Computers and Electronics in Agriculture 133 (2017) 30–36

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

An intelligent precision orchard pesticide spray technique based on the depth-of-field extraction algorithm

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ARTICLE INFO

Article history:
Received 7 August 2016
Received in revised form 29 November 2016
Accepted 1 December 2016

Keywords:
Depth image
Kinect
Orchard
Average distance
Leaf wall area density

ABSTRACT

Microsoft's Kinect system can capture the colour and depth information of a scene in real time. However, to date, there have been no known reports on the application of the Kinect system in the area of precision spray control. To obtain a relatively good spray effect, the present study integrates the advantages of colour and depth information using Microsoft's Kinect system and proposes equations for calculating the average distance between the Kinect system and a fruit tree, as well as the leaf wall area (LWA) density, to address the difficulty in estimating the dose of sprayed pesticides. First, to adjust and control the spray intensity of sprayers and the dose of sprayed pesticides, the present study proposes an equation for calculating the LWA average distance of fruit trees. The experimental results showed that the average distance was largest between the Kinect system and the bottom part or trunk of a fruit tree. A comparison with the measured distances showed that the distances calculated based on the data acquired by the Kinect system were accurate. Second, to better control the dose of sprayed pesticides, the present study proposes the concept of LWA density. Finally, the results of the experiment on peach trees, apricot trees and grapevines demonstrated that the intelligent orchard pesticide precision spray model established based on the average distance and the LWA density can improve the efficiency in spraying pesticides, reduce waste and environmental pollution, and achieve automated and precision orchard production.

1. Introduction

Due to human or natural factors, fruit trees are often subject to various types of diseases and pests. Disease and pest prevention and control are necessary throughout the entire process of crop growth. Currently, during the tree disease and pest prevention and control process, in general pesticide application systems apply pesticides evenly and in the entire area, regardless of whether there to apply pesticides on targets. However, in reality, there is always certain spacing between crop plants, and different fruit trees have different canopy shapes. Even, constant spray method will result in non-targeted pesticide deposition, which in turn results in waste and environmental pollution. The main objective of precision spray techniques is to obtain the target information and apply pesticides as needed.

In current precision orchard pesticide spray systems, various methods are employed to determine the optimal dose of pesticides. However, it is difficult to estimate the dose of pesticides in most applications. Therefore, people have further increased the pesticide-use efficiency by improving these methods (Koch, 2007; Walklate et al., 2011; Llop et al., 2015; Morais et al., 2016). The leaf wall area (LWA) is the main target area when spraying pesticides and its main parameters need to be collected using sensors. Of the various types of sensors used in current precision spray systems, ultrasonic sensors have relatively low costs and can be easily implemented. However, the reflection of the sound waves emitted by an ultrasonic sensor is significantly affected by the directional angle and material of the measured plane. Different leaves of a fruit tree have different angles, which will also change when the tree is blown by wind. As a result, the angle of tree leaves can easily affect the measurement of the LWA and cause errors in the determination of the distance from the fruit tree and the LWA (Molto et al., 2000; Jejčič et al., 2011). A light detection and ranging (LiDAR) system can accurately measure its distance from a fruit tree and, when combined with a Global Positioning System, can determine the position of the fruit tree, thereby facilitating precision spray control. However, because laser beam scanning is in fact scanning with a point light source, LiDAR systems have low

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http://dx.doi.org/10.1016/j.compag.2016.12.002
0168-1699/

accuracy in measuring the LWA density (Escolà et al., 2013; Mendez et al., 2012; Seidel et al., 2012; Rosell and Sanz, 2012; Wellington et al., 2012; Osterman et al., 2013). Near infrared (IR) sensors emit IR light via transmitters. They have high response rates, can be used to perform noncontact inspection, and provide results with high accuracy and resolution. As a result, near IR sensors have been widely used worldwide in the detection of crop targets (Chueca et al., 2008; Llorens et al., 2010; Lee et al., 2010; Browna et al., 2008). Because the IR light emitted by a near IR sensor covers a small area and is uneven in this area, the implementation of multiple collaborative sensors is required, increasing the processing difficulty and errors. A video camera can capture video images of fruit trees and segregate parameters such as LWA, height and density based on the colour information through video processing techniques. However, due to a lack of measured distance information, distance can only be estimated based on the pre-calibrated distance from the video camera, which may easily generate relatively large errors. In addition, LWA detection can be easily affected by a complex background (Hoevar et al., 2010).

The Microsoft Kinect system can capture the colour and depth information of a scene in real time. However, to date, there have been no known reports on the application of the Kinect system in the area of precision spray control. To obtain a relatively good spray effect, the present study integrates the advantages of colour and depth information using Microsoft's Kinect system and proposes equations for calculating the average distance between the Kinect system and a fruit tree and the LWA density, thereby solving the difficulty in estimating the dose of applied pesticides. The intelligent precision orchard pesticide spray model established based on the aforementioned two factors can determine the spray area and realize precision spray of pesticides.

2. Materials and methods

Microsoft's Kinect system consists of a multi-array microphone, a red, green and blue (RGB) video camera, a monochrome complementary metal-oxide semiconductor (CMOS) video camera and an IR transmitter. The colour CMOS camera generates colour images, and the IR transmitter and the IR CMOS camera generate depth images. The Kinect system outputs a 640×480 RGB image and an IR depth image. Because conventional depth sensors (e.g., laser ranging radars) are deficient with respect to sensitive information readability, depth cameras have become an important means for measuring the depth-of-field (DOF) information of scenes. Under ideal conditions, the resolution of depth information acquired by a depth camera can reach 3 mm.

During the precision spray process, it is necessary to accurately examine various LWA information and parameters, including distance, area, shape, height and density. The information for these parameters needs to be collected through sensors. Therefore, the types of parameters that can be measured, as well as the accuracy of the obtained information, are determined by the performance and acquisition mode of the sensors. The present study uses the Kinect system, determines the distances between the Kinect system and fruit trees based on the depth images, separates the background in the images using an image segmentation technique, extracts the LWA information from the videos based on the depth images, and investigates methods for measuring and calculating the LWA density to accurately locate and examine the spray targets.

2.1. Experiment materials and conditions

An experiment was conducted on three different types of trees, namely, peach trees, apricot trees and grapevines, in three experimental orchards in Baoding, Hebei Province in northern China. The peach and apricot trees investigated in the experiment were two years old and had a planting spacing of approximately 3 m, a row spacing of approximately 4 m and an average height of 2.5 m. The grapevines were more than five years old and had a planting spacing of approximately 1.3 m, an average row spacing of 2 m and an average height of 2 m. Pesticides were sprayed first along one side of the fruit trees and then along the other side of the fruit trees. The experiment was conducted on one side of the fruit trees to ensure that the experimental environment and climatic conditions were consistent. The experiment was conducted between May 14 and 16, 2015. The climatic conditions during the experiment are as follows: average temperature: 18–22 °C; relative humidity: 20–40%; and wind force level: 1–2.

The video acquisition component of the system mainly consisted of a Kinect system and a computer. Because the Kinect system was not equipped with a power source, a mobile power source was employed when using the Kinect system in the orchards. During the experiment, the Kinect system was used to synchronously acquire depth and colour video and image information as well as process the acquired information. Video files acquired by the Kinect system are stored with an extension of ".xed ". In the present study, .xed files were converted to images with an extension of ".bmp" and video files with an extension of ".avi" using a conversion algorithm to facilitate reading and processing.

2.2. Detection analysis

Currently, the majority of studies that use machine vision for LWA detection analyze and process the image of each frame in a video sequence using an image processing technique; These systems rely solely on the acquired colour image information to extract LWA information based on the colour difference, brightness information and edge information; and obtain LWA information through image thinning using the image erosion algorithm (Hoevar et al., 2010). However, when used as the background, back-row fruit trees will be erroneously determined as a part of the LWA. The aforementioned approach is disadvantageous in that it is susceptible to light and background effects and cannot accurately estimate the distance. The Kinect system can not only acquire colour video information but can also acquire depth images through the IR transducer. The value of each pixel in a depth image represents the distance. Therefore, the Kinect system can be employed to obtain more accurate distance information and facilitate the determination of the LWA and the values of various parameters.

2.2.1. Preprocessing algorithm

The detection distance of Microsoft's Kinect system is 4.096 m. As a result, distant fruit trees outside the spray range will not appear in the acquired depth image. The disadvantage of using depth images is that green tree leaves cannot be differentiated from grey tree trunks. In comparison, when using colour images, tree leaves can be differentiated from tree trunks by colour. Therefore, by integrating the advantages of these two types of images, the spray area can be accurately determined.

Hence, at the image processing stage, it is necessary to first process the colour image and extract the green layer of the RGB image to obtain the green part of the fruit tree in the image, which is used for further processing. To obtain the precise spray area, it is necessary to segment the colour image to obtain the outline of the canopy of the fruit tree. Otsu's method maximizes the interclass variance and is used to automatically determine the threshold. Otsu's thresholding method is simple, has a high processing speed, and is widely used in threshold selection. Given the aforementioned information, the present study uses Otsu's method to