A PRELIMINARY EVALUATION OF A LOW-COST MULTISPECTRAL SENSOR FOR NON-DESTRUCTIVE EVALUATION OF OLIVE FRUITS' FAT CONTENT

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Abstract

This study presents a preliminary evaluation of a low-cost multispectral device for the non-destructive assessment of olive fruits' fat content. The developed device integrates a multispectral sensor, with a spectral response of 18 channels falling in a range from 410 to 940 nm, a calibrated light source, and a programmable board, in a 'gun'-shaped device whose trigger activates sample reading. The device was used to measure 50 intact olive samples, which were subsequently chemically analysed to determine their actual fat content. Then, the multispectral readings from the 18 channels were used as input variables to train a neural network, using the actual fat content registers as reference data. The measured results, in terms of root-mean-square-error and coefficient of determination, shows promising capabilities of the developed low-cost device in the prediction of fat content of intact olives, what stands up for further development and experimentation.

Keywords: Precision Agriculture; Multispectral Data Modelling; Low-Cost Multispectral Device.

1 INTRODUCTION

Olive cultivation (Olea europaea L.) is an out-standing economic engine for most of the Mediterranean basin. It is particularly remarkable for Spain, Greece, Portugal and Italy, which provided more than 55% of the total amount of olives produced worldwide in 2018, and concentrate more than 44% of the area harvested [2]. This economic activity has a great impact in a vast production chain characterised by a large variety of involved actors, including growers, mills, holdings, bulk merchants, packers/packing plants, retailers, wholesalers, and olive oil brokers. Moreover, olive growing goes further the economic aspects, as it is also greatly transcendent socially. An example illustrating this statement is that olive oil is the cornerstone of the Mediterranean diet, which has been declared as Intangible Cultural Heritage of Humanity by the UNESCO in 2010 [7].

Water and oil are the major components of olive fruits [3]. The ripening process begins after a period of 25 weeks of fruit growth, moment at which fruit acquires its final size and starts accumulating fatty acids, mainly oleic, which is responsible for oil's acidity. When this process reaches lipogenesis stop, fruit is objectively at its optimum time to be harvested [1], as fat content is one of the main components determining quality of olive fruits [4]. Notwithstanding, this variable can evolve during ripening at a diverse pace in the different areas of a field, resulting in heterogeneity in terms of the optimum harvest time across the orchard.

The determination of the quality parameters in the laboratory is carried out by standard analytical methods, which implies sample milling [4]. This technique is expensive, destructive, and provide incomplete information since sampling is based on a limited number of sample points. Furthermore, the results usually take several days, so the decision of the harvest time may therefore be delayed. All the mentioned limitations lead to a homogeneous harvesting based on subjective visual interpretation, or on partial, incomplete, and delayed objective inputs. We argue that this approach can be improved by developing objective monitoring methodologies, directly applicable in the field, and affordable.

In this sense, this paper presents the preliminary evaluation of a new low-cost and light multispectral device, designed in a "gun"-shape fashion, and potentially usable in the field as it incorporates a calibrated light source. This device was developed from the basis of that presented by the same authors in [5], both only sharing the same multispectral sensor and the Arduino board (Arduino LLC, Italy). The original device was operable only under laboratory conditions attached to a tripod, with the illumination provided by a halogen light source, and governed by an external PC. Thus, the improvements applied include a complete redesign of the exterior body to make it portable and manually operable, the integration of a calibrated light source, the inclusion of an OLED display for information delivery, and the

https://doi.org/10.17979/spudc.9788497498418.0475

inclusion of software and hardware resources that make it completely autonomous. Given the magnitude of the changes, which affects usability and also nature of the multispectral readings, a new validation procedure is required. In this paper, we describe the results of a first-phase testing of the new device's ability to estimate fat content of intact olive fruits, by modelling the readings of its 18 spectral channels with a neural network to predict analytical values.

2 MATERIALS AND METHODS

2.1 OLIVE FRUIT DATA SAMPLING

Starting from the 14th of October, 2021, 10 olive fruit samples of *Olea europaea* L., cv. Picual variety, were manually collected per consecutive week, for a total of 5 weeks ($n = 50$). Every sample was composed of 250g of olives, as it was the minimum amount required by the laboratory experts to determine samples' fat-on-dry-matter content by applying the Soxhlet technique [6]. Thus, every olive-fruit sample was measured with the developed 18-band multispectral device described below in section 2.2, having as gold-standard reference its fat content value measured by means of chemical analysis, thus enabling data modelling and experimentation.

2.2 MULTISPECTRAL DEVICE

The proposed device is designed and built around the following main components:

- Spectral sensor: a unit of the AS7265x smart spectral sensor family (AMS, AG, Austria) was selected (see Figure 1). This sensor is composed by 3 chips, having each of them 6 independent on-device optical filters whose spectral response is defined in a range from 410nm to 940nm, with full width at half maximum (FWHM) of 20nm per band. The combination of the three sensors results in an 18-channel multispectral sensor.
- Calibrated light source: an IR broadband LED emitter (OSLON P1616 SFH 4737, OSRAM, Germany) was integrated, as it is specifically designed for spectroscopy applications, thus providing a wide emission spectrum. A constant current LED driver (RCD-24, RECOM, Germany) allows to modulate capturing parameters (lighting intensity and power on time).
- System controller: the whole device is controlled by an Arduino MKR development board (Arduino LLC, Italy). Once the software is initiated it generates a new data file. Then, it waits for a user input (by pressing the trigger button) to capture a sample spectrum. When capturing is triggered, the Arduino board sends the command to the sensor and gathers data. Then, the acquired data is stored in a SD-card for further analysis. The controller board can be connected to a PC for configuring internal parameters of the device (exposure time, gain, lighting time, and led intensity) by means of a custom software. To help and guide the user during the measurement, the developed device includes an OLED display, specifically a 0.96-inch panel with a resolution of 128 by 64 pixels. The system is powered by a 2s LiPo (Lithium-ion Polymer) battery connected to the device controller board.
- External device's case: it was designed in a "gun"-like fashion using Freecad 0.16, and it was manufactured with a 3D printer using biodegradable polylactic acid (PLA) filament.

Regarding manufacturing costs, it should be stressed that they do not exceed 200 € including electronic components, battery, consumables for 3D printing and other minor concepts. This massively contrasts to the price of industrial-standard near-infrared analysers such as OliveScan^{TM} 2 (Foss, Hilleroed, Denmark) [8], which reaches several tens of thousands of euros, while it is not adapted for manual and portable manipulation, thus preventing its use in the field.

Figure 1: AS7265x board integrating three sensors able to acquire, within the spectral band ranging from 410nm to 940nm, 18 multispectral readings.

Figure 2 shows the developed multispectral device. As it can be observed, all device's elements are housed inside the developed casing, excepting the battery, which is installed outside to avoid temperature interferences with the sensor that could affect the precision of the measurement, as well as to simplify its in-field replacement.

https://doi.org/10.17979/spudc.9788497498418.0475

Figure 2: View of the developed 18-band low-cost and portable multispectral device, sensitive within the range 410-940nm.

2.3 MULTISPECTRAL DATA MODELLING FOR OLIVE FRUITS' FAT-ON-DRY-MATTER CONTENT ESTIMATION

The 50 multispectral readings of the olive-fruit samples taken with the developed device were used to feed and train an artificial neural network (NN), concretely a fully connected feedforward multilayer perceptron, structured in the following layers: 1) an input layer with 18 neurons, one per spectral band; 2) a hidden layer with 25 neurons; 3) an output layer with a single neuron. The chemical analytical results of fat-on-dry-matter content for every sample were used as output for net's fitting, being the model trained using a leave-one-out-cross-validation (LOOCV) scheme. The selected activation function was sigmoid.

2.4 NEURAL NETWORK PERFORMANCE EVALUATION

The ability of the trained NN to estimate olives' fat content from multispectral measures taken with the developed device, was evaluated using two metrics. In both cases, the output of the NN applied to the validation datum excluded during training at every iteration following the LOOCV paradigm, was used, what configured a test set of 50 predictions.

On the one hand, the Pearson's coefficient of determination, R^2, was applied to assess the relationships between the actual and the predicted fat content values. On the other hand, the root-mean-square-error was also calculated as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{50}\left(fc_i^a - fc_i^p\right)^2}{50}} \tag{1}$$

where fc_i^a is the actual fat-on-dry-matter content of the ith sample determined by chemical analysis, and fc_i^p is the fat-on-dry-matter content predicted by the NN.

3 RESULTS AND DISCUSSION

Table 1 statistically characterises the actual and predicted datasets in terms of minimum (Min) and maximum (Max) value, average (Avg), and standard deviation (Sd). Magnitudes are expressed as percentage of fat content existing in the dried matter of the samples, as it is the standard used in the field of chemical analytics. Attending to the figures, it can be concluded that both distributions are statistically comparable, being the most divergent feature Sd, although the contained difference indicates only slightly lower dispersion for the set of predicted values. This similarity between both distributions is corroborated by $RMSE$, which is limited to 2.61%, what represents 10.62% of error with respect to the distribution width (18.83%).

Table 1: Statistical characterisation of actual and predicted datasets, and root-mean-square-error ($RMSE$) of prediction.

	Statistic			
Dataset	Min (%)	Max (%)	Avg (%)	Sd (%)
Actual fat content	32.9	51.73	45.28	5.15
Predicted fat content	31.28	52.12	44.89	4.69
	$RMSE$ (%)			
	2.61			

The discussed positive results can also be found when considering the actual and predicted datasets as variables and facing their behaviour. Indeed, Figure 3 plots the result of representing both variables in the space, showing a promising linear correlation between them, quantified by an R^2 value of 0.7459.

4 CONCLUSION

This paper presents the preliminary results of the evaluation of a new low-cost and portable multispectral device, in its use for the estimation of fat-on-dry-matter content of olive fruits, which is carried out by modelling the readings from the 18 multispectral channels of the device by using a neural network.

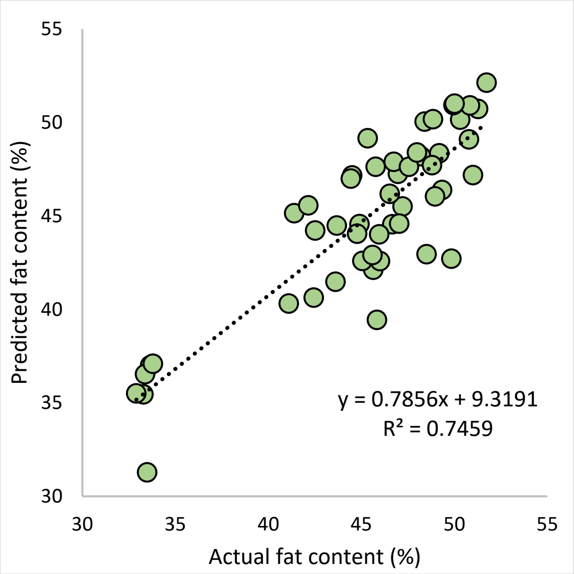

Figure 3: Correlation study between actual and predicted fat content.

The results obtained by a neural network trained using leave-one-out- cross-validation on a set of 50 samples taken during the last weeks of the ripening phase of olive fruits, indicate promising potential of the comprehensive developed solution. It increases the confidence in validating the hypothesis that the developed device can offer an affordable solution to assess portably and in a non-destructive manner fat content of olive fruits, which is a key information for managing olive orchards harvesting.

Future work will be focused in designing and carrying out experiments including large datasets, considering different olive varieties, and also diverse sampling scenarios.

Acknowledgment

This work was supported by grant PID2020-119217RA-I00 funded by MCIN/AEI/ 10.13039/501100011033, and grant IJC2019-040114-I funded by MCIN/AEI/ 10.13039/501100011033, and also by project TIColiVA with grant P18-RTJ-4539 funded by the Regional Government of Andalusia through the "PAIDI, Plan Andaluz de Investigación, Desarrollo e Innovación".

The authors would also like to thank "Cooperativa Nuestra Señora de la Oliva", for generously providing the olive samples with which this research was conducted.

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https://doi.org/10.17979/spudc.9788497498418.0475