row and forward speed, the dominant factor on the water sensitive paper is forward speed. Asaeia et al. (2019) reported that variation in horizontal location, vertical location and forward speed the area of WSPs covered by sprayed liquid significantly (p<0.01). The similar results have been reported by Brown et al. (2008) and Giles et al. (2011).

Table 5 Analysis of the variance showing the effect of data of sprayed area on water sensitive paper

Variation Source	Degree of freedom	Mean squares	$F_{calculated}$
Horizontal row	2	0.86	14.33^{**}
Vertical row	2	2.35	39.17^{**}
Forward speed (km h^{-1})	2	10.23	170.5^{**}
Error	108	0.06	
Total	114		

Note: ** Significance at 1% level.

Tables 6-8 show the results of mean comparison of percent of sprayed liquid on sensitive papers in different locations of WSP on tree canopy. According to Table 6, it is apparent that either variation in papers located in horizontal rows had a significant effect on the percent of sprayed liquid on sensitive papers (p<0.05).

Table 6 Mean comparison of WSP spray coverage (%) of papers located in horizontal rows

Horizontal rows of WSPs	Spray coverage (%)
Upper row	48.95^{a}
Middle row	54.65^{b}
Lower row	46.92^{a}

Among the studied levels of horizontal row, the highest percent belonged to middle row with value of 54.65% and also the middle row received significantly more spray droplets than the upper and lower rows where the papers received a statistically equal amount of sprayed liquid. This may be attributed to the overlapping of upper and lower nozzles with the middle nozzle as well as the convex surface of the tree canopy which put the papers closer to the nozzles. Asaeia et al. (2019) also reported the similar results and justification.

The means with the same letter is not significant at 5% level according to Duncan's multiple ranges test.

Figure 8 shows the average values of spraying percentage on WSPs positioned in horizontal rows at the studied forward speed levels. As it can be seen from this figure, the percentage of sprayed liquid on papers positioned in the upper and lower rows are lower than those of middle row.

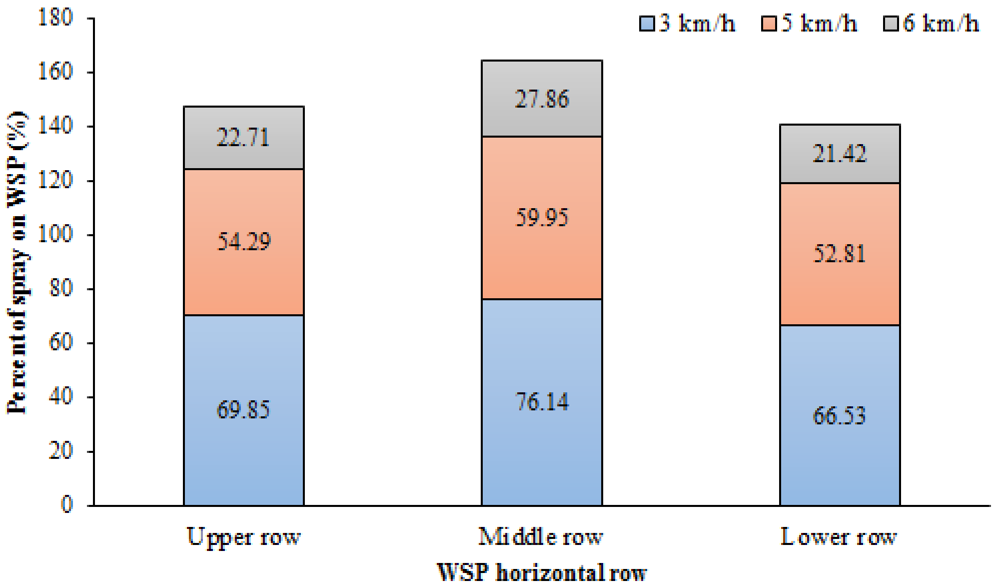

Figure 8 Average values of spraying percentage on WSPs on horizontal rows at studied forward speeds

Mean comparison of percent of sprayed liquid on sensitive papers in different levels of studied columns (Figure 6) also indicated that columns A, B and C had a significant difference with each other and also column B received more spray droplets than the ones positioned on columns A and C (Table 7).

Table 7 Mean comparison of WSP spray coverage (%) of papers located in vertical rows

Horizontal rows of WSPs	Spray coverage (%)
Column A	40.85[a]
Column B	52.53[b]
Column C	45.15[c]

This might possibly be due to the convexity of the tree canopy that puts the papers positioned in place B closer to the nozzles than the other two vertical columns. As it can be found from this Table, the papers positioned in place A obtained fewer spray droplets than the other places. The similar trend was concluded by Asaeia et al. (2019). They reported less spray deposition on column A papers might be attributed to spatial lag at the start of spraying.

The means with the same letter is not significant at 5% level according to Duncan's multiple ranges test.

The average values of sprayed liquid on water sensitive papers positioned at various places of tree canopies at three studied forward speed levels are reported in Table 8.

Table 8 Mean comparison of WSP spray coverage (%) of papers located in vertical rows

Position of WSP on tree canopy	Speed 3 km h^{-1}	Speed 5 km h^{-1}	Speed 6 km h^{-1}
A_1	63.23	37.24	13.14
A_2	71.52	43.36	18.12
A_3	66.28	39.72	15.11
B_1	72.55	45.75	27.24
B_2	81.43	55.73	33.26
B_3	76.78	50.89	29.15
C_1	65.81	42.52	19.71
C_2	74.15	49.26	26.44
C_3	69.62	44.26	21.41

As it can be found from this Table, the chemical deposition for each studied position decreased as the forward speed increased from 3 to 6 km h^{-1}. So the optimum forward speed of the sprayer should be adjusted so that to satisfy the effective deposition of the chemical on the tree. In agreement with these results, Asaeia et al. (2019) reported that the chemical deposition decreased with the increase in forward speed from 2 to 5 km h^{-1}.

3.2.3 Evaluation of pesticide consumption

Table 9 shows that there was a significant difference among the amounts of sprayed pesticide in two modes of conventional air-blast spraying (continues) and target (sensor-equipped) spraying. The percent of the reduction in pesticide consumption achieved by the target-sensing sprayer was determined by the on-board electronic system on the sprayer. As it can be seen from this table, use of the sensor-equipped sprayer resulted in spray savings over 50%, meaning that less pesticide was applied in every studied forward speed level. The mean comparison results for the sensor-equipped spraying and conventional air-blast spray treatments are given in Table 10. Two separate effects are found when comparing the two different spray treatments. First, in two modes of conventional air-blast spraying (continues) and target (sensor-equipped) spraying, decreased value was observed for the high forward speeds. Other researchers have reported a similar effect (Asaeia et al., 2019; Brown et al., 2008; and Giles et al., 2011). Second, in all cases, target-sensed spray treatments resulted in less values when compared with the conventional air-blast spray treatments.

Table 9 The average value of consumed pesticide out of a nozzle at both studied spraying modes

	Speed (km h^{-1})	Conventional spraying (ml)	Target spraying (ml)	Reduction of pesticide consumption (%)
Amount of consumed pesticide out of a nozzle (ml)	3	856.95	423.56	50.57%
	5	652.23	322.15	50.61%
	6	501.26	246.19	50.88%

Table 10 Comparison of consumed pesticide out of a nozzle for studied forward speed levels using target sensing versus conventional air-blast spraying

Spraying mode	Forward speed levels (km h^{-1})		
	3	5	6
conventional air-blast spraying	28.26^{a}	25.52^{a}	19.14^{a}
Target sensing	14.136^{b}	10.42^{b}	8.26^{b}

Note: The means with the same letter is not significant at 5% level according to Duncan's multiple ranges test.

Through the literature review, Planas et al. (2006) could achieve 70%, 28%, and 39% saving of the chemical liquids in olive, pear and apple orchards, respectively by turning a conventional sprayer into a variable rate sprayer using ultrasound sensors. Brown et al. (2008) reported that the target-sensing sprayer produced a 40% reduction in the spray application rate and achieved a 41% reduction in ground deposition compared with the conventional air-blast sprayer. In another research, a saving of 40% for a variable rate sprayer was reported by Giles et al. (2011). Asaeia et al. (2019) showed about 54% saving in pesticide consumption implementing variable rate in comparison with the conventional overall spraying on olive trees.

4 Conclusion

In this study, sensor technology (optical sensors) was integrated into an orchard conventional air-blast sprayer to apply pesticide specifically on target tree canopy with the aim of pesticide reduction in the spaces between trees. The tests included laboratory tests (delay time to start and stop spraying, spatial lag) and field tests (evaluation of water sensitive paper, evaluation of pesticide consumption). The following are concluded from this investigation:

1. The results of variance analysis showed that the effect of forward speed on the delay time of nozzles to start the spraying was not significant at the 5% of probability level. This reveals that optical sensors and actuators work independently regarding sprayer forward speed .

2. Considering the values of delay time at the time of stop spraying indicated that the effect of forward speed on the delay time of spraying cutoff was not significant (p<0.05). Consequently, it was expected that the delay of stop spraying would not be subjected by the forward speed.

3. Variance analysis of data of sprayed area on water sensitive paper (WSP) indicated that the effects of forward speed, vertical and horizontal place of water sensitive papers on the area of WSPs covered by sprayed liquid were significant at the 1% of probability level.

4. At studied forward speed levels, the percent of

liquid deposition on WSP located at middle row was higher than upper and lower locations, which was due to overlapping of upper and lower nozzles on the middle nozzle as well as the convexity of tree canopies.

5. The results of measuring the amount of sprayed liquid at studied forward speed levels showed about 50% saving in pesticide consumption, implementing variable rate in comparison with the conventional spraying.

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