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Close-range air-assisted precision spot-spraying for robotic applications: Aerodynamics and spray coverage analysis

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Orchards and grapevines are currently sprayed overall. Most bush and tree crop sprayers use airflow assistance which generates movements in canopy exposing both sides of the leaves to the spray. Also, large coherent vortices are formed further contributing to improved spray coverage. A new close-range air-assisted spot-spraying method for the selective treatments of disease foci is evaluated here which is promising for reduction of pesticides. Targets structures are expected to have typical diameters around 150 mm and the size of the unit matches this. In contrast to conventional methods, this size of unit prevents the generation of large scale coherent turbulent structures in the airflow that could provide spray coverage of both sides of the target leaves. Therefore, to enhance the beneficial effects of local turbulence, and to induce leaf movement whilst retaining the small size of the spray unit, a rotating screen to generate airflow pulses with discrete peaks in velocity was added and tested. Experiments on the close-range spraying of young grapevine plants using the rotating airflow screen were performed. A high-speed camera, image analysis system and water sensitive papers were used for analysis of the spraying. Natural frequencies of individual leaves showed sharp fluctuations at discrete frequencies and single leaf fluctuations of root mean square velocity corresponded well to the pulsating airflow. Spraying was evaluated as percentage spray coverage and number of droplet impacts. Spray coverage of front side of leaves (facing the sprayer) was good, but coverage on the back of the leaves was limited.

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Nomenclature

Abbreviations

CROPS	Clever Robots for Crops
RMS	Root Mean Square
SEEF	Spraying End Effector
WSP	Water Sensitive Paper

Symbols

C(i,j)	correlation at position (i,j)
$\bar{f}$	average value of grey level of all points in the image *f*
f(x,y)	image at position (x,y)
K	width of sub image *w* (pixel)
L	height of sub image *w* (pixel)
M	width of image *f* (pixel)
N	height of image *f* (pixel)
N	number of measurements
R	normalised correlation coefficient
Tu	turbulence level %
U_i	airflow velocity (m s^{-1})
U_{mean}	mean airflow velocity (m s^{-1})
U_{RMS}	root mean square of airflow velocity (m s^{-1})
$\bar{w}$	average value of grey level of all points in the sub image *w*
w(x,y)	sub image at position (x,y)

1. Introduction

Application of agrochemicals is at present the method most used to protect plants from diseases, pests and weeds (Oerke & Dehne, 2004). To do this, pesticide formulations are diluted in water and distributed over the vegetation in form of sprays. To protect plants from diseases and pests, agrochemicals are sprayed uniformly to ensure coverage of susceptible targets at the appropriate time in the season. In orchards, grapevines and greenhouses susceptible targets (fruits, bunches, new sprouts, younger leaves, etc.) can be located anywhere in the vegetation, consequently current spraying techniques aims to cover all parts of plants, front and behind, top and bottom, as well as within the canopy.

As a result, high volume air-flow has been used to assist the transport and deposition of pesticide droplets the innermost parts of the canopy. Coarse spray can runoff from leaf surface or fail to deposit before reaching the target, whilst buoyancy can cause fine spray to drift away from target, with uncontrolled diffusion to soil and air. When treating plants with sparse canopy, a portion of the spray can travel through the foliage without being impacted. Thus a certain amount of pesticide can go off-target, with significant negative effects on production costs, impact on the environment and the quality of the produce (Cunha, Chueca, Garcerà, & Moltò, 2012; Jong, Snoo, & van de Zande, 2008; Otto et al., 2013).

Current robotic technologies can be applied to crop protection (Mulla, 2013) enabling the possibility of precise and selective targeting of the spray (Esau et al., 2014; Khot et al., 2012; Zamana et al., 2011). This represents one of the most promising options for reducing the amount of pesticide used, whilst maintaining crop-protection efficiency.

The concept of precise application of pesticides also involves the possibility of real-time adjustments of spraying application to the local needs of the target (plant, or part of the plant) on which the treatment is being applied (Andújar, Weis, & Gerhards, 2012; West et al., 2003). Hence, there is a need to develop and introduce techniques and systems for disease detection and pesticide distribution (Dekeyser et al., 2013) which are able to optimise the spot-application of pesticides according to the specific characteristics of the target, such as disease susceptibility, or the presence of infection symptoms.

In the broad field of agricultural robotics, research work is focused on the development and validation of intelligent and selective agricultural robots with crops-care capabilities by integrated use of cutting-edge robotics and further advancing of sensing technologies (Bontsema et al., 2014). Among these robots, a novel robotic sprayer may have a modular architecture, enabling flexible, adaptive and coordinated operation of multiple spraying units, giving to the machine the unprecedented capabilities of continuously adapting pesticide spraying pattern to the crop-canopy characteristics (as volume and foliage density), as well as selectively spot spraying only selected targets (as disease foci or fruits to be protected) (Oberti, Marchi, Tirelli, Calcante, Iriti, Borghese, 2014; Oberti, Marchi, Tirelli, Calcante, Iriti, Hočevar, et al., 2014). Rapid optical detection of disease is essential for precision spraying (West et al., 2003).

Here a new technique of spraying is introduced. For close range precision spraying small patches of disease are required to be treated during their early development. For this a close range precision application a spraying end effector (SEEF) is required. In the following an SEEF design will be presented and measurements of the properties of the airflow around the plant will be investigated. The compatibility of close range precision spraying with emerging robotic technology as part of the development of precision agriculture will be investigated.

1.1. Flow aerodynamics around plants and leaves

In the context of spraying tree and bush crops, airflow from an air-assisted sprayer carries pesticide spray towards its target and provides pressure to the surface of leaves and branches. The main goal is to establish flow conditions in canopies, required for good pesticide application (Endalew et al., 2010).

Large coherent structures can form under such flow conditions, enabling good penetration of the spray and interaction with the plant. These structures manifest themselves as airflow with constantly changing velocity and direction. To some extent, large coherent structures are responsible for flux of pesticide droplets to the backs of leaves (Sánchez-Hermosilla, Rincón, Páez, & Fernández, 2012) but plant movement also increases the probability of spray droplets impacting these areas (Pujol, Casamitjana, Serra, & Colomer, 2013).

To be effective against early discrete disease foci, and not causing excessive pesticide consumption, the size of the spray plume should be approximately of the same size as the disease foci. For close-range precision spot spraying of an

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