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TOWARDS AUTONOMOUS HARVESTING OF TEA USING MACHINE LEARNING

by Gaspard Russias, Sofian Helmer, Denis Mazerolle, Denis Tregoat, and Stephane Perrin

In-field harvesting automation of young tea leaves is currently challenging due to their low thickness and required accuracy. In this context, Photonics Bretagne developed a vision-based solution for robotic-assisted precision agriculture, allowing collecting a high-quality tea. This work focuses on the combination of classical RGB imaging with spectroscopy in the visible and near-infrared ranges. The implementation of a machine-learning algorithm enables to both detect the location of tea shoots and a real-time decision of harvesting. This white paper describes the experimental and the numerical methods and shows the first results obtained in-field.

HARVESTING consists in picking and storing the ripe agricultural products, *e.g.*, fruits or vegetables, for further processing. Automation of harvesting tasks, using for example machinery, has facilitated the work of farmers and increased its efficiency [1]. Moreover, hardware and software advances in robotics for precision agriculture, *e.g.*, implementation of deep learning algorithm for apple harvesting [2], have recently enabled the identification of the specimen leading to a higher accuracy and better targeted harvest. However, tea plucking is usually performed by hand due to the precision requirements and the land topographies. Despite the low labour costs in some parts of the world, this activity remains repetitive and intensive. In European countries where high-quality-tea cultivation is emerging, robotic-based harvesting solutions appear to be relevant. Advances have recently been suggested to meet this need such as tea detectors [3] and tea pickers (Tea Research Institute, Chinese Academy of Agricultural Sciences). However, the accuracy and speed of these systems remains insufficient. Furthermore, their energy consumption could be critical given the current ecological context.

The Biophotonics Group of Photonics Bretagne (FR) carried out an innovating study on the detection of tea leaves for the robotics-based automation of picking at different level of requirement, *e.g.*, high-quality tea. This work was made in collaboration with a tea grower in Brittany, Filleule des Fées SAS (FR).

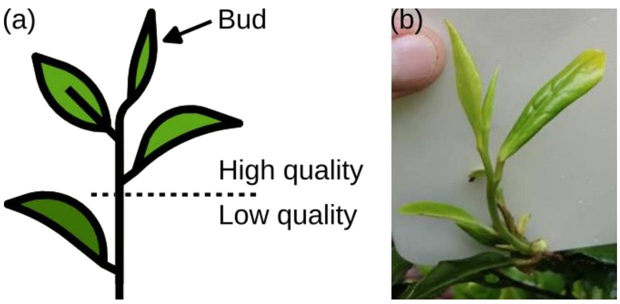

Fig. 1 – *(a) Illustration of a young tea shoot highlighting the limit of high-quality requirement for tea, beyond which the picking is considered coarse. (b) Photography of a young tea shoot (Camellia Sinensis).*

The younger the leaves harvested, the higher the tea quality (Fig. 1). Three main levels of requirement thus remain. “Imperial” plucking consists of collecting only the apical bud. Traditionally, this high-quality tea was reserved for dignitaries in China. Today, it is still used for certain teas such as Yin Zhen. Fine plucking includes a first and sometimes second leaf and is mainly used in most premium quality teas. Finally, the most widespread method for producing affordable tea uses the first three (or even five) leaves.

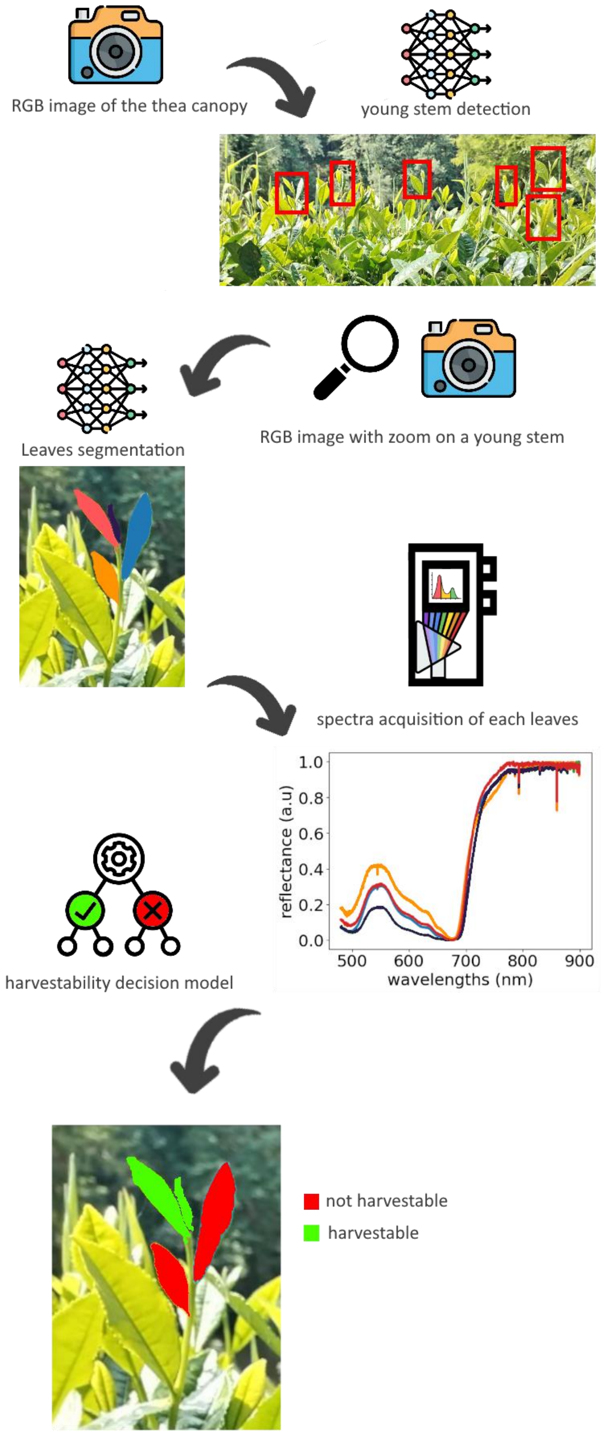

Fig 2 – *Illustration of the method for detecting and estimating the harvestability of four young tea leaves (the bud and the first leaf remain harvestable).*

Challenges in vision for the automation of high-quality-tea harvesting are both the precise location of the young tea shoots and the harvestable estimation of leaves. As a result, not all leaves are picked according to the requirement. Thus, in this work, the location of leaves-of-interest is extracted from the RGB images of plant cover to perform a segmentation. Then, the spectral response of each numerically segmented leaf allows taking a decision on their harvestability (Fig. 2).

This vision-based method is iterated on whole tea shoots and will be the cornerstone of the future robotic system that will automatically harvest high-quality tea.

1. Materials and Method

In 2021 and 2022, Photonics Bretagne realized two measurement campaigns on three tea cultivars in a tea plantation. Each of the cultivars

- *Kolkhida*, between 4 and 16 years old,
- *Cuilü*, 4 years old,
- *Cbis*, between 4 and 16 years old.

These campaigns allowed, first, to build a database of both RGB images and reflectance spectra, *i.e.*, 400 nm < λ < 900 nm, and then, to study the feasibility of the leaf harvesting automation. Second, these were used to define the in-field ability of the method and to quantify the robustness of the algorithmic chain in this modality, *i.e.*, validation process.

Twenty RGB images of plant cover were acquired from which zoom views of young shoots were extracted. In addition, reflectance spectra of the adaxial side of each tea leaf were measured using a point-of-care spectrometer working in the VIS-NIR range. At the same time, the harvestability (or not) of the tea leaves was previously determined by a qualified person (Filleule des Fées).

2. Detection of young tea leaves

Due to the wide diversity of tea plants, *i.e.*, cultivar, age, and cultivation methods, and the outdoor measurement conditions, a CNN algorithm (convolutional neural network) was implemented for young-tea-shoot detection [4] and for the leaf segmentation.

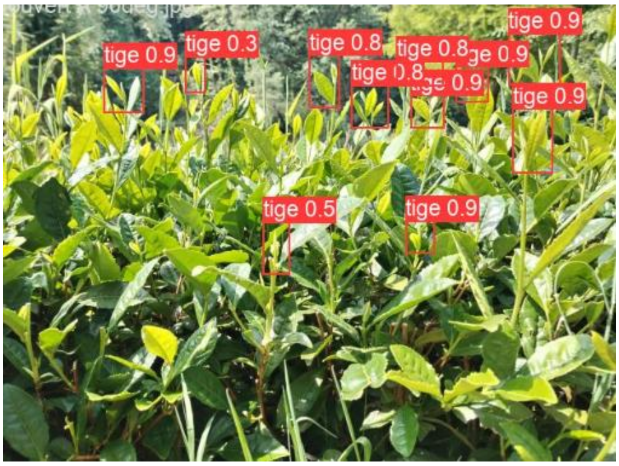

Fig. 3 – *Ability and robustness of the YOLOv8 algorithm to detect young tea shoot.*

The RGB frames which were acquired during the first measurement campaign, were used for the learning phase of the CNN algorithm by performing 2000 epochs. The validation phase of the YOLOv8 object detection algorithm was made through additional RGB frames (Fig. 3) and reached around 71% of good prediction.

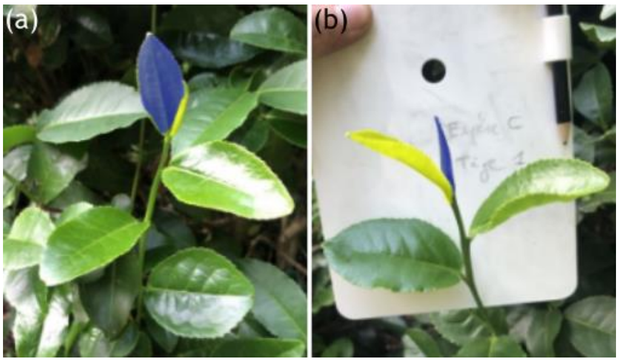

Fig. 4 – *Ability of the Mask R-CNN algorithm to segment the first two leaves after detecting young tea shoot. The apical buds and the first leaves are masked in yellow or in purple.*

Then, a numerical segmentation of young leaves of tea shoots was made using a Mask R-CNN deep learning model with a FPN architecture (feature pyramid network) and a ResNet101 backbone. The algorithm was trained both on widefield RGB frames of plant covers and on RGB zoom views on young shoots, *i.e.*, around hundred images with 100 epochs. The validation phase was achieved through frames acquired during the second campaign, see Fig. 4.

3. Harvestability

Spectral reflectance of segmented tea leaves was then analysed to establish a harvestability decision model. The averaged spectrum per leaf was measured in the VIS-NIR range (Fig. 5) and pre-processed by applying a normalization using the flat-top region (800 nm < λ < 900 nm).

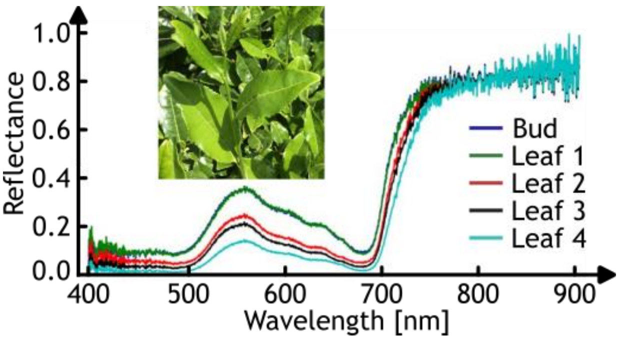

Fig. 5 – *Typical spectral responses of the bud and the leaves of a tea shoot.*

Then, a PCA analysis (principal component analysis) is made on the spectra, highlighting the differences between the leaves which can be harvested and others, Fig. 6(a). Loadings of the components PC0 and PC1 show bands of interest at wavelengths ranging between 500 nm and 600 nm, and between 690 nm and 800 nm, *i.e.*, red edge. These spectral bands are assigned to the absorption bands of the chlorophyll, which is a harvest marker. A harvest estimation model was then carried out by defining in a supervised manner the dividing line between harvestable (HAR) and non-harvestable (NHAR) leaves in the PCA mapping. In our case, PC1 = -0.15 PC0 + 0.002. Using this model on the spectral database, the harvestability prediction rate reaches 91%.

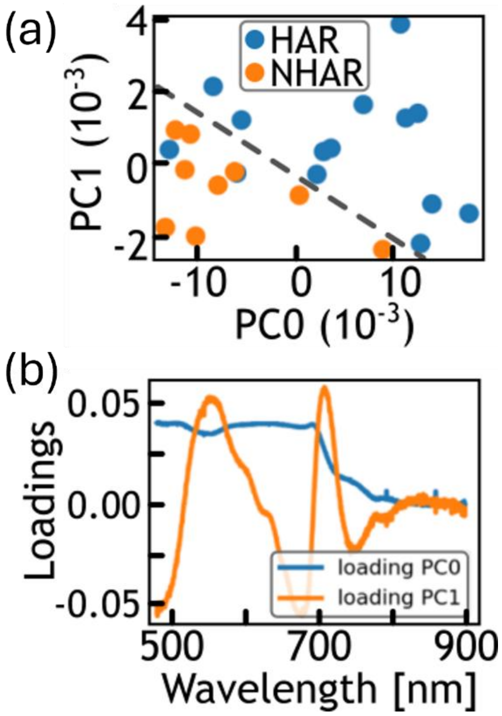

Fig. 6 – *Statistical analysis of the reflectance spectra of tea leaves. (a) PCA mapping. HAR, harvestable. NHAR, non-harvestable. (b) PC0 and PC1 loadings as a function of the wavelength.*

4. Discussion

Photonics Bretagne developed a vision-based method for in-field harvesting automation of young tea leaves. The method involves segmenting the young shoots using RGB images, and then analysing the spectral responses of leaves to define their harvestability. The harvestability prediction rate reaches 91% according to the selection made by a qualified person (Filleule des Fées). This method relies on two CNN algorithms, *i.e.*, YoloV8 and Mask R-CNN, and a PCA analysis.

To date, the training and the validation steps of the CNN algorithms have been achieved using only a few RGB frames of tea cover, which is quiet low. This currently leads to missing young shoots, false positives, and small mask area, *i.e.*, not filling the whole leaf surface. These pinpoint errors will be considered to meet performance in precision agriculture, for example, by increasing the quantity of data and the number of epochs.

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