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Automatic green fruit counting in orange trees using digital images

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ABSTRACT

Yield estimation is an important factor in a production process planning. In the case of citrus crops, can be useful in industrial management and as guidance for farmers, showing a decisive role in the product market strategies and cultivation practices. Several techniques are being studied for estimating citrus crop yield. On the basis of the known correlation between the number of visible fruits in a digital image and the total of fruits present in an orange tree, we developed a method for green fruit feature extraction with a combination of the techniques of color model conversion, thresholding, histogram equalization, spatial filtering with Laplace and Sobel operators and Gaussian blur. In addition, we built and tested an algorithm to recognize and count them, with detection rates of false-positives of 3% in images acquired in good conditions. It is possible to estimate the mean number of visible fruits in the trees within a tolerated error of 5% with up to 46 images and taking approximately 8 min without any human interaction.

1. Introduction

Among the technology resources that are part of the modern production processes aiming to improve management strategies and crop yield, stand out the Global Positioning System (GPS), Geographic Information Systems (GIS), Remote Sensing (RS), Variable Rate Technology (VRT), yield mapping and advances in sensors and information technology. These improvements have enabled farmers to see the field in a wide and detailed manner, helping resource planning and diminishing its waste, taking into account the variability observed in the field (Annamalai et al., 2004).

Citrus crops are known to show an alternated behavior regarding its yield, as an outcome of plant's intrinsic energy storage mechanisms. These mechanisms generate a large temporal variation with respect to fruit yield and fruit quality (Isagi et al., 1997; Noguchi et al., 2003). Consequently, the known prediction methods do not show satisfactory results, becoming more inefficient as the prediction period increases (Sakai et al., 2008). For that reason, an efficient and practical sampling method is important, in order to be applied regularly for a better follow up on the plants.

Knowledge and follow up on each plant individually have becoming each time more important, since this alternated behavior dynamic has a proved endogenous and individual source (Sakai et al., 2008). This makes it essential to a reasonable sampling plan not to be destructive. Moreover, traditionally, procedures as liming and fertilizing take into account soil and climate conditions, leaving aside plants individual characteristics, treating them uniformly. With the rise of precision agriculture, more specific knowledge on the plants individually is gaining practical advantages, being possible through detailed maps and equipment capable of vary the application rates with spatial precision of centimeters.

Important attempts on citrus yield prediction have been made. Sakai et al. (2008) demonstrated that prediction was successful for one-year forecasting in a season based on a very short ecological time series, with relative root-mean-square error (RRMSE) of 0.678 and correlation coefficient (CC) of 0.734. Greater prediction time increased the RRMSE to 0.993 and decreased the CC to 0.116, indication long-term unpredictability. A prediction system in real time showed positive results (Annamalai et al., 2004) but only when the fruits are in a more advanced maturation state because they are segmented in the images by their color. In this stage, the application of techniques to improve yield is not possible and there is not enough time for market and industrial planning. The system purposed by Triboni and Barbosa (2004) has the same disadvantage, counting only the ripe fruits in the trees. There is also an *Android* application that showed efficient for fruit counting in the same conditions, with estimations up to 90% between the real yield values and the ones estimated for individual trees (Gong et al., 2013).

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Leaves and fruits were analyzed for differences in the reflected electromagnetic spectrum through hyperspectral images (Annamalai et al., 2004). Aerial images acquired with help of an aerial model remotely piloted were used for fruit recognition (MacArthur et al., 2006) and embedded sensors were used for image acquisition and posterior processing for fruit recognition and counting (Annamalai, 2004). Digital image processing methods as the *watershed* transform were used for the segmentation of clustered fruits (Chinchuluun et al., 2006), neural networks were used in aerial hyperspectral images (Ye et al., 2006) and the number of new leaves and floral flushes were studied, with help of vegetation indices, for relation with the number of fruits through a least-squares method for yield estimation, without positive results (Ye et al., 2007). More recently, the performance of the TBVI (*Two-Band Vegetation Index*) was reassessed (Ye et al., 2008), as the green fruit detection through hyperspectral images (Okamoto and Lee, 2009). The use of digital images for yield prediction in citrus is promising, given that there is a functional relationship between the number of visible fruits in the images and the total number of fruits in the plants (Triboni and Barbosa, 2004).

However, those methods have several limitations, requiring highly specialized labor or expensive equipment and generally a low efficiency (Gong et al., 2013). In addition, some are not affordable by small farmers. All the cited methods need improvements, considering that even in hyperspectral images the number of false-positives is large, precluding its application in estimation processes. Further studies are needed (Okamoto and Lee, 2009) mainly because even with good results, low cost and easy application for prediction with ripe fruits (Gong et al., 2013), it is still necessary to enable the yield estimation with more time before harvesting.

Texture analysis through digital image processing techniques enables the generation of images that simulate a bas-relief effect, as in bronze sculptures of famous artists as Donatello. The bas-relief representation gives us a more enhanced notion of depths and texture. Computerized techniques of bas-relief generation are been studied and evaluated (Belhumeur et al., 1999; Cignoni et al., 1997; Ji et al., 2014). Regardless the limitation of the digital image to be a visual representation in two dimensions, the main concept of these images generation is the simulation of the effect present in the sculpture of a solid material.

Obtaining those bas-relief representations from common digital images involves several digital image processing procedures, as border detection, image enhancement, spatial filtering and fusion, among others (Durand and Dorsey, 2002; Paris and Durand, 2006; Wang, 2011; Weiss, 2006). Border detection is one of the fundamental problems of digital image processing and computer vision, being obtained by operators well known like the Laplacian, Sobel, Robert's cross operator, Prewitt's and Canny's (Wang, 2011). A bas-relief representation of a common digital image would be result of a combination from the above methods, for example.

Therefore, bas-relief representations are important for the extraction of texture features of the objects in the image, what becomes clear regarding the spherical shapes, that shows a region of high brightness and other with low brightness, considering a single source of illumination. The concept of texture is of extreme importance in images, enabling the definition of measures of properties like smoothness, rugosity and regularity. Hence, texture can be defined as the difference on the intensity pattern between pixels in a neighborhood (Gonzalez and Woods, 2000).

After the texture analysis for feature extraction the next step is the recognition and classification of those features. In this case, we are interested in the classification of a region of the image as a fruit or not. For that task, there are several reports of the use of machine learning techniques as, for example, neural networks, also in the recognition of orange fruits (Regunathan and Lee, 2005). Another important method of machine learning is the Support Vector Machines (SVMs). In a similar way of the neural networks, the SVMs require a learning step and, after its training they become a pattern classifier. This type of method has a wide application in image processing, with positive results in the recognition and classification of apples, applied in images treated with Otsu's thresholding (Otsu, 1975). The authors verified segmentation errors ranging from 3 to 25% using a linear SVM and errors lower than 2% using an adjustable method for the classifier.

SVMs are maximum margin classifiers. Instead of the association of probability distribution models to the training vectors, SVMs try to split the different classes finding the adequate immediate borders between them. For this purpose, they build separation hyperplanes in the separation region between those classes (Keuchel et al., 2003).

This recognition method has large application in image processing applied to agriculture. It is reported as the best method of recognition and classification of oil palm areas in aerial images, showing a good performance even with a small training set (Li et al., 2015). It is also reported as one of the best methods in the recognition and classification of different varieties of rapeseed (Kurtulmus and Ünal, 2015), and presented 100% of correct classifications of mango fruits quality, overcoming all other tested methods (Sa'ad et al., 2015). There is also reports of its use in flower cultivation, showing good results in the detection of diseased rose leaves (Nagasai and Rani, 2015).

Early yield estimation of orange crops could enable the modification of cultivation practices in order to increase fruit size and quality, provide better planning for market and industrial process and make possible the generation of precise yield maps to be used in VRT. The objective of this work was to build and test an algorithm for automatic counting of green fruits in digital images of orange trees, on the basis of texture analysis and SVMs.

2. Materials and methods

The relationship between the number of visible fruits in the images and the number of fruits counted by the algorithm was evaluated through linear regression analysis. The 1328 images were obtained with collaboration of Citrosuco Company in the 2011 crop year. All images were taken at 2 m of distance between the end of the tree's canopy and the camera, in field conditions, in different hours of the day and several climate and lightning conditions. Regular digital cameras were used (Sony DSC-W530) and images were taken in a 2592×1944 pixels spatial resolution (approximately 5 Megapixels), with flash always on and without optical or digital zoom.

At the moment the image was taken, it was identified regarding the plants' variety and age. Tests were performed in orange trees from four varieties (Hamlin, Natal, Pêra, Valência) in three groups of ages (from 3 to 5 years old, from 6 to 10 years old or older than 11 years). Each plant was photographed twice (one image from each accessible side of the canopy).

The automation of manual tasks is always very attractive because brings up the potential of time saving and precision at its execution. Consequently, the performance of a proposed method should be tested against a well known and reliable method. In this case, the automatic method was compared to the visual manual counting, where all the images were counted by human inspectors in digital monitors.

The manual counting on the images was helped by the development of a software, in which the user just needed to click over the fruits to increase an automatic counter. The results of this step enabled the study of the relationship between the number of visible fruits in the images and the outcome of the algorithm