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Research Paper

Automatic fruit recognition and counting from multiple images

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In our post-genomic world, where we are deluged with genetic information, the bottleneck to scientific progress is often phenotyping, i.e. measuring the observable characteristics of living organisms, such as counting the number of fruits on a plant. Image analysis is one route to automation. In this paper we present a method for recognising and counting fruits from images in cluttered greenhouses. The plants are 3-m high peppers with fruits of complex shapes and varying colours similar to the plant canopy. Our calibration and validation datasets each consist of over 28,000 colour images of over 1000 experimental plants. We describe a new two-step method to locate and count pepper fruits: the first step is to find fruits in a single image using a bag-of-words model, and the second is to aggregate estimates from multiple images using a novel statistical approach to cluster repeated, incomplete observations. We demonstrate that image analysis can potentially yield a good correlation with manual measurement (94.6%) and our proposed method achieves a correlation of 74.2% without any linear adjustment for a large dataset.

1. Introduction

There are an increasing number of robotics applications aimed at detecting fruits from images or videos (De-An, Jidong, Wei, Ying, & Yu, 2011; Ji et al., 2012; Linker, Cohen, & Naor, 2012; Tanigaki, Fujiura, Akase, & Imagawa, 2008). Although various research efforts have been made in this field, challenges still remain for complex scenes with varying lighting conditions, low contrast between fruits and leaves, foreground occlusions and cluttered backgrounds. Most of these applications have been to find the fruits for automatic harvesting. A recently new direction is to find the fruits for plant breeding purposes (Alimi et al., 2013): to automatically recognise, count and measure the fruits in order to assess the differences in quality of the genetic material. When the measurements are made by a computer, this is often referred to as digital phenotyping and the field is growing in importance, e.g. Furbank and Tester (2011).

The aim in our application is to locate and count green and red pepper fruits on large, dense pepper plants growing in a greenhouse. Alimi et al. (2013) described the use of manual fruit measurements (manual phenotyping) for predicting yield in pepper plants. Our work is to automatically detect and

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Fig. 1 – Examples in the training data. The top three rows are fruit examples, and the bottom three are background. The background templates are much larger than the fruit templates, and their sizes have been adjusted for display purposes.

count any fruit in images of dense pepper plants, to reduce manual measurement and labour requirements, and to increase objectivity. In a recent paper, van der Heijden et al. (2012) showed that several manual measurements could be replaced by image analysis leading to the same QTL (positions on a genetic map, which shows a relation with the trait under study). Besides they showed that image analysis could aid in the identification of additional physiological traits that are hard or impossible to measure by human operators.

Machine vision applications developed for fruit have been reviewed by Brosnan and Sun (2004) and Lee et al. (2010). Compared with previous fruit applications, e.g. finding red apples in green canopies (Bulanon, Kataoka, Ota, & Hiroma, 2002), we are looking for predominantly green fruits. Stajnko, Lakota, and Hocevar (2004) described the use of thermal imaging for measuring apple fruits. In their work, they used morphological operations and constant shape constraint to separate the round apple fruits from leaves. This is not possible for our images, since the difference in colour and shape between fruits and other plant parts are small.

Jimenez, Jain, Ceres, and Pons (1999) provided a review of different vision systems to recognise fruits for automated harvesting using a laser range-finder. Zhao, Tow, and Katupitiya (2005) presented methods to recognise apples grown on trees, which used the texture and redness colour. It was shown that redness works equally well for green apples as for red ones. Yang, Dickinson, Wu, and Lang (2007) proposed methods to recognise mature fruit and locate cluster positions for tomato harvest applications. Kitamura and Oka (2005) described a picking robot to recognise and cut sweet peppers in greenhouses, but their image analysis methods were developed only for this specific application under fixed lighting conditions.