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Automatic fruit count on coffee branches using computer vision

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In this article, a non-destructive method is proposed to count the number of fruits on a coffee branch by using information from digital images of a single side of the branch and its growing fruits. In order to do this, 1018 coffee branches at different ripening stages. They had different numbers of fruits, harvest dates, were of different varieties, and were at different stages of coffee tree's life. A Machine Vision System (MVS) was constructed, which was capable of counting and identifying harvestable and not harvestable fruits in a set of images corresponding to a specific coffee branch was constructed. This MVS consists of an image acquisition system, based on mobile devices (it does not require to control of the environmental conditions), and an image processing algorithm to classify and detect each one of the fruits in the acquired images. After obtaining information regarding the number of fruits identified by the MVS, linear estimation models were constructed between the detected fruits automatically and the ones observed on the coffee branch. These models were calculated for fruits in three categories: harvestable, not harvestable, and fruits whose maturation stage were disregarded. These models link the fruits that are counted automatically to the ones actually observed with an R^2 higher than 0.93 one-to-one. Not only is the MVS used to estimate the number of fruits on the branch but also to estimate their maturation percentage and weight. The MVS was validated in four Variedad Castillo® coffee plots, in different stages of development and with different densities. We found that MVS neither overestimates nor underestimates the number of fruits and that it shows a correlation higher than 0.90 at early stages of crop development, when tree fruits are still not harvestable. The information obtained in this research will spawn a new generation of tools for coffee growers to use. It is an efficient, non-destructive, and low-cost method which offers useful information for them to plan agricultural work and obtain economic benefits from the correct administration of resources.

1. Introduction

The coffee trade is the second most profitable industry worldwide, followed by oil. In spite of its importance, and excepting for some farms in Brazil, coffee is a type of crop for which growers still do not employ all the available technology in agricultural works, especially at harvest. As far as we know, said growers do not have the type of technology which would allow them to obtain information about coffee production in advance, and plan a better use of their resources, namely labor. Normally, coffee growers can make approximated calculations about their crops. Based on their experience, they evaluate the flowering intensity, fruition, the phytosanitary condition of the plant, and also track previous production cycles to predict whether their current harvest will be good, average, or bad. Nevertheless, a coffee plantation may be negatively influenced, by external or handling factors, which can lead to flower and/or fruit decay, and, therefore, alter the size of the harvest.

Counting of the number of fruits on the trees and branches would be the most reliable method to obtain production data. However, the count must be performed when all the fruits of the productive cycle are on the tree, that is to say, at the beginning of the harvest cycle. This measurement would show the quantity of fruits produced per tree, and the number of fruits per plot could then be interpolated. With this information, a coffee grower could be ready to sort out their needs for workers during the harvest, prepare the facilities and conditions for the post-harvest, carry out machine maintenance, ask for loans (when necessary), and enter into marketing agreements more safely. However, most coffee growers do not possess efficient tools to obtain information about the production of their farms in advance. Some of them carry

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out destructive sampling practices to identify the production of their farms, which leads to additional costs and production losses.

1.1. Related work

Knowledge of the productivity of a crop is a strategic matter for the government, agro-industrial enterprises, farmers, and sellers. This information is applied to the planning of trading strategies, which are policies that decrease the economic risk of production due to a lack/excess of the product. It is also applied to the planning of tasks on the farm such as harvest and post-harvest. The productivity of a crop can be defined as: the produced mass per unit area within a given time, which can be measured or estimated in the field. Authors such as, Lobell et al. (2009), Montoya et al. (2009), Agrawal (2005), Huddleston (1978), Cotter et al. (2010), Basso et al. (2013), Vogel and Eaton (1985), Cilas et al. (2009), Upreti et al. (1991), and Castro-Tanzi et al. (2014), report models or statistical expressions for different crops, which relate historical productions, econometric models, climate dynamics models, lack or excess of a chemical element, soil characteristics, incidence of plagues or diseases, and phenology of the plant.

In the specific case of a coffee crop, Cilas et al. (2009) and Upreti et al. (1991) show coffee production estimations which are based on the different production components of the tree. (Eq. (1)): number of stems per tree s_t, number of branches per stem b_s, number of glomeruli per branch g_b, and quantity of fruits per glomeruli f_g. Additionally, they report stratified methods for variances in area, height, soil, and area/ground and area/altitude relationships. This estimation method is destructive; this means that the coffee fruits must be picked from the trees to obtain the expression variables.

$$F = s_t\, b_s\, g_b\, f_g. \tag{1}$$

Models reported in direct measuring in field are reported by Vogel and Eaton (1985), Cilas et al. (2009), and Upreti et al. (1991). In said models, they carry out a count of the vegetative-productive structures on the plantation, such as fruits, glomeruli, branches, and stems. These type of models offer a value that is very close to the real production of the crop. The advantages are: (i) use of the quantitative method; (ii) development on physiological bases; (iii) elimination of harvest distribution problems when sampling is strictly defined; (iv) incorporation of climatic variability and handling of the harvest; and (v) incorporation of expressions of the plants in their ground-atmosphere relationship. The main disadvantages are: (i) requirement of destructive sampling; (ii) requirement of certified labor; and (iii) definition sampling moments, as it is likely that the plant physically changes between the moment the information is acquired and harvest.

Other authors, such as Castro-Tanzi et al. (2014), also use the fruit count method with a random and stratified sampling, employing empirical models, formulated by using dependent and independent variables on a logarithmic scale. In the case of the Caturra and Catuaí varieties of coffee, they used the number of productive lateral branches per tree and the number of fruits per branch. They found that, by counting the fruits that are present in 8 or 9 branches per tree, it was possible to determine the total number of fruits per tree, having using two stems for each of the aforementioned varieties, with regression coefficients between 0.73 and 0.92. The authors themselves point out the importance of making estimations about the harvest season and highlight the difficulty of such estimation, since the coffee plant is not phenologically synchronized and various flowering stages may take place throughout the year. Moreover, nutrition events and presence of rain may alter production method.

The aforementioned methods use destructive and/or manual counts of the fruits on the branches and tend to require a great deal of labor. The increasing availability of technology has lead the agro-industrial sector to develop innovative techniques to monitor crops, carrying out non-destructive and tasks more efficiently. In the state of the art, authors have used digital processing of images to automatically estimate the production of crops such as apples, grapes, mangoes, and oranges. Satellite, aerial, and land images have been used to measure variables and estimate production. Stajnko et al. (2009), Aggelopoulou et al. (2011), Wang et al. (2013), and Nuske et al. (2011) report production estimation models for apples and grapes based on the measurement of the features of fruits and flowers in specific field conditions. High resolution cameras are set up in vehicles that move along the plantation furrows. These cameras take pictures and the information is processed in order to count fruits or flowers and to determine production using statistical expressions. In each one of these cases, the performance was different: Stajnko et al. (2009) obtained a detection efficacy of 89% for apples. In the case of Nuske et al. (2011), an overestimation of 10% was generated with grapevines as well as a 60% correlation between what is real and what is estimated.

1.2. The research problem and contributions of this study

Currently, coffee growers have no means for determining coffee production in a non-destructive way and, therefore, obtain no information in advance which would help them to program of agricultural tasks or sell the product in advance. This research proposes a system for obtaining information about the production of coffee tree branches in a non-destructive way, based on partial information collected with acquired images on a single visible side of the branch. This system, which is based on a machine vision, allows for detection and recording of the number of fruits on the coffee branches and their weight, with no need for destructive samplings and under uncontrolled lighting, branch contrast, and occlusion of fruit conditions. The images in this research were acquired with the main camera of a mobile device and, were simultaneously processed using an algorithm to detect and count coffee fruits based on their maturation stages. This algorithm determined the number of visible fruits on a single side of the branch and, with this information, the total number of fruits on the branch were estimated. The system was evaluated and validated using coffee branches in different crop conditions and production stages.

The contributions of this research are the following: (i) to determine the number of fruits on a coffee branch, the maturation percentage of said branch, and the weight of detected fruits, with no need for destructive samplings, based on partial information obtained with mobile devices and image processing algorithms; (ii) a masking technique that detects occluded and unoccluded fruits in field images and which classifies them either as harvestable or not harvestable; (iii) estimation models that neither overestimate nor underestimate the number of fruits per branch and that achieve one-to-one relations, with determination coefficients higher than 0.93; and (iv) a measuring tool in the field to determine the number of fruits in different moments of the harvest cycle.

The information from our research and of the system we propose is shown in Fig. 1. Both a manual and an automatic count were carried out: the manual count by certified personnel, and the automatic count as shown in the stages of Fig. 1, starting with the acquisition and adaptation of the images, and following different steps until obtaining the number of fruits per branch. The values of the manual and the automatic count were compared to one another to obtain linear estimation models, which were later evaluated. Finally, a validation of the proposed system on branches in four experimental parcels was performed.