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Analysis of food appearance properties by computer vision applying ellipsoids to colour data

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ABSTRACT

The use of computer vision for estimating composition in food products has become wide spread in recent years, especially for products where by measuring colour or other spectral features, we are able to estimate the composition, variety, or ripeness. On the other hand, the appearance is one of the most worrying issues for producers due to its influence on quality and consumer preferences. Computer vision is the best option to satisfy the need of measuring colour and heterogeneity in these products. Previous studies have expressed the heterogeneity with the standard deviation or other magnitudes that do not explain accurately the distribution of colour in CIELAB colour space. Graphing the scatterplot of the a^*b^* values belonging to the pixels of the image helps to explain the shape of the point cloud, but currently there is not an objective procedure to quantify these point clouds. This work has established a method for improving the illustration of colour measurements by image analysis. The proposed algorithm classified the point clouds by clustering methods and established the methodology for fitting the resulting clusters into ellipsoids. Their geometric features described the shape of the clouds in a quantitatively manner and they could be useful in multivariate statistical techniques for classifying and predicting chemical properties.

1. Introduction

Computer vision has radically changed the outlook of evaluating the composition of food products in recent years. Its advances have improved within the framework of accuracy, and joined to chemometrics, 'Chemical Imaging' is widely used nowadays (ElMasry and Sun, 2010). The higher requirements on quality control has entailed that it is not enough analysing only the chemical composition but also the spatial distribution within a sample (Du and Sun, 2004). The relationship between chemical composition and spectral properties have been well studied in infrared and visible spectra by several techniques, such as near infrared spectroscopy, near infrared reflectance spectroscopy, and visible and infrared hyperspectral imaging (Hernández-Hierro et al., 2012; Rodríguez-Pulido et al., 2012; Barbin et al., 2013; Mathiassen et al., 2011; Romano et al., 2012). Besides of composition, these measurements are important since food appearance is one of the most important characteristics due to its relationship with quality and consumer preferences (Fernández-Vázquez et al., 2011; Calvo et al., 2001). Since food industry includes products having very different sizes and shapes, computer vision arises as a suitable option to satisfy the need of measuring colour regardless the nature of samples. Moreover, computer vision allows measuring not only colour but also other features related to appearance, that do not vary the colour, but they affect to how the human eye perceive it, such as texture or heterogeneity (Valous et al., 2009).

Back in 1942, David L. MacAdam used ellipsoids for marking regions in colour spaces having common properties (MacAdam, 1942). In that study, the standard deviations were represented in terms of distance in the CIE 1931 colour space chromaticity diagram and these regions were fitted into ellipses. They showed that sources radiating spectral distributions belonging to these regions of the diagram appeared to have the same colour, for the average human observer. Later, some authors used a "closest packing" lattice of points to improve the understanding of the space involved by ellipsoids (Salmerón et al., 2012; Wyszecki, 1954; MacAdam, 1974; Luke, 1999; Judd and Wyszecki, 1975). In these cases, the lattice constant might represent the smallest number of just-noticeable chromaticity steps between the two chromaticities represented by the two points.

In computer vision, device-dependent colour spaces are commonly employed in image analysis because this kind of information is given by cameras directly (Jack, 2008). Nevertheless, colour must be measured by device-independent colour spaces (its appearance does not depend on the device) to ensure the

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objectivity of the measure. Among these spaces, CIELAB is one of the colour spaces recommended by the International Commission on Illumination (CIE) and it is considered perceptually uniform, meaning that just-detectable visual difference constitutes a constant distance in any location or direction within the space (CIE, 1976). Therefore CIELAB is widely used as a standard space for comparing colours because of its reliability.

Within CIELAB, a psychometric index of lightness (L^*) and two colour coordinates (a^* and b^*) are defined. L^* is the quantitative attribute of relative luminosity, which is the property according to which each colour can be considered as equivalent to a member of the grey scale, ranging between black ($L^* = 0$) and white ($L^* = 100$). Coordinate a^* takes positive values for reddish colours and negative values for greenish ones, and b^* takes positive values for yellowish colours and negative values for bluish ones. From the Cartesian coordinates (a^* and b^*), two angular parameters can be defined: chroma and hue or hue angle. Hue angle (h_{ab}) is the qualitative attribute that allows any colour to be graded as reddish, greenish, etc., and chroma (C^*_{ab}) is considered the quantitative attribute of colourfulness, allowing assessing the degree of difference of any given hue relative to a grey colour with the same lightness (Hutchings, 1999).

Obtaining the CIELAB coordinates by image analysis requires a camera which records visible light in gradations of three basic colours: red, green and blue (RGB). This device-dependent colour space may be transformed into CIELAB coordinates by means of a calibration which in turn requires controlled lighting (CIE, 2007; León et al., 2006). After taking images and transforming between colour spaces, a segmentation criterion is applied for calculating colour only from pixels with analytical information, also known as region of interest (ROI). There are different techniques of segmentation, being thresholding and edge-detection the main ones (Cheng et al., 2001; Zheng and Sun, 2008).

Since colour can be extracted from each pixel of the ROI, some variables emerge in order to express the degree of heterogeneity. Most of the studies show the result of measurements as the average colour and its standard deviation from all the pixels selected of the ROI (Yam and Papadakis, 2004; Valous et al., 2009; Mendoza et al., 2006; Girolami et al., 2013; Dufossé et al., 2005), being this standard deviation mainly a consequence of the heterogeneity instead of the measuring error. Besides the standard deviation, there are more scalar magnitudes in order to quantify the heterogeneity of samples, such as the mean colour difference from the mean (MCDM) (Berns, 2000) and entropy, which is dimensionless (Arzate-Vázquez et al., 2011). Further than a simple point plus a scalar explaining its heterogeneity, some authors resort to graph the scatterplot of the a^*b^* values as a point cloud, corresponding the points to the colour of each pixel (Urban et al., 2007; Palus, 2006). This option is quite useful, because these graphs are fairly explanatory and give an idea about the colours present in the sample as well as the relative presence of each one. However, a problem arises when the colour of a sample is spread out in two or more different point clouds. In these cases, the average colour may represent a point that cannot even be present in the sample. Currently, there are not objective procedures for discerning how many groups of colours are present in a sample. Some authors have used clustering methods on image analysis, not for classifying colours but for segmentation or detection purposes (Li et al., 2012; Yin et al., 2011).

This work has established an easy to carry out methodology for improving the evaluation of heterogeneous colours in food products and the illustration of these measurements in CIELAB colour space. The proposed algorithm could be useful for obtaining analytical information in studies where by chemometrics, the relationship among colour, appearance, and composition wants to be studied.

2. Materials and methods

2.1. Imaging system

For acquiring images, the DigiEye® system based upon a calibrated digital camera was used (Luo et al., 2001). It includes an illumination box specially designed by VeriVide Ltd. (Leicester, UK) to illuminate the samples consistently and a digital camera connected to a computer. The digital camera used for image acquisition was a 10.2-megapixel Nikon® D80 with Nikkor® 35 mm f/2D objective. It was calibrated with the DigiTizer (VeriVide Ltd., Leicester, UK) colour chart with the aim of characterise the camera response by relating its RGB signals to CIE specifications. The cabinet is equipped with two fluorescent tubes that emulate the CIE standard illuminant D65 and offer stable lighting conditions (CIE, 2007). They were switched on at least 10 min before being used, according to manufacturer indications, to stabilize them.

The application of the methodology and the algorithm for computing the ellipsoids from point clouds were developed on MATLAB (The Mathworks, 2009). Within MATLAB, the Fuzzy Logic, Image Processing, Partial Differential Equation and Statistics Toolboxes were also used.

The aim of this work was the establishment of a new methodology for the interpretation of the colour heterogeneity, so the development of the method and its application to different food samples have been included in Section 3.

2.2. Samples

The algorithm was applied to food products having different size and appearance for showing the results in a clear manner. Cabbages (*Brassica oleracea* var. Viridis), oranges (*Citrus sinensis* L. Osbeck var. Navelate), apples (*Malus domestica* var. Kanzi), and tomatoes (*Solanum lycopersicum* L. var. Kumato) purchased from local retailers were studied. Seeds from red grapes (*Vitis vinifera* var. Syrah) were included as representative of small-size samples. These fruits and vegetables were chosen based on the representativeness of foodstuff having different colour and heterogeneity. Homogeneous food products such as wines or juices were not considered since the evaluation of heterogeneity in this type of samples has not sense.

For proving the potential of the method, the sugar content of grapes, which is an indicator of maturity in oenology, was estimated by means of the proposed method. For this purpose, 254 white grapes (*V. vinifera* var. Zalema) were taken at nine dates during the interval of time where the change of colour occurs. The vineyards sampled are included under the "Condado de Huelva" Designation of Origin, in Southwestern Spain, harvested in 2012. As reference method, an Abbe refractometer was used to evaluate the sugar concentration according to the method of The International Organisation of Vine and Wine (OIV, 2013).

3. Results

3.1. Methodological procedure

3.1.1. Image acquisition

As is usual in computer vision, the images were acquired under diffuse illumination for avoiding undesired glints and shadows. The background were chosen for make easier the segmentation process, to the extent possible. A thick sheet was used for this purpose since it is considered a good Lambertian surface (diffuse reflectance surface which does not vary depending on the viewing angle) (Jaglarlz et al., 2006).