BIOSYSTEMS ENGINEERING 172 (2018) 92–101

Available online at www.sciencedirect.com

ScienceDirect

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

Research Paper

An automatic trunk-detection system for intensive olive harvesting with trunk shaker

Jose T. Colmenero-Martinez, Gregorio L. Blanco-Roldán, Sergio Bayano-Tejero, Francisco J. Castillo-Ruiz*, Rafael R. Sola-Guirado, Jesús A. Gil-Ribes

Department of Rural Engineering, E.T.S.I. Agrónomos y Montes University of Córdoba, Campus de Rabanales, Ctra. Nacional IV Km 396, Córdoba, Spain

ARTICLE INFO

Article history:
Received 9 October 2017
Received in revised form
17 January 2018
Accepted 9 June 2018

Keywords:
Vibration
Harvesting automation
Trunk grabbing
Trunk gripping
Effective field capacity
Debarking

Trunk shakers are widely used for olive harvesting, being the main detachment system for fruit harvesting. In recent decades, the components of trunk shakers have evolved at mechanical, hydraulic and control levels. However, machine accuracy depends on the operator, whose expertise is a key factor for issues such as trunk debarking caused by grabbing systems, shaking parameters, or on-foot operator safety. The objective of this work was to develop an automatic trunk-detection system to reduce operator influence on the process. Thus, the automatic system via infrared sensor was implemented on a trunk shaker head hitched to a tractor. A control algorithm, control logic and display for trunk grabbing automation were developed. The automatic system was tested under laboratory and field conditions to assess the influence of some variables on trunk detection. The evaluated variables were colour, material, diameter, and target location within the sensor field of vision. The success rate of the automatic system was 91% for trunk grabbing. In the field phase, the efficacy of the automatic system was compared to an operator performing the tasks manually, obtaining times of 16.05 ± 2.8 s tree^{-1} and 21.54 ± 5.29 s tree^{-1} respectively, and a percentage of success in trunk grabbing of 92.9%. Automatic mode improved manual mode by saving 27.3% of time, improving effective field capacity. The automatic mode developed here provided a high ratio of success and it showed highly reliable and efficient performance compared with manual mode.

1. Introduction

Due to the increasing costs of labour, operational efficiency is currently a key factor for agricultural machinery (Kester, Griepentrog, Hörner, & Tuncer, 2013). In addition, some agricultural tasks suffer from a lack of trained workers (Bechar & Vigneault, 2016) along with a need to increase productivity, which could be achieved using automation and robotics (Xia, Wang, Chung, & Lee, 2015). There is a slow but steady implementation of robotics in the agricultural sector in general (Xue, Zhang, & Grift, 2012), but its use in olive groves has to

* Corresponding author.
E-mail addresses: g32comaj@uco.es (J.T. Colmenero-Martinez), ir3blrog@uco.es (G.L. Blanco-Roldán), p52bates@uco.es (S. Bayano-Tejero), g62caruf@uco.es (F.J. Castillo-Ruiz), ir2sogur@uco.es (R.R. Sola-Guirado), mc1giroj@uco.es (J.A. Gil-Ribes).
https://doi.org/10.1016/j.biosystemseng.2018.06.002
1537-5110/

date been scarce for various reasons, among which are the difficulty of obtaining standardised orchard categories that adapt the crop to the machine, or tailoring the machine to the crop (Gil-Ribes, Blanco-Roldán, & Castro-García, 2010). Experimental progress is being made which could open the doors to the application of robotics in the short to mid-term in the sector, and automation is increasingly widespread for many agricultural applications; however, despite many on-going developments at the experimental stage, there has been little in-field automation in olive orchards.

The automation of processes within harvesting is an ongoing development for woody crops such as citrus (Li, Lee, & Hsu, 2011) and vegetable crops such as the sweet pepper (Bac et al., 2016) or greenhouse cucumbers (Van Henten et al., 2002). Automatic collection systems based on artificial vision face the difficulty of locating objects that are poorly defined by their position, shape, size and colour (Bac, Henten, Hemming, & Edan, 2014). The cost of a robotic system is usually too high when compared to the wages of a labourer on a temporary contract (Longo & Muscato, 2013), despite the fact that the last 20 years have seen excellent results in autonomous collection systems that have reduced costs, mitigated staff shortages and compensated for the existence of low-skilled workers (Kapach, Barnea, Mairon, Edan, & Ben-Shahar, 2012) in seasonal tasks. Bringing automation to agriculture would introduce high technology to the sector and, in the near future, the application of sensors initially developed for other spheres will be a first step for deploying robotic systems in harvesting.

Introducing new technologies to olive harvesting is a strategic need for the modernisation and sustainability of the sector, which could be enhanced using robotics or automated devices. In most cases, olive orchards suffer from a lack of profitability and the need to improve orchard management in several process areas. The harvesting of oil olives represents approximately 40% of the cost of the crop (AEMO, 2012) and is a key factor for orchard profitability. Furthermore, as olive costs are highly conditioned by orchard category, management and topography there is no harvesting method suitable for all orchard types. Nevertheless, increased mechanisation, particularly of the harvesting operation, is necessary as it would bring major improvements to the sector's competitiveness and to the quality of the oil.

Intensive olive orchards are usually planted with rectangular spacing, which is adapted to mechanical harvesting (Rallo et al., 2013) and other mechanised operations. Planting density is between 180 and 800 trees per hectare. This orchard category covers 2,174,076 ha worldwide (COI, 2015) and represents approximately 21.8% of the total surface area for olive tree culture. Intensive orchards have been developed in new areas with high water availability and better soil-climatic conditions (Fernandez Escobar et al., 2013). Although this type of intensive orchard is prepared for mechanical harvesting with trunk shakers, the harvesting system employed has a low level of automation. The structure of an intensive olive orchard (with one trunk, trained trees that are clear of low branches and have a crotch height of 0.8–1 m) makes it possible to develop an automatic system for trunk grabbing using trunk shakers. It has been established that the main response of the olive to forced vibration differs depending on tree architecture (Castro-García, Blanco-Roldán, Gil-Ribes, & Agüera-Vega, 2008), vibration parameters that facilitate acceleration transmission to the fruit (Jimenez-Jimenez et al., 2015), and locating production in the middle and upper part of the crown (Castillo-Ruiz, Jiménez-Jiménez et al., 2015, Castillo-Ruiz, Pérez-Ruiz, Blanco-Roldán, Gil-Ribes, & Agüera, 2015). Although the peduncle is a distinctly different structure from the branch in which it is inserted (Torregrosa, Albert, Aleixos, Ortiz, & Blasco, 2014), it is possible to reach high fruit detachment efficiencies in autonomous systems of vibration collection, which may be facilitated through annual moderate or heavy pruning (Tombesi, Boco, Pilli, & Farinelli, 2000).

Mechanical harvesting in intensive olive orchards is mainly carried out using trunk shakers along with hand-held shaking combs or manual poles, and gathering the detached fruit on nets extended under the tree canopy or on previously prepared soil (Gil-Ribes, López-Giménez, Blanco-Roldán, & Castro, 2008). To improve the competitiveness of the olive sector, it is advisable to replace manual labour with mechanical harvesting (Fergurson et al., 2010). In recent years, attempts to tackle this problem have seen the development of intensive olive harvesting systems such as canopy shakers, which directly apply vibration to fruit-bearing branches (Sola-Guirado et al., 2014). Although a large part of operations are mechanised in intensive olive orchards, very few operations are automated in olive cropping, and those that are mainly consist of olive harvesting with trunk shakers. A vital step towards the automation needed in olive cropping would be to make advances in the design of an intelligent robot with human-like perceptual abilities (De-An, Jidong, Wei, Ying, & Yu, 2011).

In Spain, trunk shakers are widely used for harvesting several woody crops. Trunk shakers can be tractor-hitched or self-propelled with three (the most common due to higher manoeuvrability) or four wheels. The total number of vibrators sold in Spain in 2015 was 325 units (ROMA, 2015), of which 86.15% were tractor-hitched compared to 13.85% self-propelled, and 86.67% of the total sold were tricycle type. To make immediate improvements in this area it is necessary to develop a vibrator coupled to a tractor and automate the tasks of detection, approximation and trunk grabbing, in addition to refining the vibration and collection systems, all of which would improve the machine's working capacity.

The objective of this paper is to develop a new driver assistance system for olive harvesting with trunk shakers using a robotic system to control shaking head movement. To do this, we developed a control logic, implemented in software and hardware systems, which were tested to build an automation system for a tractor adapted to trunk shaker operations.

2. Material and methods

The trunk shaker prototype that was tested consisted of a mechanical-hydraulic part hitched to the tractor and another electronic part that formed the automation system (Fig. 1) composed of hardware and software. The trunk shaker was designed to work in intensive olive orchards.