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Adaptive self-configuring computer vision system for quality evaluation of fresh-cut radicchio

Bernardo Pace [a,1], Dario Pietro Cavallo [b,1], Maria Cefola [a,*,1], Roberto Colella [b], Giovanni Attolico [b]

[a] Institute of Sciences of Food Production, CNR-National Research Council of Italy, Via G. Amendola, 122/O – 70126 Bari, Italy
[b] Institute on Intelligent Systems for Automation, CNR-National Research Council of Italy, Via G. Amendola, 122/O – 70126 Bari, Italy

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ABSTRACT

An innovative computer vision system (CVS) that extracts color features discriminating the quality levels occurring during fresh-cut radicchio storage in air or modified atmosphere packaging was proposed. It self-configures the parameters normally set by operators and completely automates the following steps adapting to the specific product at hand: color-chart detection, foreground extraction and color segmentation for features extraction and selection. Results proved the average value of a^* over the white part and the percentage of light white with respect to the whole visible surface to be the most discriminating color features to significantly separate ($P \leq 0.05$) the three desired quality levels (high, middle and poor) occurring during fresh-cut radicchio storage (whose true value was verified on the base of ammonium content and human evaluated visual quality). The proposed procedure significantly simplifies the CVS design and the optimization of its performance, limiting the subjective human intervention to the minimum.

Industrial relevance: The non-destructive quality control represents a valuable tool to monitor fruits and vegetables along the whole chain from production to the end-user. Increased consumers' satisfaction and reduction of waste are only two examples of benefits that can come from a frequent and consistent control of food. CVS represents the most powerful and flexible way to reach these results. The current state-of-the-art makes their design strongly related to the specific product at hand. Thresholds and features are characteristics that play a critical role in determining the final performance of the system but are generally set by designers or operators using a-priori knowledge and/or trial-and-error processes. The proposed innovative procedure allows the CVS to self-configure most of these parameters and to easily adapt to different products regardless of the number and kind of colors associated to their surface. It results of practical applications in food processing, providing a non-destructive, automatic, cheap, fast and simple technology for the quality level evaluation, whose configuration requires a reduced, less critical and less technical human intervention.

1. Introduction

In the last years, due to the increased consumers' requests for quality, the food industry has paid great attention to measure and control the visual appearance of products (Wu & Sun, 2013a; Zhang et al., 2014). As regards fruits and vegetables, visual appearance is normally strongly related to overall quality and is therefore a very useful method to judge the quality level. In particular, in these products, accurate measurements of some chromatic properties (such as intensity, hue, chroma, color uniformity) provide important indicators of visual appearance. Generally, bright and vivid colors are associated with freshness and better quality, while dull colors are a normal consequence of an overall quality loss (Nunes, 2015). It has been proved that specific color features are correlated with quality level of fruits and vegetables. Pace et al. (2011), and Pace, Cefola, Da Pelo, Renna and Attolico (2014) reported a strong relationship of visual appearance with and b^* (or Chroma) in fresh-cut nectarines and with brown pigments in lettuce. Similarly, Nunes (2015) found significant correlations between color parameters and visual appearance in many fruits and vegetables. Generally, the color parameters related to visual appearance are manually acquired by colorimeter in a proper set of sample points on the product's surface. Recently, there is an increasing attention to the use of computer vision systems (CVSs). CVSs are more vulnerable to instabilities of the acquisition environment than colorimeters but, if properly calibrated and used, proved to be more robust, since they can analyze the complete surface of the product and are not affected by the arbitrary and subjective choice of sampling points (Pace et al., 2011, 2013; Pace, Cefola, et al., 2014; Wu & Sun, 2013a; Zhang et al., 2014; Manninen, Paakki, Hopia, & Franzén, 2015). CVS can extract from an image several features including color histograms, the presence and size of defective areas and color texture (Hernández-Carrión, Hernando, Sotelo-Díaz, Quintanilla-Carvajal, & Quiles, 2015). However, it is important to

* Corresponding author. Tel./fax: +39 080 5929304/9374.
E-mail address: maria.cefola@ispa.cnr.it (M. Cefola).
[1] First authorship is equally shared.

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highlight that, in several cases, only specific color features, are well related to the quality (Pace, Cefola, et al., 2014).

Starting from these considerations, the automatic identification of the most discriminative colors by CVS could improve the non-destructive quality level evaluation of fruits and vegetables, reducing the error due to subjective identification of the most discriminating colors (and of related parameters) of the overall quality level. Automatic quality classification, based on image analysis was reported by Zhang et al. (2014). In addition, Kordecki and Palus (2014) reported an automatic color-chart detection algorithm that determines the type and locations of color-patches in images. Color-charts are placed in the scene to provide reference colors that enable the evaluation and the reduction of effects of acquisitions environment on the behavior of the CVS. The algorithm, proposed by Kordecki and Palus (2014), used k-means clustering to accomplish color quantization and segmentation of a collection of regions some of which are the color-chart's patches. Further criteria, inspired by the a-priori knowledge about the structure of the color-chart (shape, number, position, shape and size of patches) were used to select and to identify the color-chart. Recently, Zhang et al. (2015) proposed a CVS to automatically detect defective apples by combining background removal, automatic correction of lightness, counting defected regions and a relevance vector machine (RVM) classifier. The system used a camera that acquires RGB and NIR (Near InfraRed) registered images of the same scene. The binary mask of the foreground was obtained using a (experimentally identified) threshold on the NIR image. A morphological filling was therefore applied to increase the quality of the segmented region. A lightness correction was applied in the peripheral part of the apple to compensate for the change of geometry between light, camera and surface. Moreover, Avila, Mora, Oyarce, Zuñiga, and Fredes (2015) proposed an automatic method to construct olives' and grape seeds' color scales maturity: the system used an illumination invariant color model and the threshold for foreground segmentation was determined using the Otsu's method (Otsu, 1975). However, most of the cited literature is related to products characterized by mostly homogeneous color. The evaluation of color change in products characterized by nonuniform color is still a critical task (Balaban, 2008; Wu & Sun, 2013a).

Starting from these findings, in this paper an automatic procedure for the non-destructive extraction by CVS of color features was proposed and applied for the evaluation of the quality level during storage of the fresh-cut radicchio, characterized by nonuniform color.

2. Materials and methods

2.1. Plant material and processing

Radicchio di Chioggia heads (*Cichorium intybus* L. group *rubifolium*) belonging to two hybrids (Corelli and Botticelli), were provided in two different harvest times by a farm located in Pontecagnano (south Italy) and immediately transported in cold condition to the Postharvest Laboratory of the Institute of Sciences of Food Production. Heads of each hybrid were selected to discard damaged samples and processed as fresh-cut product. In detail, radicchio heads were prepared by removing and discarding wrapper leaves and the stem with sharp stainless steel knives. Radicchio pieces (3 × 4 cm), obtained by using a vegetable cutter (CL52 Robot Coupe, Vincennes-Cedex, France), were pooled and blended to minimize product heterogeneity. Radicchio pieces were washed in tap water at 4 °C for 4 min. After washing, pieces were dried using a manual centrifuge and packaged in polypropylene bags (25 × 30 cm, 30 μm, Carton Pack, Rutigliano, Italy) containing each one about 150 g of product either sealed in passive modified atmosphere (pMA, at equilibrium: 10% O_2 and 7% CO_2) or in unsealed bags (AIR). In total, 120 bags (two radicchio hybrids × six replicates × five quality levels × two packaging conditions) were prepared and stored at 4 (±1.0) °C. All items, at proper times during storage, were graded using a five quality level scale, based on sensory evaluation, as reported below. Images of samples belonging to each quality level were acquired and processed by computer vision system (CVS); moreover the same samples underwent a chemical analysis for the ammonium content (NH_4^+).

2.2. Quality level classification and NH_4^+ analysis

Along the storage, fresh-cut radicchio was classified using five quality levels (QL) according to the following scale: 5 = very good (very fresh, no signs of wilting, decay or bruises), 4 = good (slight signs of shriveling, bruises), 3 = limit of acceptability or marketability (moderate signs of shriveling, browning, dryness, wilting, bruises), 2 = poor (severe bruises, evident signs of shriveling, pitting, decay), and 1 = very poor (unacceptable quality due to decay, bruises, leaky juice). The QL 3 was considered the minimum threshold of acceptance for sale or consumption (Nunes, Emond, Rauth, Dea, & Chau, 2009).

For NH_4^+ analysis the method reported by Pace, Cefola, et al. (2014) was used. In detail, 5 g of chopped sample was extracted in distilled water and, after the reaction with nitroprusside reagent and alkaline hypochlorite solution, color development was determined after incubation at 37 °C for 20 min, reading the absorbance at 635 nm (UV-1800, Shimadzu, Kyoto, Japan).

2.3. Color analysis by computer vision system (CVS)

2.3.1. CVS description and setup

The images used in the experiments were acquired using a 3CCD (Charged Coupled Device) digital camera (JAI CV-M9GE). The camera has a dedicated CCD for each color channel and provides a reliable color measure at full resolution, without the artifacts of most digital cameras (based on the Bayer filter). The uncompressed TIFF format was used to save images while avoiding any color artifacts produced by lossy compression algorithms. The camera mounted a Linos MeVis 12 mm lens system whose optical axis was perpendicular to the black background onto which the products were placed. Eight halogen lamps, divided along two rows placed at the two sides of the imaged area, were used. They were oriented using a 45° angle with respect to the optical axis of the CCD camera and to the plane on which the products were placed (Pace, Cefola, et al., 2014).

2.3.2. Color-chart detection

A small color-chart (X-Rite Color Control Patches, Fig. 1) has been placed in the scene during the acquisition of each image. Its patches allow the estimation and reduction of color variations occurring in time due to the behavior of CVS components and to uncontrollable changes of environmental conditions. X-Rite releases the numerical values associated to the color of each patch in the CIE $L^*a^*b^*$ space. To use this

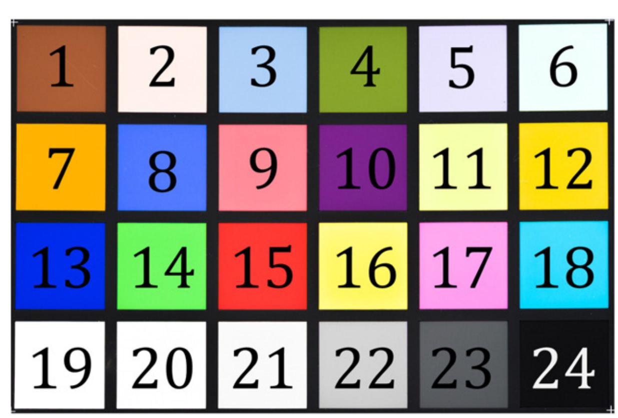

Fig. 1. The X-Rite color-chart used in the experiments. It provides a set of gray levels on the bottom row. Several colors, properly distributed in the color space, allow the evaluation of color fidelity of the acquisition system: the expected $L^*a^*b^*$ values are provided by the manufacturer.