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Multispectral detection of floral buds for automated thinning of pear

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ABSTRACT

Thinning of pome and stone fruit involves the reduction of tree crop load in order to regulate fruit set and quality. As it is typically carried out through manual labor, thinning comprises a large part of a grower's production costs. Mechanized thinning has been shown to be a cost-effective alternative but the performance of existing thinning devices needs to be further improved by taking the variation in bearing capacity of the individual trees into account.

In this work, a multispectral camera system is developed to detect the floral buds of pear (cv. *Conference*) during the growth stages prior to bloom. During a two-year field trial, the multispectral system was used to measure orchard scenes in six distinct optical wavebands under controlled illumination. These wavebands are situated in the visible and near infrared region of the spectrum and were selected based on hyperspectral laboratory measurements described in previous work.

The recorded multispectral images were converted to a database containing the spatial–spectral signatures of the objects present in the orchard. Subsequently, canonical correlation analysis was applied to create a spectral discriminant model that detects pixels originating from floral buds. This model was then applied to the recorded data after which an image analysis algorithm was designed and optimized to predict the number of floral buds. In total, approximately 87% of the visible floral buds were detected correctly with a low false discovery rate (<16%). Therefore, it is expected that the multispectral sensor can be used to improve the efficiency of existing thinning devices. Additionally, it could as well be used as a stand-alone sensor for early-season yield estimation.

1. Introduction

Horticulture involves many tedious and labor-intensive tasks which require the employment of expensive, trained personnel. As it is becoming increasingly difficult for growers to hire a sufficiently large work force (Maas and van der Steeg, 2011), an increasing amount of research is targeted to automate or augment the operation of cultivation techniques. Many of these horticultural practices require some form of feedback to either assess the state of the canopy (e.g. disease detection) or determine the location of certain objects (e.g. harvesting). As humans typically rely on their sight to perform these tasks, robotic systems are often equipped with a vision system to match or even improve on the performance of their human counterparts. In this work, we focus on the development of a vision system in the context of automated thinning in fruit orchards.

As fruit trees have a natural tendency to produce heavy crop loads, the sugars produced in the leaves (sources) need to be distributed over too many fruits (sinks). This often results in the production of many small fruits which are not suited for fresh market sale. Thinning decreases the competition for photosynthetic products by removing the excess buds, flowers or fruitlets. This not only allows the remaining fruits to reach commercially interesting sizes, but also increases fruit quality, tree vigor and yield regularity (Lopez et al., 2011; Theron, 2010 and Meland, 2009). Research has shown that early thinning – at or even prior to bloom – leads to stronger positive effects than the traditional late season thinning, because it minimizes the investment of the trees in fruits which will not be harvested (Theron, 2010; Meland, 2009; Link, 2000; Bertschinger et al., 1998). Together with pruning and harvesting, thinning is one of the most labor-intensive – and thus expensive – cultivation measures as these are still typically performed by hand. Consequently, a strong demand exists among growers for alternative thinning methods.

Over the years, the potential of chemical thinning has been extensively studied. Though it can be considered a practical and cost-effective method, it cannot completely and reliably replace hand thinning (Miller and Tworkoski, 2010). Generally speaking, chemical thinning suffers from two main drawbacks. Firstly, the

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efficacy of the currently available thinning agents is strongly related to cultivar and environmental conditions (Kviklys and Robinson, 2010; Peck and Merwin, 2009). Secondly, chemical thinning often has detrimental effects on the environment, tree vigor and human health (e.g. laborers). It is for this reason that many chemical thinning agents have been withdrawn from the market (Hong, 2010). However, even under perfect conditions, growers still have to await the actual response of the trees as chemical thinning offers no direct feedback.

Mechanical thinning machines developed in recent years have demonstrated that automated thinning can be a viable alternative for the traditional methods and can yield economic savings. String thinners realize apple and peach blossom thinning by means of fast rotating flexible strings (Hehnen et al., 2012; Martin-Gorriz et al., 2012, 2011; Baugher et al., 2010). Spiked drum-shakers were used for peach fruitlet thinning by using rotating drums to transfer shaking energy to the canopy branches (Miller et al., 2011; Schupp et al., 2008). Wouters et al. (2014) removed floral pear buds by pulses of compressed air. Finally, Yang (2012) and Nielsen et al. (2012) developed a prototype robotic manipulator and clamplike end effector for brushing off peach blossoms. Other techniques such as trunk shaking (Glozer and Hasey, 2006) or limb shaking (Martin-Gorriz et al., 2010; Rosa et al., 2008) have been investigated as well, but were found less effective.

Although positive results were realized by these automated techniques, their thinning speed and efficiency need to be further improved by taking into account the tree-to-tree variability. As the floral bud distribution is non-uniform throughout an orchard, certain trees – or regions on a tree – will benefit from less or more severe thinning. Since most of the existing techniques often cause injuries to shoots, leaves and bark, thinning in a way tailored to the needs of each individual tree would prevent unnecessary tree damage. This maintains tree vigor and reduces the risk of disease spread (Kon et al., 2013; Ngugi and Schupp, 2009; Schupp et al., 2008; Bertschinger et al., 1998). Furthermore, it would allow to prevent overthinning of high-value crops.

In recent years, several researchers have investigated vision systems to detect and quantify fruit blossoms with the goal to provide this information as feedback to a thinning machine. Gebbers et al. (2013) introduced a shock absorbing stereo camera platform to map the flower density on apple trees. They used this information to control the rotation speed of a string thinner and thereby the thinning intensity. Nielsen et al. (2012) achieved good peach blossom detection by means of a trinocular stereo color camera. They were able to locate the three dimensional (3D) position of the blossoms with a spatial accuracy of less than 1 cm. Emery et al. (2010) developed a scanning laser range imaging system to measure the 3D shape of peach trees with a spatial accuracy of 1.2 cm.

These detection techniques all rely on the sharp color contrast between the blossoms and their environment as quantified using standard RGB cameras. However, this approach is not suitable for detecting floral buds prior to bloom as the brightly colored petal leaves are still contained within the buds. To our knowledge, no attempt has been made to develop a sensor to detect floral buds prior to bloom.

Previous work has shown that multispectral imaging can be successfully applied for object recognition in many agricultural applications (e.g. Bac et al., 2013; Bulanon et al., 2010; Okamoto and Lee, 2009; Wallays et al., 2009). This technique produces images with a higher contrast between objects of interest by combining more and narrower wavebands than the red, green or blue regions of the spectrum.

In previous work (Wouters et al., 2013), we determined the optimal wavebands for building a multispectral vision system which is able to detect floral pear buds in the phenological stages before bloom (*Pyrus communis* cv. *Conference*). Using these wavebands, a discrimination model was built that already showed good pixel classification under laboratory conditions (i.e. 95% correct pixel classification). However, additional steps are required to make this technique suitable for floral bud detection under field conditions. In this we work, we deal with the following three challenges: (1) going from pixel to object recognition, (2) taking into account the presence of additional objects which are not included in the original discriminant model and (3) performing the detection at faster, more realistic speeds. First, a new multispectral setup is elaborated which was tested during a two-year field trial. Hereafter, details are provided on the construction of a new pixel classification model and the image analysis used to realize object detection. Finally, conclusions are presented regarding the potential of the detection system and suggestions are made for future research.

2. Materials and methods

2.1. Image acquisition setup

A low-cost custom movable camera platform was built to perform multispectral measurements in field conditions (Fig. 1a), similar to the setup used by Bulanon et al. (2010). The setup consists of a 12 bit monochrome CCD camera (TXG14NIR, Baumer, Frauenfeld, Switzerland) with a resolution of 1392 × 1040 pixels and a 16 mm monofocal manual iris lens (C1614A, Pentax, Tokyo, Japan). In front of the lens a fast rotating multispectral filterwheel (FW103H/M, Thorlabs Inc., Newton, NJ, USA) is placed which houses six optical bandpass filters in the range 400–1000 nm with a diameter of 25 mm. These filters are rotated sequentially in front of the lens with a change time of approximately 55 ms between adjacent filters. This operation enables to perform fast multispectral measurements (<1 s) with no or very limited distortions between the different filter images, e.g. motion blurring caused by wind. The filters are commercially available bandpass filters which were selected to have bandpass regions that match as closely as possible to the desired optimal wavebands to discriminate between floral buds and their environment (Wouters et al., 2013). Both the actual and optimal transmission bands of the filters are displayed in Table 1.

To check the effect of the difference between the optimal and actual wavebands, the methodology and dataset used to select the optimal wavebands (Wouters et al., 2013) were again used to predict the pixel classification performance of the actual filters. It was found that difference between the actual and optimal wavebands reduced the predicted correct pixel classification by less than 1 %. This is attributed to the typical high correlation between information gathered from (partly) overlapping wavelengths (Table 1). Therefore, the effect of choosing the commercially available filters instead of the optimal wavebands can be considered negligible.

Data acquisition and control of the setup was realized by means of a laptop running a custom software written in Labview 2009 (National Instruments, Austin, Texas, USA).

2.2. Orchard description and phenology

During the growing seasons of 2012 and 2013, field measurements were conducted in a commercial pear orchard situated in Bierbeek, Belgium (50°49′36.35″N, 4°47′40.35″E). Trees of the pear cultivar *Conference* were trained in an intensive V-hedge system with four main fruiting branches on one central stem (Quince C rootstock, planted in 1992). The trees possessed an average height of 2.5 m and were spaced at 3.5 m × 1.3 m (1978 trees ha^{-1}).