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Author(s)

First Name	Middle Name	Surname	Role	Email
Ron	(or initial)	Berenstein		berensti@bgu.ac.il, ron2468@gmail.com

Affiliation

Organization	Address	Country
Ben-Gurion University of the Negev	Beer-Sheva 84105	Israel

Author(s) – repeat Author and Affiliation boxes as needed--

First Name	Middle Name	Surname	Role	Email
Yael		Edan	ASABE Member?	yael@bgu.ac.il

Affiliation

Organization	Address	Country
Ben-Gurion University of the Negev	Beer-Sheva 84105	Israel

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2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

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Robotic precision spraying methods

Berenstein Ron

Ben-Gurion University of the Negev, Beer-Sheva 84105, Israel, berensti@bgu.ac.il

Edan Yael

Ben-Gurion University of the Negev, Beer-Sheva 84105, Israel, yael@bgu.ac.il

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Abstract. *This paper presents comparison of three precision spraying methods used by a robotic sprayer. The spraying deposition model of the three methods is described along with sensitivity analyses in order to reveal the influence of different parameters weights and to maximize spraying process profit. Simulations of the spraying deposition methods indicated that the best spraying method for vineyard grapes is the method that uses one shot for each target.*

Keywords. spraying, selective spraying,

Introduction

Pesticides are an integral part of the worldwide agriculture. Between 30 and 35% of crop losses can be prevented when harmful insects and diseases are eliminated by spraying pesticides (Cho and Ki, 1999). Latest studies show that up to 60% of pesticide material can be reduced by using selective sprayers (Gil et al., 2007; Goudy et al., 2001).

Several spraying robots have been developed (Nishiwaki et al., 2004; Shapiro et al., 2009; Slaughter et al., 2008) and much like other agriculture robots; these developments have not yet become commercial products. Only few commercial automated sprayers are available to farmers. These sprayers are mounted onto a dragging tractor and are manually operated along the rows. Ultrasound sensors automatically detect proximity to foliage. Follow the proximity detection, the sprayer's computer controls specifics nozzle corresponding to the foliage (Tree See, Durand Wayland).

To enable commercial implementation the selective target sprayer must overcome three main barriers, autonomous navigation along the vineyard, target detection with a HIT rate exceeding 95% (Blackmore et al., 2001) and accurately deposition of the pesticides toward the target. Several researches have dealt with improved navigation methods (Åstrand and Baerveldt, 2005; Benson et al., 2001; Rovira-MÃs et al., 2002). Ongoing parallel research is focusing on improved target detection by advanced image processing techniques (Berenstein et al., 2010) and development of a human-robot cooperative target recognition system (Bechar and Edan, 2000; Bechar and Edan, 2003).This work deals with the last barrier mentioned, accurately apply pesticides toward agricultural targets. The case study used for this work was vineyards with grape clusters as the targets.

SPRAYING DEPOSITION METHODS

Quantitative data regarding the target coverage quality in terms of false alarm rate and overlapping of sprays is important to develop an efficient spraying deposition method. The assumption is that the targets are accurately detected and that the sprayer aims accurately at the target. The spraying deposition methods are designed to cover the entire target (i.e., 100% target Hit Rate). Uniform distribution of all spray material is assumed and will be deeply investigated during future work. Analytic evaluation of the spraying methods was not possible due to the amorphous shape of the targets and high variability. Therefore, a simulation analysis was developed.

Spraying methods

Three types of spraying deposition methods were evaluated. The first spraying deposition method (Fixed Nozzle Spacing) is based on existing spraying techniques in which a set of nozzles are organized vertically on a spraying column with predetermined spacing (Figure 1).

Figure 1 - Spraying column with a fix position nozzles

In this method, the nozzles position and spray diameter (nozzle aperture) are set before the spraying process regardless of the targets shape and size. The vertical length between the nozzles is derived from the spray diameter and is set to minimize the sprays circles overlapping (Figure 2). To enable spraying dispersing like Figure 2, an electric valve is set for each of the spraying nozzles. The electric valve allows accurate control over the spraying timing.

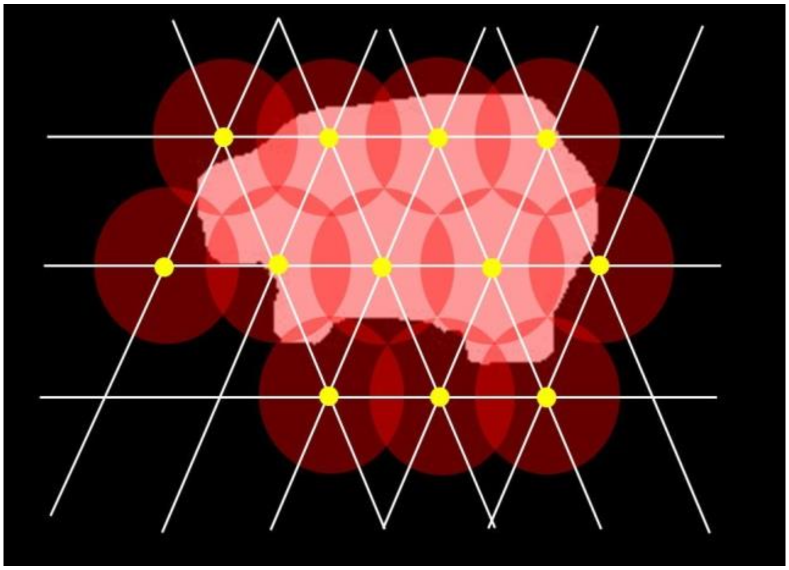

Figure 2 – Fixed nozzle spraying method

The second spraying method (Optimal Spray Coverage) aims to cover the target area optimally while using a single nozzle, with a preset spray diameter, attached to a pan\tilt head (Figure 3).

Figure 3 – Pan\tilt head with spraying nozzle attached

The pan\tilt head provides flexible control over the spray position. The target coverage will seem similar to the first spraying method with an exception that the area coverage will be optimal.

The third spraying method (One Target-One Shoot) is based on the assumption that the spraying circle diameter can be controlled in real-time. With this method, each target will be sprayed once for complete coverage. This type of spraying can be achieved by connecting a single nozzle with a controlled nozzle aperture to a controlled pan\tilt head (Figure 3). The pan\tilt head will direct the nozzle toward the center of the target and by adjusting the spray diameter the entire target will be sprayed (Figure 4).

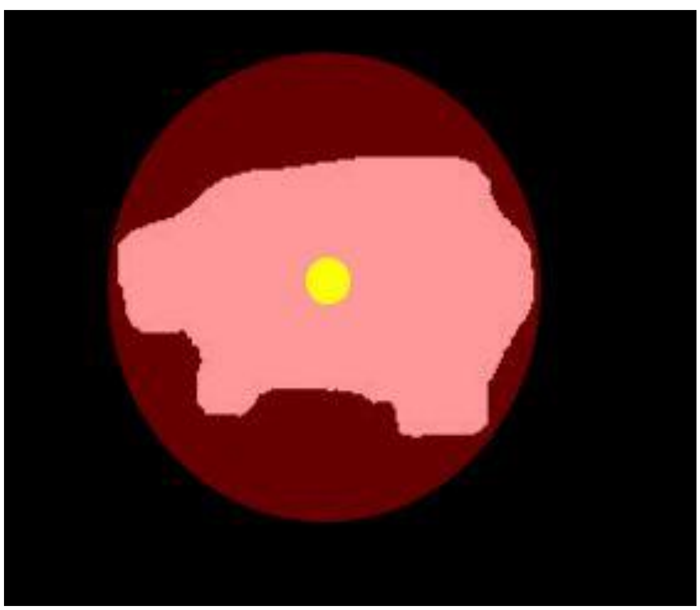

Figure 4 – Varying spray diameter

Figure 5 – (a) Grape clusters, (b) Ground truth of grape clusters

Spraying methods evaluation

The three spraying methods were evaluated using a dataset of 129 images sampled in a commercial vineyard along the season of 2009. The images contained grape clusters images with ground truth marking of the grapes area (Figure 5). Each image was evaluated by the three spraying methods and the results were compared to the corresponding ground truth image. The spraying methods were designed to have 100% hit rate so the performance measures that were defined as the False Alarm rate (non-target area that was sprayed) and the number of sprays required for the entire image (to cover 100% of the target). The Fixed nozzle spacing method and the Optimal spray coverage method were evaluated with a range of spray diameters (3-100[Pixel]) in order to find the optimal spray diameter.

RESULTS AND ANALYSIS

Spraying evaluation results

Results of the spraying methods evaluation (Figure 6) are the average outcome of the 129 images used for the simulation. The results shows that for the Fixed Nozzle Spacing and Optimal spray coverage spraying methods there is a direct relation between the spray diameter and the pesticide waste given in (1) and (2) respectively:

(1) $\text{Pesticide Waste} = 13820 * \text{Spray Diameter} + 54282$

(2) $\text{Pesticide Waste} = 18034 * \text{Spray Diameter} + 30255$

Since the **One Target-One Shoot** spraying deposition method does not depend on the spray diameter the pesticide waste value is constant (3):

(3) $\text{Pesticide Waste} = 125518$

The number of sprays per image (Figure 7) shows that for the Fixed Nozzle Spacing and Optimal spray coverage spraying deposition methods there is a power shape function given in (4) (5) respectively:

(4) $\text{Number of sprays} = 588.45 \cdot (\text{Spray Diameter})^{-1.208}$

(5) $\text{Number of sprays} = 481 \cdot (\text{Spray Diameter})^{-1.08}$

Since the **One Target-One Shoot** spraying deposition method does not depend on the spray diameter the number of sprays per image is a constant number (6) representing the average number of targets in one image.

(6) $\text{Number of sprays} = 7.89$

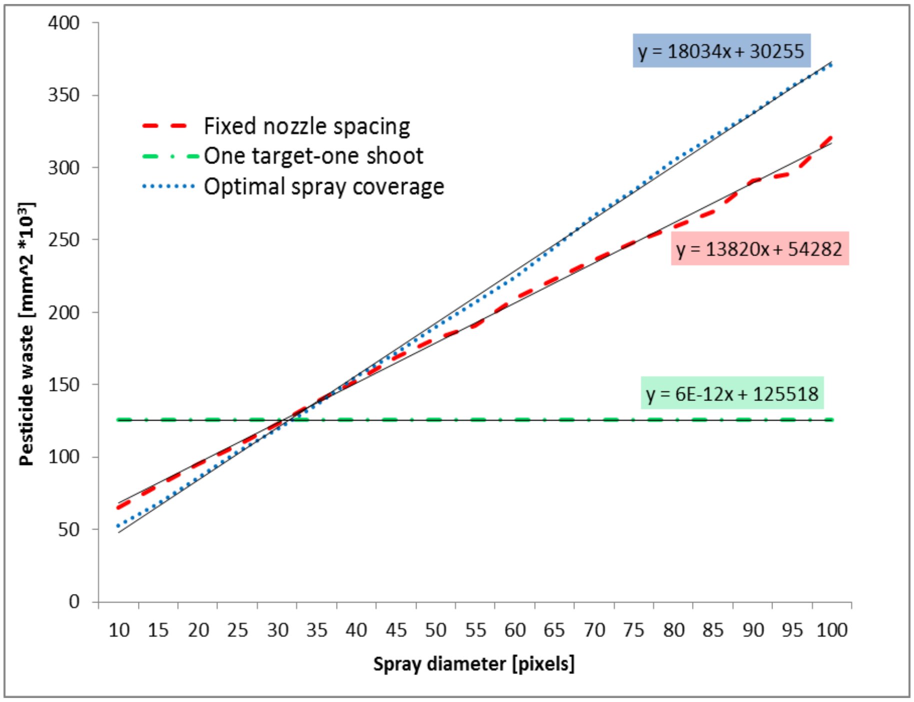

Figure 6 - Pesticide waste (False Alarm + overlapping)

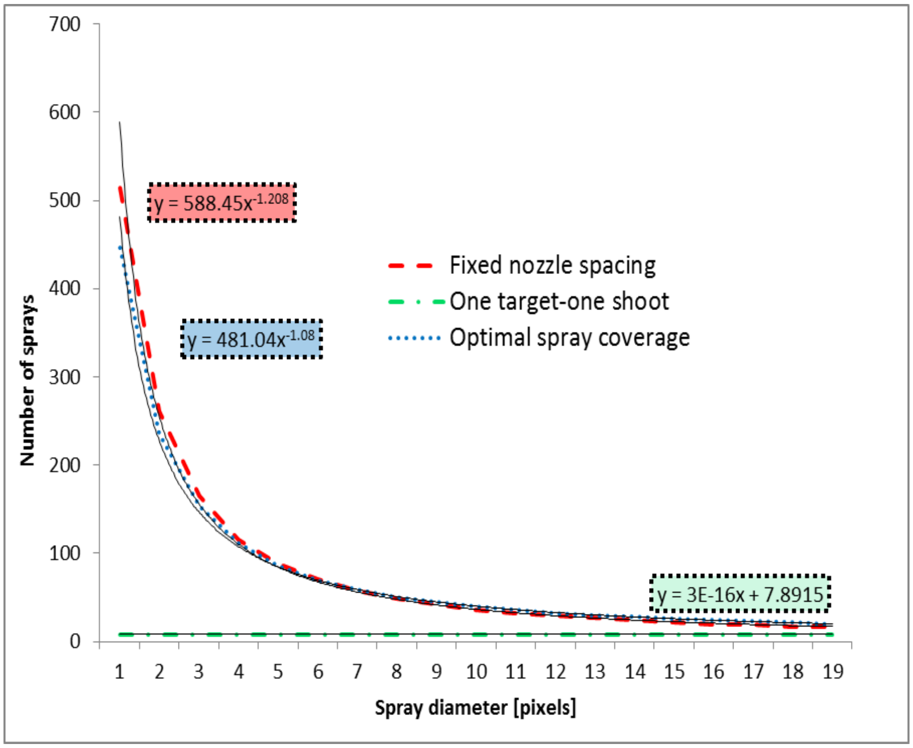

Figure 7 – Number of sprays

Results analysis

Determining the preferred spraying deposition method best suited for the application is achieved by constructing an economic function for each of the spraying methods (7) (8) (9). The economic functions are a combination of the pesticide waste and the number of sprays. The outcome value of these functions is the farmer expense which must be minimized.

$$V_{\text{Fix Nozzle Spacing}} = (13820 \cdot SD + 54282) \cdot (WV) + (588.45 \cdot SD^{-1.208}) \cdot (ST \cdot TC) \quad (7)$$

$$V_{\text{Optimal Spray Coverage}} = (18034 \cdot SD + 30255) \cdot (WV) + (481 \cdot SD^{-1.08}) \cdot (ST \cdot TC) \quad (8)$$

$$V_{\text{One Target} - \text{One Shoot}} = (125518) \cdot (WV) + (7.89) \cdot (ST \cdot TC) \quad (9)$$

Where, $V_{\text{Spray Method Type}}$ [$] is the function result value which represents the cost of spraying one image (one image equal 1.5m of vineyard length), SD is the Spray Diameter used in the spraying process, WV is the pesticide Waste Value [$/mm2], ST [s] is the Switch Time between targets and TC [$/s] is the Time Cost.

Operational parameters values, updated for nowadays, were calculated in order to evaluate and compare the economic functions:

- $WV = 10^{-6}[\$]$ (1 liter of pesticide covers $10m^2$ and cost 10$)
- $TC \cong 0.00695[\$/s]$ (human working hour worth 15$/h, robot operation worth 10$/h)
- $ST = 0.2\,[s]$ (estimation)

Applying the operational parameters to the economic functions reveals that the One Target-One Shoot spraying method is the less expensive method, regardless to the spraying diameter, for the farmer for the values analyzed (Figure 8).

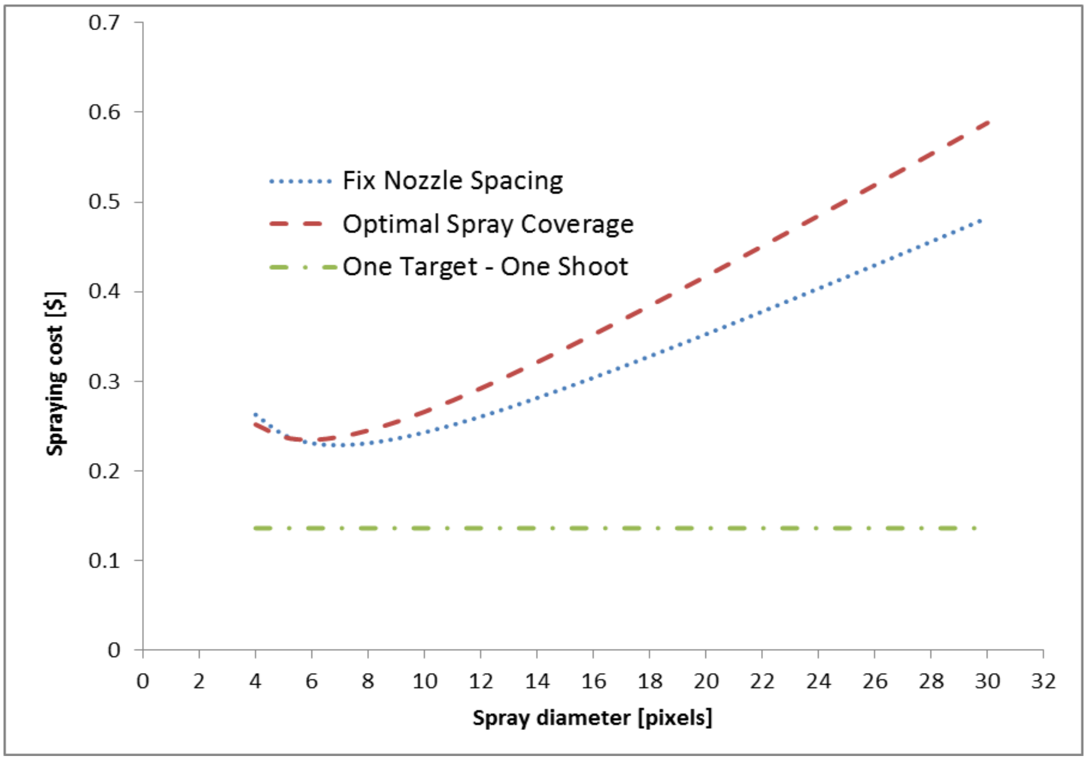

Figure 8 – Economic function results

Sensitivity analysis

Drastic changes of the operational parameters values can drive to choose other method rather than One Target-One Shoot spraying method. An equilibrium point between the One Target-One Shoot and the Optimal spray coverage is obtained when $WV = 6 \cdot 10^{-6}[\$]$, implying that the spraying process will be equally costly to the farmer (Figure 9).

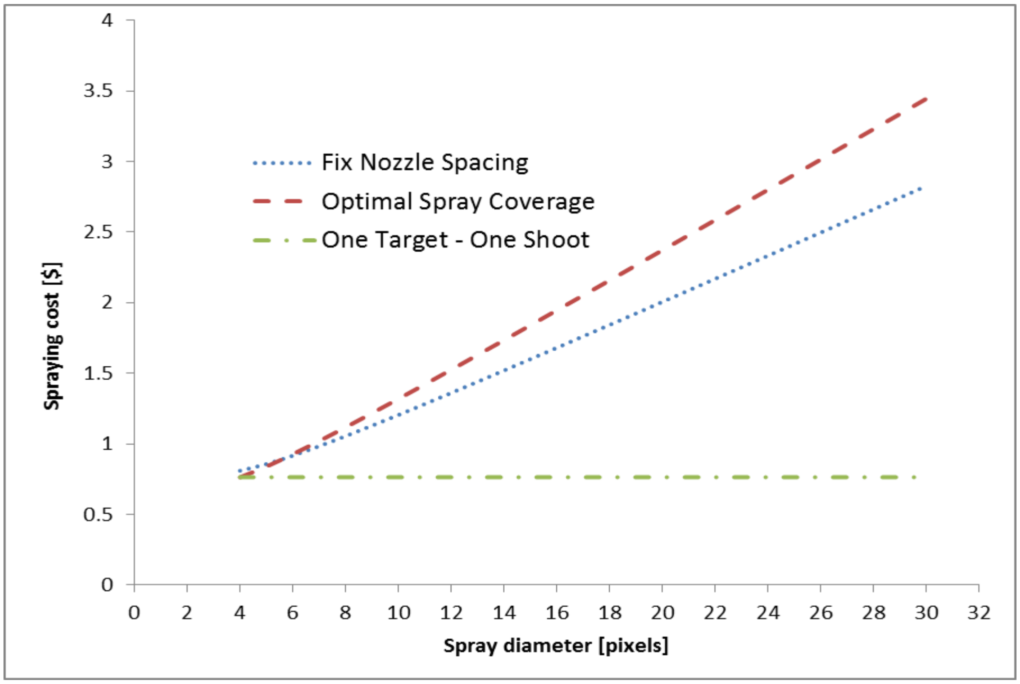

Figure 9 – Economic function results ($WV = 6 \cdot 10^{-6}[\$]$)

Additional equilibrium points are described in Table 1.

Table 1 – Equilibrium points

Method 1	**Method 2**	**WV [$/mm^2]**	**TC [$/s]**	**ST [s]**
One Target-One Shoot	Optimal spray coverage	$6*10^{-6}$	0.00695	0.2
One Target-One Shoot	Optimal spray coverage	10^{-6}	0.00695	0.03
One Target-One Shoot	Optimal spray coverage	10^{-6}	0.0012	0.2

CONCLUSIONS AND FUTURE WORK

This work focuses on comparing methods for spraying pesticide toward grape clusters, and provides the farmer with a tool to reduce his every day costs.

Results indicated that for targeting grape cluster spraying the best spraying deposition method is the **One Target-One Shoot**. This result will change if there will be large changes in the operational parameters values (i.e., if operational parameter will exceed his equilibrium point).

Farmers that prefer to use the **Fixed Nozzle Spacing** method (due to lack of suitable equipment) should set the spraying diameter to minimum to maximize their profit.

Future work will include the development of a computational tool that will advise the farmer which is the best spraying method among the three suggested according to the farmer specific operational parameters values.

It should be noted that achieving a spray diameter smaller than 50[pixels] (58[mm]) requires very accurate and expensive equipment that is hard to find for agricultural tasks. The equilibrium points are formed at small spraying diameter size (Figure 8, Figure 9). According to these findings we argue that for most common agriculture spraying tasks, the best spraying method is the **One Target-One Shoot**. A unique specific sprayer will be developed according to the **One Target-One Shoot** spraying method in future work.

Additional work will focus on evaluation of the influence of target detection and spraying accuracy on the results. Field experiments are undergoing to validate the computer simulation results. These are also necessary to validate the spraying coverage model. Although several models exist they are very inaccurate and highly dependent on the machinery and environmental conditions (Arikan and Balkan, 2000). Hence, in this research we assumed uniform distribution although this is inaccurate. The intention is to include data from field experiments (actual operational results) into the analysis instead.

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