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Automated system for real time tree canopy contact with canopy shakers

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A B S T R A C T

Most crops destined for industrial transformation employ mechanical harvesters that have been developed satisfactorily by adapting the tree to the machine features. Not all fruit trees can be adapted, and this is the case in traditional olive orchards, where canopies are very irregular and a complex harvesting system is necessary to adapt to different tree geometries and sizes. Lateral canopy shakers have arisen as an alternative system, the use of which is spreading as they allow continuous integral harvesting of several crops such as citrus fruit or, more recently, the olive. Contact between the shaker and the canopy is a key harvesting factor that must be studied. Manually positioning several shaker heads at different heights to follow the tree contour during continuous harvesting is a tedious task for an operator and may decrease potential efficiency. However, automation of shaker contact with the canopy may increase harvester efficiency. Two automatic systems composed of several electronic devices were developed and incorporated into a harvester with several shaker heads. The first system controlled canopy contact based on measuring the distance between the shaker and the tree contour. The second system measured the variation of the shaker mechanism's hydraulic pressure in order to adjust the position of each head relative to the canopy. Both systems were compared to manual control by studying removal efficiency, harvesting efficiency, debris production and percentage of shaking time within the control intervals. Results determined the suitability of automatic harvesting systems with an increase of 5.9% in removal efficiency based on the criterion of tree resistance to shaking, with no significant differences in tree damage and an increase in field capacity ha h-1 person-1. Laser LED may be a valid technology for measuring the distance to canopy in real time and gave satisfactory results but a decrease of 7.9% in removal efficiency compared to manual sighting. The bottom, middle and top of the tree present different patterns in the harvesting process, and as resistance mode adjusts control intervals to the different patterns, it may provide a closer fit to follow than distance mode. Further improvements are required to enhance harvesting efficiency by connecting automation between the removal system and the catch frame.

1. Introduction

The use of mechanical removal systems based on a trunk or branch shaker is widespread for detaching fruits like cherries, apricots, pistachios, olives, etc. (He et al., 2015; Torregrosa et al., 2006; Polat et al., 2007; Jimenez-Jimenez et al., 2015). These systems need to apply vibration on the tree structure and have a limited field capacity which depends mainly on orchard plant density. Canopy shakers, on the other hand, shake the canopies and allow integral harvesting with a shake-catch method, for several crops where the fruits are destined for industrial transformation, such as olives or oranges.

In recent years, the trend in new orchards has been to increase the number of plants per hectare, so it has thus been beneficial to use canopy shakers for continuous harvesting to increase field capacity in terms of hectares harvested per hour (Sanders, 2005). These harvesters have two main configurations: lateral single-row harvesters (Savary et al., 2011) and straddle harvesters (Ravetti and Robb, 2010). For the olive in particular, the use of straddle harvesters has grown in recent years mainly due to the increase in new high-density orchards that are more competitive compared to pre-existing orchards. This has mainly been possible due to the adaption of trees to machine: single trunks aligned in rows for a linear machine trajectory, an elevated skirt height so that catch frames do not clash, tree height adapted to an over-row pass, and a reduced canopy diameter and density for effective shaking. However, many orchards cannot be adapted to these harvesters for technical, economic or social reasons. In the case of the olive, traditional orchards have not undergone this mechanisation process, and are currently suffering serious profitability issues, despite the fact that 73%, 9.9 Mha, of the world's olive orchards are still traditional (39.9% of them are suitable for mechanisation) (IOC, 2015).

In this regard, lateral canopy shakers represent a promising alternative for harvesting intensive or traditional olives trees (Sola-Guirado

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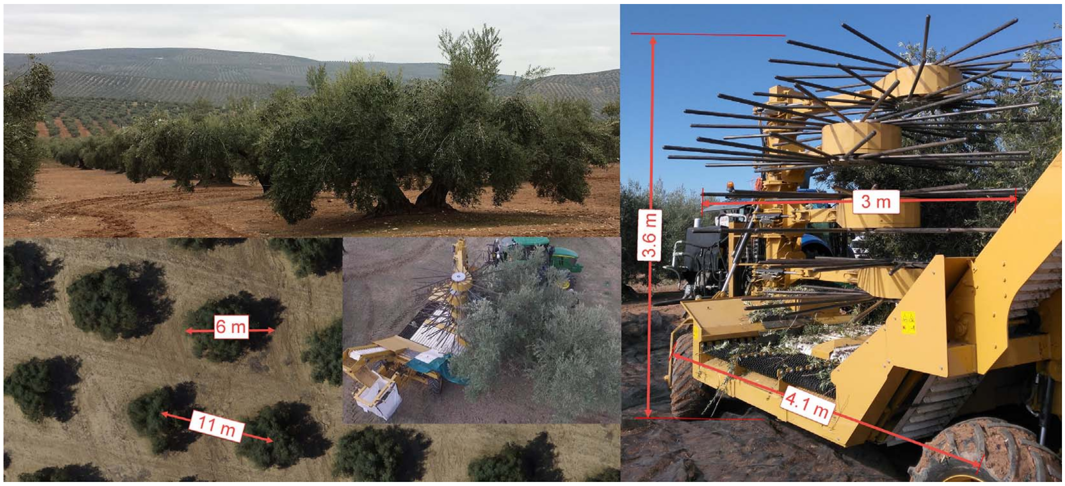

Fig. 1. Harvester with four canopy shaker heads for adapting to canopy olive trees.

et al., 2014; Famiani et al., 2014), or even other crops such as citrus with similar problems. Several studies have been undertaken to determine the influence of machine configuration on the tree (Sola-Guirado et al., 2016a), or tree pruning on machine efficiency (Ferguson et al., 2012). However, new knowledge and research are needed about the way in which contact of the shaker with the tree is established. This aspect is a key for detaching the maximum fruit with low debris (Castillo-Ruiz et al., 2017; Ferguson and Castro-Garcia, 2014; Savary et al., 2011), which is the main target of farmers. Normally, contact between beating rods and bearing branches is guided by an operator who moves the shaker to the canopy crown based on sight. However, this task may be extremely demanding as it requires a very high degree of concentration in continuous harvesting and removal efficiency may decrease, or debris production may increase, if it is not performed correctly. This is why automation of this process has such great importance (Honghua et al., 2011), in a similar way to that developed in other machinery, such as spray booms (Gonzalez-de-Soto et al., 2016) or the air-blast sprayer (Pérez-Ruiz et al., 2015). In order to advance in automatic fruit harvesting using canopy shakers, we propose the development of two different systems for automatic contact between the shaker and tree canopy in a real-time process.

The first system is based on measurement of the distance between the canopy shaker and the tree canopy. A wide variety of tree crown detection and delineation methods have been developed in recent years, although the most commonly used ones are based on passive aerial remotely sensed imagery (Ke and Quackenbush, 2011). The integration of high spatial resolution optical imagery with other sensors that provide data from the vertical structure may be particularly useful for obtaining more accurate information about tree crown geometry. In this regard, active sensors can directly capture data for vertical tree crown characterisation using, for example, LiDAR sensors (Lee and Ehsani, 2009), which are very widespread. However, despite their advantages, they can result in large volumes of data, high operation costs (Zhen et al., 2016), and can be highly time-consuming when analysing results, which makes the real-time control of applications difficult. Other devices such as ultrasonic sensors have been used to more swiftly measure canopy dimensions for a specific application in real time (Zaman and Salyani, 2004; Schumann and Zaman, 2005), but they must be implemented for several machine sections corresponding to independent canopy heights (Maghsoudi and Minaei, 2014). In a similar way, photoelectric distance sensors may be used to detect different zones of trees and provide a signal to control systems. We propose the use of a single sensor for measuring the whole canopy contour with a multi-ray LED scanner employing pulse ranging technology that could represent an economical and robust solution for 2D detection.

The second system is based on measurement of the variation in hydraulic pressure that occurs in the shaker heads, depending on the range of approach to the tree and the architecture of the shaken zone. Most remote sensing technologies make geometric measurements from a distance and do not consider other tree structure factors such as foliage density or branch stiffness, which are highly valuable in a shaking process. In recent years, several studies have proposed indirect canopy structure measurements based on an estimation of contact frequency or gap fraction (Weiss et al., 2004). However, all of these methods may prove inefficient for use in real-time control methods for a harvesting process. With this second system, we propose to indirectly measure tree canopy resistance to shaking.

This study was performed on the traditional olive tree because it is one of the crops with most canopy irregularities, using a harvester that allowed a fit to the tree contour at different heights, depending on canopy shaker heads. The objective of this work was to develop two automated control methods based on two different parameters (distance to tree and tree resistance to shaking) in order to maintain effective tree canopy contact in the shaking process for continuous harvesting. The removal, harvest efficiency and debris production were evaluated by comparing the two automatic modes with a manual method for maintaining each shaker in contact with the tree canopy, and by studying the percentage of time during which each parameter was in different control intervals.

2. Materials and methods

Several sensors and actuators were set in a canopy shaker harvester for automated movement of the shaker heads to the tree canopy and for an adequate contact between the shakers and tree canopy, and three operating modes were evaluated. Field tests were carried out on traditional olive trees with irregular, big sized canopies to evaluate the operating modes in continuous harvesting.

2.1. Harvester

The automated systems were implemented using the “ShaMolive” harvester (Sola-Guirado et al., 2016b) (Fig. 1), which can reach the whole canopy volume of big trees and has several shaker heads that offer a better fit for irregular crowns. The harvester had a catch frame with several conveyors supported on two axles and four wheels that allowed performance of a different harvesting path, which could even be around the tree if tree spacing were more than 9 m, with a reduced turning radius of 2.5 m. Thanks to its versatility, the harvester is also suitable for use on other fruit trees which have other canopy geometries and orchard layouts.

Four shaker heads were set in cantilevers which would be able to