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Classification of red grapes according to their state of ripeness using a low-cost multispectral device

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Abstract

The present work aims to evaluate a low-cost multispectral device for non-destructive grape ripening status assessment. The proposed device is based on a multispectral sensor, with a spectral response of 18 channels in a range from 410 to 940 nm. The experimental validation was carried out in a commercial vineyard in Rociana del Condado, Huelva. The proposed device was used to analyze 80 grape samples under laboratory conditions. After being processed with the proposed device the grape samples were analyzed with standard chemical methods to generate ground truth values of ripening status indicators (solid soluble content, and acidity). The 18-reflectance data corresponding to the spectral channels of the employed sensor, were used as input variables for developing artificial neural network models to classify the berries samples based on the mentioned ripeness indicators. The obtained results were promising, which paves the way for the implementation of a portable grape ripening appraisal system affordable for grape growers.

Keywords: **AS7265x, multispectral, low-cost, grape, ripening, and artificial neural network.**

Clasificación de los niveles de maduración de uva tinta mediante un sensor multiespectral de bajo coste

Resumen

El objetivo del presente trabajo fue evaluar la idoneidad de un sensor multiespectral de bajo costo para la determinación del estado de maduración de uvas tintas. El dispositivo propuesto se basa en un sensor multiespectral, con 18 bandas de detección en el rango entre los 410 y los 940 nm. La recogida de muestras se llevó a cabo en un viñedo comercial situado en Rociana del Condado, Huelva. El dispositivo propuesto se utilizó para adquirir la respuesta espectral de 80 racimos de uva en condiciones de laboratorio. Tras esto, cada una de las muestras fue analizada mediante métodos estándar de laboratorio para obtener indicadores objetivos de su estado de maduración (solidos solubles totales y acidez). Los 18 valores de reflectancia ofrecidos por el sensor fueron usados como datos de entrada para entrenar redes neuronales artificiales para la clasificación de las muestras de uva en función de los parámetros objetivo. Los resultados obtenidos fueron prometedores, lo cual allana el camino hacia la implementación de un sistema para la monitorización del estado de maduración de uvas asequible para los vinicultores.

Palabras clave: AS7265x, multispectral, bajo costo, uva, maduración, y redes neuronales artificiales.

1. Introducción

There are numerous ripeness variables (total soluble solids, acidity, pH, etc) currently used in the winemaking industry for determining the optimum harvest date. The post-harvest status of these parameters is a strong determinant of the features of the wine to be developed. For example, total soluble solids accumulation in the berries is a prerequisite for the subsequent alcohol content after fermentation in the wine. These variables can be modulated by the grower through cultural practices such as the irrigation regimes, pruning, etc (Hidalgo Togores, 2006; López et al., 2007). Thus, monitoring the ripening of grape berries at several timings during 3–4 weeks prior to harvest becomes more important as it helps wine growers to make the best management decision.

Traditionally, the assessment of ripeness variables has been done by means of chemical methods. However, these kinds of methodologies require laboratory equipment, expertise personal, and the sample collection in the field and its carry to the laboratory. All of this, make it an elevated cost and limits the number of sample points that can be taken into account. Thus, two main concerns accompany these methods. On the one hand, the representativeness of the berry sample from a given vineyard crop in a given date, and the number of sample dates that can be done between the veraison and the harvest. On the other hand, the time gap between the sample collection and the access to the information limits the decision making of the growers. To overcome these issues, the use of non-invasive sensors in the field, to assess grape composition parameters is a matter of great interest in recent years for the wine industry.

Under this context, spectroscopy have demonstrated to be a powerful, non-invasive technique that is being increasingly applied in the food industry thanks to the development of cheaper, faster, and more accurate sensors (Li et al., 2018; Verrelst et al., 2019). It has come to the market as a rapid and affordable technology to replace the manual classification or other tedious wet chemistry analyses. Some of the near infrared (NIR) applications already implemented in the industry include on-line quality control systems or multi-function sensors to monitor product properties at once. In the wine industry, so far, several works on the application of NIR spectroscopy to wine and grapes have already been carried out with promising results (Fernández-Novales et al., 2019; Garde-Cerdán et al., 2018; González-Caballero et al., 2012; Larraín et al., 2008; Urraca et al., 2016). However, most of these publications are centred in hyperespectral systems, which are expensive, being inaccessible for most growers and winemakers. Furthermore, in many cases, because of its operability, they can be used just in laboratory conditions.

This work presents a custom build low-cost multispectral device, designed to be portable. The proposed device was evaluated for the classification of grape berries based in ripeness variables (total soluble solids and acidity) in a non-destructive way by means of measurements taken under laboratory conditions.

2. Materials and methods

2.1. Spectral System

The proposed device included an AS7265x development board, based on the AS7265x smart spectral sensor family (AMS, AG, Austria). 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. The combination of the three sensors results in an 18-channel multispectral sensor. As light source, an array of three IR broadband emitter (OSLON P1616 SFH 4737, OSRAM, Germany), was used. This component is developed specifically for spectroscopy applications, because of its stable emission range. The controller of the whole device is a low-cost development platform, specifically an Arduino MKR-Zero board (Arduino LLC, Italy). Once the device is turned on it generate a new data file to store the measurements. Then, it waits for a user input (pressing of the trigger button) to capture a sample spectrum. When capturing is triggered, the Arduino board sends the command to the sensor, and turns on the LEDs (with a software selectable current) and gathers data. Then, the acquired data and interesting information, such as file names, are 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 current) by means of a custom software. In order to help and guide the user during the measurement, the developed device includes a display, specifically a 0.96 inch OLED panel with a resolution of 128 by 64 pixels. The availability of an integrated display avoids the use of a computer in the field or some other external device to verify the status of the device and its proper operation, also delivering real-time data. The system is powered by a 2s LiPo (Lithium-ion Polymer) battery connected to the device controller board. The device enclosure was designed using Freecad 0.16 and manufactured with a 3D printer using biodegradable polylactic acid (PLA) 3D printer filament. Three different parts were designed: a handle that holds the trigger button, a dome that holds the light source and integrate a light diffusion film (OptSaver L-9960, Kimoto LDT, Switzerland) placed in front of the sensor to homogenising the illumination, and finally the body of the device which include two different parts (front and back) to provide a perfect enclosure and holds the rest of the components. Figure 1 shows the developed multispectral device. All device elements are housed inside the developed casing, except 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 field replacement.

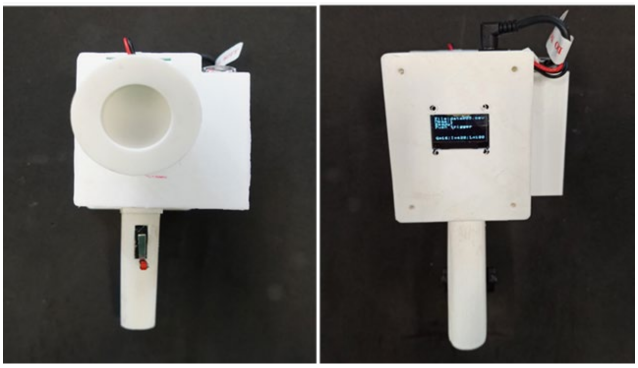

Figure 1. Custom build multispectral device.

2.2. Experimental set up

In order to evaluate the potential of the proposed multispectral device to classify grape berries based on its ripening status, an experiment was carried out. The first step was a sample collection in a vineyard under the “Condado de Huelva” appellation (Bodegas Contreras Ruiz, S.L, in Rociana del Condado, Huelva). This vineyard is cultivated with red variety (Syrah). The experimental field have a heterogeneous distribution regarding the composition and the structure of the soil. This is reflected in the physiology of the plants, with zones where the ripening is delayed. Thus, to access to an enough variability in terms of maturation, the sample collection was carried out randomly along the entire experimental field, on a date close to the harvest date (according to the criterium of the grower). A set of 80 grape cluster were collected and immediately packaged and labelled for its transport to laboratory.

The second phase of the experiment was taken under laboratory conditions. Each grape sample was processed with the proposed multispectral device. An acquisition chamber was used to isolate the spectral measurement procedure to minimize signal noise. The capture signal was done by facing the dome of the device with the upper side of the clusters and making two captures per sample, being the average reflectance of the two spectra considered as representative data of each sample. Once every 15 samples a capture of a known reflectance surface (53%) was taken, to calibrate the samples reflectance to prevent eventual errors due to variations of the light source. The 18 reflectance signals of the known reflectance surface were used as reference for normalizing the samples reflectance in the 18 bands acquired by the proposed device.

2.3. Reference Analyses

Once the spectral signal of the samples was acquired, they were subjected to destructive, chemical methods to obtain objective indicators of their actual ripening status. In this work, soluble solid content and acidity were defined as target parameters since they are widely accepted by the winery industry. Each grape cluster was shelled. Then, 50 grapes per cluster were randomly selected, which were squeezed to obtain the wort. The wort was used to determine the soluble solid content (Brix°) by means of a digital refractometer (HI96801, Hanna instruments, Spain). On the other hand, the wort was also used to assessed grape acidity (g/l sulfuric acid) with an automatic acidity titralyser (LDS1155500, Dujardin-Salleron, France).

2.4. Reference Parameter Modeling by Means of Multispectral Data

Orange 3 was used for data processing and ANN training. This is an open-source tool for data visualization, pre-processing and modelling. The whole data set was discretized to split each reference parameter (soluble solid content, and acidity) into two intervals, so that they each contain approximately the same number of instances. Then, the corrected reflectance of the 18 spectral bands captured by the sensor were used as input variables to train two artificial neural networks (ANN) aimed to classify the berries samples based on each ripeness indicator considered. For this purpose, a multi-layer perceptron (MLP) algorithm with backpropagation was used. The architecture of the neural network employed was composed of a hidden layer with six neurons, eighteen inputs and one output (one model per target parameter). Identity was used as activation function for the hidden layer, and L-BFGS-B as Solver for weight optimization. Figure 2 shows the workflow of the models. Leave-one-out was used as validation method. It holds out one instance at a time, inducing the model from all others and then classifying the held-out instances. This method is obviously very stable, and reliable so the most suitable for data set with reduced volume.

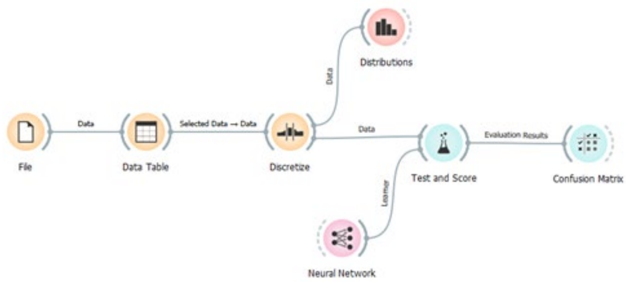

Figure 2. Simulation workflow of model in Orange 3 data mining tool.

3. Results

Table 1 shows the performance of the proposed artificial neural network models in the classification of grapes samples based on their status related to solid soluble content and Acidity respectively. Here are collected several statistical parameters such as the precision (proportion of true positives among instances classified as positive), the recall (proportion of true positives among all positive instances in the data), and the F1 (a weighted harmonic mean of precision and recall). The performance of the neural network was similar for the two ripeness variables considered and satisfactory in both cases, with F1 values approximately of 0.70.

	F1	Precision	Recall
Soluble solid content (Brix°)	0.70	0.70	0.70
Acidity (g/l sulfuric acid)	0.67	0.68	0.67

Table 1. Performance statistics of the proposed artificial neural network models.

The tables 2 represent the confusion matrix resulting of the leave one out test of the neural networks intended to classify the grape samples based on soluble solid content and acidity status respectively. The confusion matrix gives the proportion of instances between the predicted and actual class.

Table 2. Confusion matrix resulting of the leave one out test of the neural networks intended to classify the grape samples based on soluble solid content and acidity status.

			Predicted		
Soluble solid content (Brix°)	Actual		< 16.4	> 16.4	
		< 16.4	73 %	32.6 %	41
		> 16.4	27 %	67.4 %	39
			37	43	80
Acidity (g/l sulfuric acid)			Predicted		
	Actual		< 4.68	> 4.68	
		< 4.68	64.4 %	28.6 %	39
		> 4.68	35.6 %	71.4 %	41
			45	35	80

4. Conclusions

The objective of this work was to evaluate the suitability of a custom build multispectral device for grape berries ripening assessment. The 18 reflectance values captured by the sensor were used as input to train artificial neural network models aimed to classify grapes berries according to ripeness variables (soluble solid content and acidity) acquired by chemical methods. The satisfactory results showed by both models suggests a correlation between the spectral signature acquired by the sensor and the status of both parameters in the fruit. The good performance showed by the proposed device along with its low-cost and easy to use paves the way for the implementation of a grape berries quality appraisal system affordable for winegrowers. Further, cost saving will allow the sensors to be installed on a permanent basis, continuously monitoring the ripening process in different locations of the orchard, covering its spatial variability. Continuous monitoring of fruit quality conditions would allow adjustment of the moment of harvest according to objective standards instead of subjective criteria such as a visual judgment. This will allow to harvest wineberries in an optimum quality state, assuring the best raw material for wineries and the best economic returns for winegrowers.

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