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Research Paper

Autonomous systems for precise spraying – Evaluation of a robotised patch sprayer

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Advances in different technologies, such as global navigation satellite systems, geographic information systems, high-resolution vision systems, innovative sensors and embedded computing systems, are finding direct application in agriculture. These advances allow researchers and engineers to automate and robotise agricultural tasks no matter the inherent difficulties of the natural, semi-structured environment in which these tasks are performed. Following this current trend, this article aims to describe the development and assessment of a robotised patch spraty -20ying system that was devised for site-specific herbicide application in agricultural crops and is capable of working in groups or fleets of autonomous robots. The robotised patch sprayer consisted of an autonomous mobile robot based on a commercial agricultural vehicle chassis and a direct-injection spraying boom that was tailor-made to interact with the mobile robot. There were diverse sources (on-board and remote sensors) that can supply the weed data for the treatment. The main features of both the mobile robot and the sprayer are presented along with the controller that harmonised the behaviour of both main subsystems. Laboratory characterisation and field tests demonstrated that the system was reliable and accurate enough to accomplish the treatment over 99.5% of the detected weeds and treatment of the crop with no weed treated was insignificant; approximately 0.5% with respect to the total weed patches area, achieving a significant herbicide savings.

1. Introduction

In recent decades, research on weed-sensing technologies, sensor fusion and selective crop management with herbicides or others control treatments have progressed significantly (Jeon & Tian, 2009; Khot, Tang, Steward, & Han, 2008 and Lee et al., 2010). Particularly noteworthy is the improvement in the navigation capabilities of vehicles and agricultural implements by combining global navigation

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Nomenclature

a	Equidistant spacing of the nozzles
D_c	Applied dose (l ha^{-1})
FCS	Frontal cell size (m)
GNSS	Global navigation satellite system
GPS	Global positioning system
LCS	Lateral cell size (m)
MWC	Minimum weed coverage
n_a	Number of active nozzles
NWT	Not weed treated (m^2)
p	Ratio, herbicide volume/volume water
PLC	Programmable logic controller
Q_{ch}	Injected herbicide flow (l min^{-1})
Q_n	Nominal workflow (l min^{-1})
Q_w	Total water flow (l min^{-1})
RHEA	Robot fleet for highly effective agricultural and forestry management
RTK	Real-time kinematic
v	Robot speed
WCM	Weed control map
WDS	Weed detection system
WNT	Weed not treated (m^2)
WPP	Weed patch perimeter (m)
WPPA	Weed patch perimeter angles (rad)

satellite system (GNSS) sensors with dynamic measurement units. Nevertheless, many of these studies have focused solely on individual developments with only individual components of the whole system being studied, tested and evaluated. For example, Blackmore, Griepentrog, Nielsen, Nørremark, and Resting-Jeppesen (2004) focused on the development of an autonomous tractor, whereas Wisserodt et al. (1999) concentrated on controlling a hoe. Nørremark, Griepentrog, Nielsen, and Søgaard (2008) attempted to develop intra-row weed management using a self-propelled, unmanned hoe that was composed of an autonomous vehicle and a cycloid hoe. The vehicle and the tool were controlled independently to follow a pre-planned task. Nonetheless, both of the subsystems had their own GNSSs, and therefore expensive components in the system were duplicated. These efforts revealed a need to simplify systems and to develop integrated autonomous agricultural equipment.

Recently, Berge, Goldberg, Kaspersen, and Netland (2012) presented a GPS guided autonomous robot for weed control in cereals based on machine vision, a system able of perform weed monitoring and spraying in the same operation. Also there are some commercial systems for the automatic weed control in agriculture, for example the "Robocrop Spot Sprayer" offered by "Garford Farm Machinery" (Garford, 2015).

The latest development is the use of multi-robot systems, or fleets of robots, for outdoor applications including applications that are related to agriculture, to perform tasks in a collaborative way (Vougioukas, 2012). This idea was introduced a few years ago (Bautin, Simonin, & Charpillet, 2011 and Bouraqadi, Fabresse, & Doniec, 2012), but the first real attempts were conducted only recently (RHEA, 2015). Improvement in the integration of individual components (acquisition, guidance, decision making and actuation) appears to be essential to establish fully autonomous agricultural systems. Furthermore, new developments must consider the specific requirements of the vehicles to be used as members of autonomous fleets.

The components that are required to build such a system come from different research areas and demand diverse disciplines (agronomy, robotics, automatic control, machine vision, etc.). Therefore, the integration task requires a multidisciplinary approach, whereby each discipline must address different technologies, operating systems, programming languages, methodologies, etc.

The main aim of this work is to describe and assess an attempt to configure a fully integrated path spraying technology for site-specific herbicide application in agricultural crops that is capable of being integrated into fleets of autonomous, heterogeneous robots.

This study is part of the results that were derived from the project RHEA – robot fleet for highly effective agricultural and forestry management, which is funded by the European Union through its Seventh Framework Programme. This project, which was devoted to developing a fleet of heterogeneous robots for agricultural specific-site treatment, configured a fleet of aerial robots based on a hex-rotor that was equipped with perception systems operating remotely (Peña, Torres-Sánchez, de Castro, Kelly, López-Granados, 2013 and Rabatel, Gorretta, & Labbé, 2014), and a fleet of ground vehicles based on a commercial agricultural vehicle chassis that were equipped with perception (Romeo et al., 2012) and actuation systems to operate in three scenarios: wheat and maize fields and olive orchards (Frasconi et al., 2014; Perez-Ruiz et al., 2014 and Sarri, Lisci, Rimediotti, & Vieri, 2014). These essential subsystems were complemented by other systems: a Mission Manager, which was in charge of generating the tasks (Conesa-Muñoz, Ribeiro, Andujar, Fernandez-Quintanilla, & Dorado, 2012); a Communication System to communicate between the robot and the base station (Drenjanac & Tomic, 2013); a Safety System to address safety issues for humans and animals; and a Location System to obtain the position of every vehicle with respect to the base station (Perez-Ruiz, Slaughter, Gliever, & Upadhyaya, 2012).

The RHEA fleet was fully operative by mid-year 2014 and generated positive results after successful demonstrations were conducted throughout the first half of that year. However, this article goes further in quantitatively assessing the performances of a specific subset of components comprising the unmanned ground vehicle (i.e. the robot), the sprayer prototype (i.e. the implement) and the relevant integration subsystems (i.e., the main computer and location system). The main objective of this work is to analyse a smart herbicide application system based on a direct-injection sprayer used for precision weed control. In this analysis the weed area not treated and the area without weeds treated was estimated according to the weed control map (WCM) and these values were measured using real systems. This system needs a WCM that is provided by a weed detection system (WDS) that can be used with on-board systems (in real time) or using external devices.

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