BIOSYSTEMS ENGINEERING 146 (2016) 203–215

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Special Issue: Robotic Agriculture

Research Paper

Selective spraying of grapevines for disease control using a modular agricultural robot

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ARTICLE INFO

Article history:
Published online 13 January 2016

Keywords:
Precision spraying
Agricultural robot
Crop protection
Automation
Disease sensing

Due to their recognised role in causing environmental pressures, the need to reduce production costs and public concerns over the healthfulness of fresh products and food, reducing pesticide use in agriculture is a major objective. In current farming practice, pesticides are typically applied uniformly across fields, despite many pests and diseases exhibiting uneven spatial distributions and evolving around discrete foci. This is the fundamental rationale for implementing the selective targeting of pesticide applications such that pesticides are deposited only where and when they are needed and at the correct dose. This approach is explored using the example of powdery mildew on grape vines controlled by means of a modular agricultural robot developed within the EU-project CROPS. The CROPS manipulator was configured to six degrees of freedom and equipped with a new precision-spraying end-effector with an integrated disease-sensing system based on R-G-NIR multispectral imaging. The robotic system was tested on four different replicates of grapevine canopy plots (5 m in length × 1.8 m in height) prepared in a greenhouse setup by aligning potted plants exhibiting different levels of disease. The results indicate that the robot was able to automatically detect and spray from 85% to 100% of the diseased area within the canopy and to reduce the pesticide use from 65% to 85% when compared to a conventional homogeneous spraying of the canopy. This work, to the best of our knowledge, is the first using a totally automatic selective system for spraying of diseases in specialty crops.

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http://dx.doi.org/10.1016/j.biosystemseng.2015.12.004

Nomenclature

CAN	controller area network
CCU	central control unit
CROPS	clever robots for crops project
DoF	degree of freedom
EU	European Union
PWM	pulse width modulation
R-G-NIR	red, green, near-infrared (spectral channels)
ROI	region of interest (of an image)
ROS	robot operating system
TCP	tool-centre-point (frame of reference)
VIS-NIR-MIR	visible, near-Infrared, mid-infrared (spectral bands)

Symbols

x	axis defined by the robot traveling direction (parallel to the canopy wall)
y	axis defined by the front direction from the robot to the canopy
z	vertical axis
α	latitude angle defined by rotations around the x−axis
γ	longitude angle defined by rotations around the z−axis

1. Introduction

In recent decades, the reduction of pesticide use in agriculture has been a major objective of EU policy; it was one of the strategic themes of the 6th Environment Action Programme and the topic of a framework directive on sustainable pesticide use (2009/128/EC). Indeed, pesticides are recognised to play a major role in environmental pressure (Sabatier et al., 2014; Stehle & Schulz, 2015), agricultural production costs and public concerns about the healthfulness and wholesomeness of fresh products (Abdollahi, Ranjbar, Shadnia, Nikfar, & Rezaie, 2004; Burns, McIntosh, Mink, Jurek, & Li, 2013; Rauh et al., 2012).

The objective of reducing pesticide use has been tackled through different and complementary approaches, including selection of resistant varieties, crop management techniques, crop scouting practices, application of biocides and beneficial organisms, and regular maintenance and optimal setting of spraying equipment.

In current farming practice, pesticides are typically applied uniformly to fields. However, several pests and diseases exhibit an uneven spatial distribution, with typical patch structures evolving around discrete foci (localised areas exhibiting symptoms), especially during early stages of development (Everhart, Askew, Seymour, & Scherm, 2013; Spósito, Amorim, Bassanezi, Filho, & Hau, 2008; Waggoner & Aylor, 2000).

This is the fundamental rationale for implementing selective spraying capability by means of highly automated equipment or robots. Such systems would enable the selective targeting of pesticide application only where and when it is needed, with the aim of controlling the initial foci and preventing the infection establishment and its epidemic spread to the whole field (West et al., 2003).

This approach has been explored within the EU-funded project CROPS (www.crops-robots.eu), which is aimed at developing, optimising and demonstrating a highly modular and reconfigurable robotic system for accomplishing multiple agricultural operations, including selective spraying, ripeness monitoring and selective harvesting. This system is also able to work on different specialty crops, such as grapes, sweet peppers and apples (Baur, Pfaff, Ulbrich, & Villgrattner, 2012; Bontsema et al., 2014; Schütz, Pfaff, Baur, Buschmann, & Ulbrich, 2014).

The approach adopted in CROPS was clearly different from previous research on robotic agriculture, which typically relies on adaptation of non-modular, heavy standard industrial manipulators (e.g. Baeten, Donné, Boedrij, Beckers, & Claesen, 2008; Katupitiya, Eaton, Cole, Meyer, & Rodnay, 2005) or focuses on specific types of produce and operational tasks (e.g. Bac, van Henten, Hemming, & Edan, 2014; Guo, Zhao, Ji, & Xia, 2010; Hayashi et al., 2010; Van Henten et al., 2003). A few examples of multipurpose agricultural robotic systems have nevertheless been developed and tested especially for greenhouse operations (Belforte, Deboli, Gay, Piccarolo, & Ricauda Aimonino, 2006; Hayashi, Yoshida, Yamamoto, Iwasaki, & Urushiyama Miyagi, 2008; Mandow et al., 1996).

Over the past two decades, the idea of automated selective spraying (or spot spraying) has been introduced and investigated for herbicide applications (Felton & McCloy, 1992; Paice, Miller, & Day, 1996; Slaughter, Giles, & Tauzer, 1999), and this research has led to the development of some examples of currently available commercial equipment.

Although the concept was extended to crop-disease management (Larbi et al. 2013; Li, Xia, & Lee, 2009; Moshou et al., 2011; West et al., 2003), automated, selective spraying for diseases has not yet been developed. The reason is mainly that there have been only limited advances in automated detection systems for disease symptoms. Even if this is currently a blossoming field of research, a huge potential for improvement remains.

Sensor technologies for crop diseases have been extensively reviewed recently by Sankaran, Mishra, Ehsani, and Davis (2010), while a more focused discussion of the applications of proximal optical sensing for disease detection in arable crops can be found in West et al. (2003) and Mahlein, Oerke, Steiner, and Dehne (2012); a similar discussion for specialty crops can be found in Lee et al. (2010).

Among other case studies, grapevine is a perfect candidate crop to explore the concept of selective and targeted spraying of initial disease foci. Indeed, in current practice in viticulture, pesticide spraying is applied uniformly through the vineyard using a continuous protection approach throughout the growing season. For some of the most advanced wine-producing regions worldwide, this results in ten to fifteen or more applications per season, often conducted at high volume rates (typically 1000 l ha^{-1} or greater). A successful implementation of a timely detection system and the selective spraying of disease foci may have a dramatic impact on the amount of pesticide necessary to prevent an infection's establishment and its epidemic spread to the vineyard.