APPLICATION OF KINECT SENSOR FOR THREE DIMENSIONAL CHARACTERIZATION OF PLANT BIOMASS

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Abstract. In the last decade, three-dimensional reconstruction of plants has gained a noticeable importance, in particular for the possibility of collecting data correlated to biomass, leaves area, etc. Different sensing technologies are available for 3D imaging, as for instance laser scanning, or stereoscopic reconstruction: however, practical application is still limited by high costs, or high speed data processing demand. For the present work depth sensing cameras technology is implemented. Measurements were repeated on 17 different dates, between April and June, on a jujube (*Ziziphus jujube*) plant, collecting 3D scans through a Kinect I sensor. 3D images were analysed in order to estimate the three-dimensional volume (*Vk*) of the canopy and the leaf area, and the results were compared with biomass related data arising from hand measurements (volume and leaf area index, LAI).

Keywords: Kinect, biomass, plant, 3D reconstruction.

Introduction

The opportunity of measuring variable density of plant canopies is of great importance, to allow accurate quantification of biomass. Indeed, knowledge of biomass variability can be not only useful to estimate local health condition of the plant [1], but also a valuable input allowing variable rate management [2]. For instance, 3D canopy reconstruction can be applied in order to control pruning (trimming or pruning based on position of branches), modulate agrochemicals distribution (spraying intensity adapted local canopy density) or improve watering efficiency [3]. Furthermore, biomass estimation plays an important role for efficient management of biogas plants [4; 5]. Several research works have been published in the last years, presenting new approaches for 3D measurement of plant canopy, mainly implementing ultrasonic technology, time of flight, photogrammetry or diffraction techniques.

Ultrasonic sensors are quite common in industrial applications, mainly due to their low costs, small dimensions and easy signal processing [6]. They take advantage of reflection of an ultrasound wave, which allows reconstruction of a convoluted surface, with a resolution typically no better than 200-500 mm. Such low resolution is not suitable in the case of uneven canopies or small leaves: consequently, their implementation is acceptable only for some spraying operations. Time of flight sensor relies on scanning from a laser beam [2; 7]. Costs are relatively higher, and point clouds data processing needs advanced hardware and software equipment. Resolution depends on the scanning speed and sensor distance, however, it can be better than 10 mm, allowing fine 3D characterization of small canopy parts. At present, its implementation has been reported mainly for research applications.

Photogrammetry is also often applied to allow three-dimensional reconstruction of plants [8]. Such technique uses a stack of images taken from different perspectives in order to reconstruct complex shapes. The cost of such technique is as low as the cost of a standard digital camera, however, data processing might be challenging and on the go applications are quite difficult due both to heavy reconstruction and analysis.

Fig. 1. **Schematic representation of a three-dimensional sensor unit, positioned in front of the tractor for a feed-back system, allowing variable rate distribution with the implement**

Another approach can be based on diffraction of reference projected patterns, as in the case of the Microsoft Kinect™ depth camera. Despite its relatively low price, in the last few years such approach has proved to be fast and robust, reliably reconstructing 3D surface in many application fields, from architecture to gaming, from agriculture to livestock farming [9].In this work, a Kinect device is applied in order to allow collection of 3D information from jujube (*Ziziphus jujube*) canopies. A schematic layout is reported in Figure 1, where the sensor is installed in front of the implement and a control feedback allows regulation of sprayer parameters.

Materials and methods

Experimentation connected with the present paper was done in a typical Po Valley (Italy) private farm (45.28312 N, 11.83604 E). A single jojoba plant was chosen for the experiment, presenting a flat wall in the background. Such condition was adopted, since it allows minimization of possible disturbances and noise arising from background elements.

During analyses, the Kinect device was placed at 3 different positions at 1.5 m height from the ground and 1.5 m from the plant canopy. Such relative positions allow a lateral resolution of 1.5 mm, a depth resolution of about 4 mm and a root mean square (RMS) noise of 1.1 mm. Stitching of neighbour depth images was done taking advantage of software developed by the same authors [10]. Merging of multiple views has a double scope:

- increasing the measured range while keeping high lateral and vertical resolution,
- increasing the maximum detectable slope (MDS) [11], thus allowing better characterization of the canopy, in particular in the case of leaves, which globally or locally exceed the MDS angle.

Kinect analyses were parametrized through quantification of average canopy volume, which (on authors' experience) can be directly correlated to average biomass. Indeed, the scope of the work is to understand the applicability of the Kinect sensor for fast estimation of leaf area indexes. Besides Kinect measurements and related analyses on 3D reconstruction of the plant canopy, the following analyses where carried out:

- quantification of the leave number in the plant (hand measurement based on photographs);
- estimation of the total area of canopy leaves , based on the reference size of one leaf multiplied by the number of leaves;
- measurement of canopy projected area (hand measurement based on photographs).

Leaves were not removed from the plant canopy, in order to preserve the natural growth trend of the plant itself. Analyses were carried out on 17 different dates (at least once per week, from April to June), covering the growth season of jujube vegetation.

Results and discussion

The first representation of plant evolution during the three months dedicated to analyses is reported in Figure 2. The set of RGB images clearly shows the initial situation characterized by few very small leaves, and most of the volume occupied by plant twigs; on the contrary, the last photographs give evidence of a vigorous biomass canopy, while branches are almost not visible. The same situation is achievable from depth images, where the greyscale representation indicates different depths or heights in the direction perpendicular to the image plane. The depth information was useful in order to allow three-dimensional reconstruction of the plant canopy volume, which was eventually correlated to the estimated number of leaves and the leaf area index (LAI). If the number of leaves can help determining canopy growth, the management of tree plants can be better supported by information on the overall leaves area. The leaf area index interest is then related to the fact that it is directly connected to the plant canopy structure, and is directly connected to different canopy processes, such as photosynthesis or respiration [12].

The main results are reported in Figure 3. In particular, the first graph reports a comparison between the number of leaves and the leaf area index. The two terms exhibit a relatively high correlation ($R^2 = 0.91$) and low standard error ($\varepsilon = 0.048$ m²): this is mainly ascribable to the fact that average dimension of each leaf is undergoing only limited variations. On the contrary, a linear model does not properly describe the correlation between the number of leaves and canopy volume. Indeed, especially in the last weeks of the experiment, the canopy exhibited a continuous vegetation of new leaves, while the overall volume of the plant canopy was not proportionally increasing its dimensions: this is highlighted also by a relatively high standard error (ε = 1434). As a consequence, the graph reported in Figure 3 exhibits a plateau in the case of volumes higher than 0.6 m³, represented by the second degree best fitting polynomial curve (to be applied with volumes not higher than 0.85 m³):

$$\textit{Number of leaves} = -22922 \cdot \textit{volume}^2 + 38644 \cdot \textit{volume} - 5615$$

Such sort of saturation phenomenon prevents implementation of the Kinect sensor for leave number characterization. Nonetheless, the same device can be successfully applied for the Leaf Area Index estimation. In this case, a higher correlation was recognizable, with a coefficient of determination R^2 = 0.96.

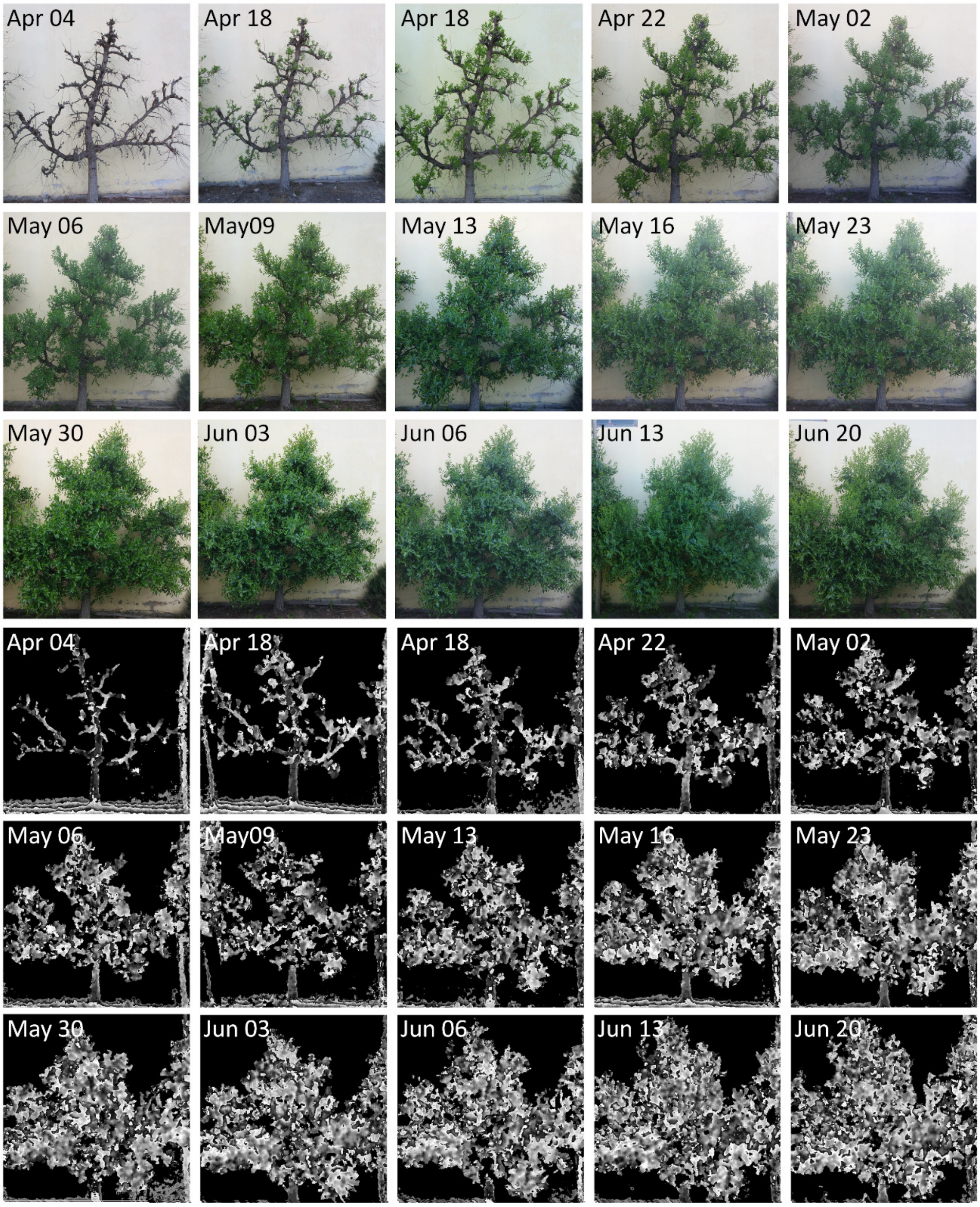

Fig. 2. **RGB images (first three lines), and Kinect depth images (last three lines) for the studied plant, on 15 of the 17 considered dates**

The best fitting linear model for volume and LAI can be expressed as follows:

$$Volume = 0.2503 \cdot \mathrm{LAI} + 0.1471$$

It is important to note how the best fitting equation presents an intercept equal to 0.147 m³. Such value is determined by the presence of branches, which constitute the large majority of the measured volumes, especially in the first experiment dates. Afterwards, the relative weight of branche volumes progressively reduces and the linear model well fits the leaf area estimations. This is highlighted also by a relatively low standard error ($\varepsilon = 0.167$ m³), which further supports the possibility of applying such model, especially in the case of leaf areas larger than 1 m².

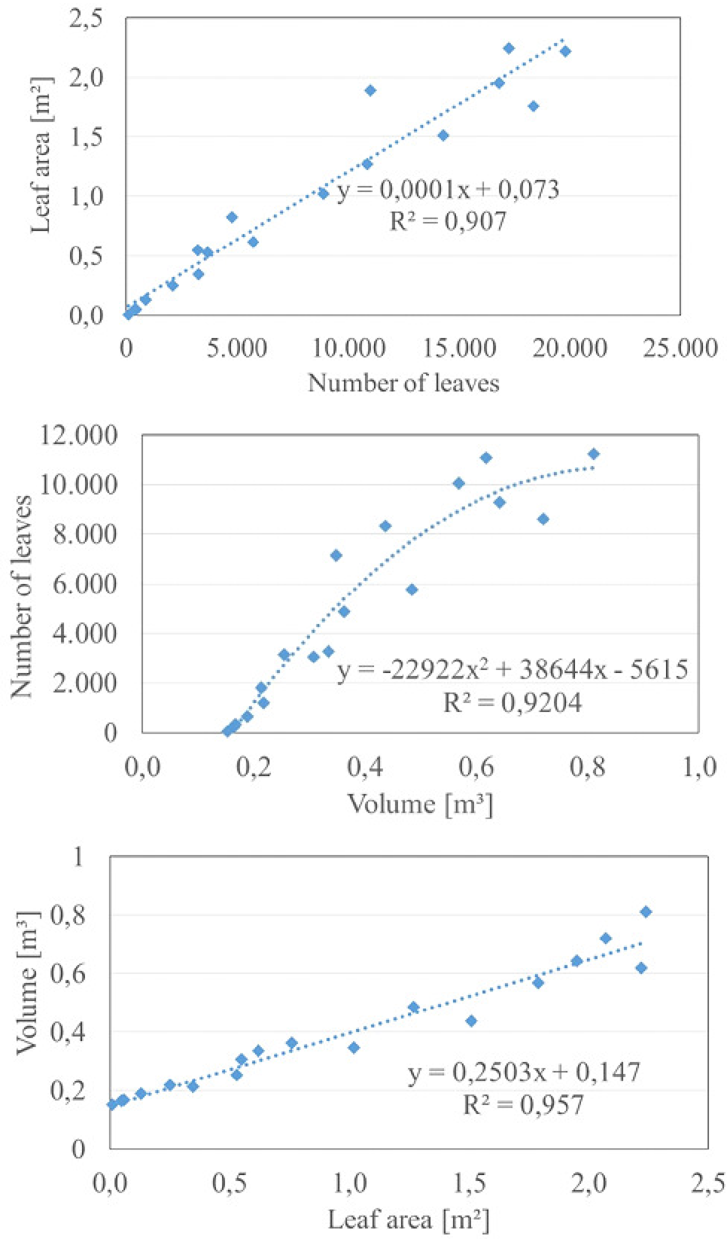

Fig. 3. **Correlations between Number of leaves vs (LAI) Leaf Area Index, canopy volume vs Number of leaves and LAI vs Volume**

Conclusions

In this work, a Kinect 3D device is introduced as a solution for fast characterization of plant canopy. Field tests were carried out on a jujube (*Ziziphus jujube*) plant; analyses gave evidence of very high correlations between the digital analysis and hand measurement results in terms of LAI and with some limitation in terms of the number of leaves, with the coefficient of determination R^2 higher than

0.9. Limitations are mainly to be ascribed to its lateral and depth resolution and to its sensitivity to sun radiation. Indeed, the device cannot be efficiently implemented in the case of plant or leaves at their early stages (when the size of the canopy is limited compared to the size of brunches). Additionally, at present no studies have been done to automatically recognize stresses or alterations on leaves or twigs. Finally, it is important to properly control environmental conditions: indeed, excessive sun light radiation could interfere with the instrument diffraction grating used for the three-dimensional reconstruction and reduce the depth image resolution.

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