CHEMICAL ENGINEERING TRANSACTIONS
VOL. 44, 2015
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Riccardo Guidetti, Luigi Bodria, Stanley Best

ISBN 978-88-95608-35-8; **ISSN** 2283-9216
DOI: 10.3303/CET1544030

Computer Vision for Laboratory Quality Control on Frozen Fruit

Davide Ricauda Aimonino*[a], Paolo Barge[a], Lorenzo Comba[a], Paolo Gay[a], Alessandro Occelli[b], Cristina Tortia[a]

[a]Dipartimento di Scienze Agrarie Forestali e Alimentari (Di.S.A.F.A.) - Università degli studi di Torino, Largo Paolo Braccini 2, 10095 Grugliasco (TO) - Italy
[b]OR s.a.s. – Via Galimberti, 50, 12030 Manta (CN) – Italy
davide.ricauda@unito.it

The appropriate amount of antioxidant compounds added in frozen light-flesh cut fruit production process is usually estimate evaluating colour changes, in particular by measuring the minimum time before browning phenomena occur. This parameter is assessed by visual inspections performed by trained operators: a time consuming and strongly subjective procedure.
The development of a Computer Vision System (CVS) for quality control in frozen fruit slice is presented in this paper. An algorithm to detect and measure browned area on fruit slices was implemented in order to describe colour changes evolution. The red component of browned areas is emphasized by an adequate linear combination of RGB colour channels of digital images, and an entropy-based automatic segmentation is applied to the obtained high contrast grey-scale image. This approach is not based on colour measurement of samples by the CVS, avoiding the colour calibration phase. Antioxidant solutions with different concentrations were applied in order to obtain different browning times and evaluate algorithm performances. Results obtained with the CVS strongly fit with visual inspections performed by trained operators, showing the reliability of the method for this specific application.

1. Introduction

The progressive increase in demand of Ready-To-Eat foods (fresh and/or frozen), together a greater awareness by consumers about food quality and healthiness, lead industries to improve and extent the quality control on their products. For this reason automatic inspection systems are required by food industries in order to replace or support visual inspection carried out by trained operators (Jackman and Sun, 2013). Computer Vision is becoming increasingly important technology in the field of quality control in many food processes. The appearance properties of food products (mainly colour, texture, shape and size) are, in fact, correlated with their organoleptic characteristics (Valous et al., 2009) and/or the presence of defects (Mendoza et al., 2006). Quality control based on image processing also eliminates the subjectivity of human visual inspection, allowing rapid and non-destructive analysis on a great number of samples (Jackman and Sun, 2013). However, the biological nature of food matrices determines a wide variability in appearance features, therefore specific image elaboration techniques have to be studied and implemented for every specific product.
In the production of frozen fruit (whole in the case of berries, sliced or diced), as well as of Ready to Eat fresh fruit snacks and salads, a stabilization phase with antioxidant compounds has to be done to avoid rapid product degradation. Colour changes are the first and most evident phenomenon that occurs, in particular in fruit with light flesh. Producers have to ensure a minimum time (after thawing in the case of frozen fruit) during which changes in appearance properties are not relevant. This time directly depends on dosage and concentration of the antioxidant solutions applied to the products. Quality control in this kind of processes are usually carried out taking samples of the end product and leaving it at room temperature for several hours. A trained operator visually checks colour changes at regular intervals of time defining the minimum periods

Please cite this article as: Ricauda Aimonino D., Barge P., Comba L., Gay P., Occelli A., Tortia C., 2015, Computer vision for laboratory quality control on frozen fruit, Chemical Engineering Transactions, 44, 175-180 DOI: 10.3303/CET1544030

within the product do not show a significant browning. This procedure is time consuming and strongly affected by the subjectivity of the operators, whereas a Computer Vision System (CVS) could perform automatically this kind of analysis, on a great number of samples, in a more objective way.
In many cases colour changes in food products are evaluated by means colour measurements carried out by CVSs, however, this method requires an acquisition system calibration procedure, because the RGB values generated by digital devices, such as cameras, are device-dependent and RGB colour space is not colorimetric (León et al. 2006). Device calibration mainly consists in finding a function, which transforms device-dependent RGB values to an absolute, device-independent, metric, colour space (usually CIELab). Target-based approaches are usually used to determine the mathematical transform between colour spaces. Using the acquisition of a reference colour card, constituted by a number of colour samples, it then is possible to design and identify different transforms, which provide absolute and device-independent colour information (León et al., 2006; Valous et al., 2009).
CVS calibration can be difficult to manage for the operators in charge to quality control, therefore the development of other techniques, in which this phase is not envisage, would fit better to factories needs.
Mery and Pedreschi (2005) developed a statistical segmentation algorithm to separate food images from background in which a high contrast grey-scale image was computed by a RGB colour channels linear combination. A similar approach was followed by Kang and Sabarez (2009) for bicolor food products, even if the CIELab colour space was considered in this case. The effect of different antioxidants on fresh-cut artichokes was assessed by Cabezas-Serrano et al. (2013), implementing a segmentation, to detect browned areas, followed by a colour measurement.
The development of a CVS for quality control in frozen light-flesh cut fruit is presented in this paper. The study was mainly focused on the implementation of an algorithm to evaluate browning kinetics of frozen apple slices, in order to assess the minimum time within colour changes are negligible. Approaches that involve colour measurements have been excluded to bypass any system calibration procedure. The red component of browned areas is enhanced by an adequate linear combination of digital images RGB colour channels, obtaining a high contrast grey-scale image. In this way browned areas of fruit slices are emphasized and separated by an entropy-based automatic segmentation.

2. Materials and methods

Experimental trials on CVS were carried out with samples of frozen apple slices made in the North West of Italy (Piemonte Region) by a factory specialized in frozen fruit production. The samples were obtained during a pre-production test, in which two lots of apples (about 100 kg each) of the same *cultivar* (Morgenduft) were treated with a solution at two different concentrations in Ascorbic Acid: 300 mg/L (CA) and 700 mg/L (CB). The production test was carried out by factory plant, in which each phase of the process (fruits washing, peeling, cutting, application of antioxidant solution and freezing) is fully automated. In particular, antioxidant solution was sprayed on apple slices by a set of nozzles placed just before the inlet end of the freezing tunnel.
Trials were carried out following the same protocol adopted by trained operators during the production quality control, adding an image acquisition system. Samples of frozen apple slices were brought at the output of the freezing tunnel. Some of them were used for CVS tests, while the others were putted on a white plate for visual inspection in order to compare the results for validation.

2.1 Image acquisition system

The implemented image acquisition system consisted of a backlighting table (Lupo P25 daylight) equipped with fluorescent lamps (colour temperature 5000 K) and a reflex digital camera (Nikon D5100), with an 18-55 mm zoom lens, fixed on a stand (Figure 1). Backlight illumination has been chosen to avoid shadows and to improve the contrast between the apple slices and the background, because they are slightly coloured and become semi-transparent after thawing. The whole system was placed within a wooden box, whose internal walls were black painted, to avoid reflections and external light.
The samples were arranged on a borosilicate plate glass placed on the backlighting table, performing three repetitions for each of the two concentrations (CA and CB) adopted for the antioxidant solutions.
The camera was set with a manual exposure (aperture f/13, speed 1/125 s, white balance 5000K). Digital images were captured in JPEG (maximum quality) format every 15 minutes, for 4 hours. The backlighting table was turned on two minutes before each acquisition and immediately turned off in order to avoid sample heating. The digital camera was remotely controlled by NKRemote© (Breeze Systems, UK) software, while the image processing algorithm was implemented using NI Vision Development Module 2009© (National Instrument, USA).

Figure 1: Laboratory image acquisition system equipped with a backlighting table

2.2 Image processing algorithm

The proposed method consists in four phases: (1) the red component of browned areas is emphasized by an adequate linear combination of Red, Green and Blue colour channels of the digital images; (2) an entropy-based automatic segmentation has been applied to the obtained high contrast grey-scale image; (3) morphological operations in order to remove small objects applied to the segmented binary image; and (4) masking with a binary image obtained separating slices from background by a second segmentation.
Browned areas, compared to the other parts of a slice, have a predominant red component. The proposed algorithm emphasized this component by the following linear combination of the Red, Green and Blue image colour channels:

$$kR-G-B \tag{1}$$

where $k \in [3,4]$ is a scalar constant which represents the gain applied to the Red colour channel. The result of the linear combination is a grey scale image where browned areas are much lighter than the rest of slices surface. Changing the gain value it is possible to vary the sensibility of the algorithm, in particular about the minimum degree of browning detected by the CVS (see results section for more details).
An entropy-based automatic segmentation (Kapur et al., 1985) was then applied to the grey-scale image obtained applying the combination defined by Eq(1). In information theory the entropy of a histogram is related to the amount of information associated with it. Let

$$p(i)=\frac{f(i)}{\sum_{j=0}^{N-1} f(j)} \tag{2}$$

the probability of occurrence of the grey level i of a grey scale image, in which $f(i)$ is the number of pixels for the level i. The entropy of a histogram of an image with N grey levels is given by:

$$h=-\sum_{i=0}^{N-1} p(i)\cdot \ln p(i) \tag{3}$$

If t is the threshold value, two different entropies can be defined.

$$h_b(t)=-\sum_{i=0}^{t} p(i)\cdot \ln p(i) \qquad h_w(t)=-\sum_{i=t+1}^{N-1} p(i)\cdot \ln p(i) \tag{4}$$

Where h_b and h_w represent the measure of information associated with the black and white pixels in the binary image after segmentation. The optimal threshold value is the grey level that maximizes the entropy in the thresholded image given by the sum of the two entropies (Kapur et al., 1985).

Erosion and close morphological operations, followed by the removal of small objects, were applied to the binary image resulting from the segmentation process.
This binary image was finally masked with a second one obtained separating the slices from the background, through an automatic segmentation here described. The segmentation was obtained by extracting the Blue colour channel from RGB image, since this one shows the highest contrast between slices and background. The histogram that comes from the correspondent grey scale image shows a peak that represents the background pixels (lighter ones), while an absolute minimum can be observed just before it. Positioning the segmentation threshold at this minimum (Figure 2), it is possible to distinguish the slices from the background. Masking was obtained performing an AND logical operation between the two binary images which represent the browned areas and apple slices.

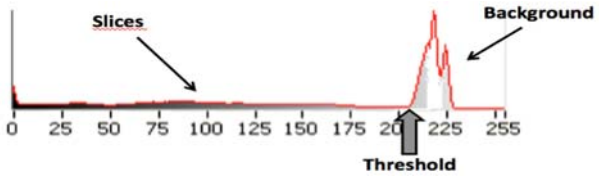

Figure 2: histogram of Blue colour channel with the threshold point adopted to separate slices from background

3. Results

Once the complete procedure (linear combination of RGB colour channels, entropy-based automatic segmentation, binary morphological operations and masking with binary images of slices) is applied on acquired images, a peculiar behaviour is shown. Browned regions are clearly identified by the algorithm when browning occurs, whereas, in absence of browning, the detected area corresponds exactly to the slices one.
This behaviour is clearly shown in Figure 3, where the results of the colour channels combination and the binary image obtained applying the entire algorithm are reported at 15, 30 and 120 min in the case of antioxidant concentration CA. No browning phenomena occur until 15 min, whereas after 30 min the first brownish blurs those appear on the slices surface are detected.

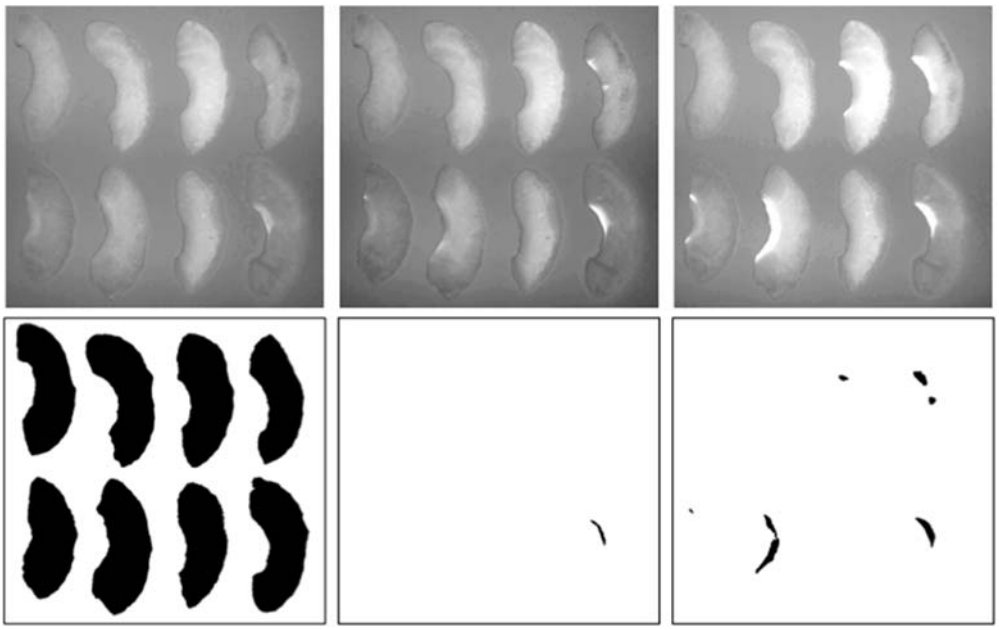

Figure 3: Results colour channels linear combination (top) and resulting binary images obtained by the proposed algorithm (bottom) at 15 (left), 30 (centre) and 120 (right) minutes (red component gain k=3) in the case of antioxidant concentration CA: original RGB image (left side)

A browning index, given by the ratio between the area of browning regions and the area of the entire slices surface, was defined in order to describe colour change kinetics and, in particular, to assess the minimum time

before browning. The index value is 1 until browning does not occur, and it falls near to zero as soon as the first brownish blurs are visible on slices surface.
The trend of the browning index respect to time, at different red component gain k, is shown in Figure 4 (on left) in the case of antioxidant concentration CA. A different sensibility to the browning can be observed by changing the gain k, even if the value of the browning index is the same regardless of the assumed gain. The minimum value of gain (k=3) gives the maximum sensibility: the algorithm detected a small browning zone with an area of about 15% of a slice surface (see Figure 3 at 30 min). On the contrary, increasing the gain the sensibility decreases (Figure 4 on left). This parameter allows implicitly setting up a threshold for the minimum degree of browning detected by the algorithm. The evident transition in browning index, in fact, defines the minimum time before browning (30, 60, 90 and 120 min in Figure 4). This time can be easily determined fixing a threshold (e.g. index equal to 0.5), without the employment of further statistical analyses. After browning phenomena take place, the index increases over time with a trend that minds, as expected, a typical colour change kinetic. The algorithm, in fact, provides quantitative information about browning kinetics, as the browning index represents the percentage of browned surface respect to total slices area.
In Figure 4 (on right) is also reported the trend of browning index obtained analysing, with the CVS at minimum value of red component gain, samples treated with antioxidant solutions at CA and CB concentrations. The algorithm clearly detects the different minimum browning time as well as the different evolution of the phenomena on time. Beyond 165 min the index for CA and CB concentrations become significantly different. In particular, for the analysed samples, the browning index values in the case of CB concentration is greater than those obtained with CA concentration, in spite CB is higher than CA. This behaviour can occur because antioxidant solutions are usually sprayed on fruit slices laid on conveyor belts, thus they not receive the same amount of product. However, this aspect does not affect the algorithm performances, moreover the browning evolution observed with CVS has been fully in according to visual inspection performed by trained inspectors.
Another important aspect is the execution time of the algorithm, although it is not critical in laboratory applications. An average processing time lower than 1 s for each image was achieved with the laptop PC (2.26 GHz dual core processor and 3 GB RAM) coupled with the image acquisition system during experimental trials. The algorithm is rather fast because the colour channels linear combination does not involve pixel-to-pixel mathematical operations with a consequent low computational load.

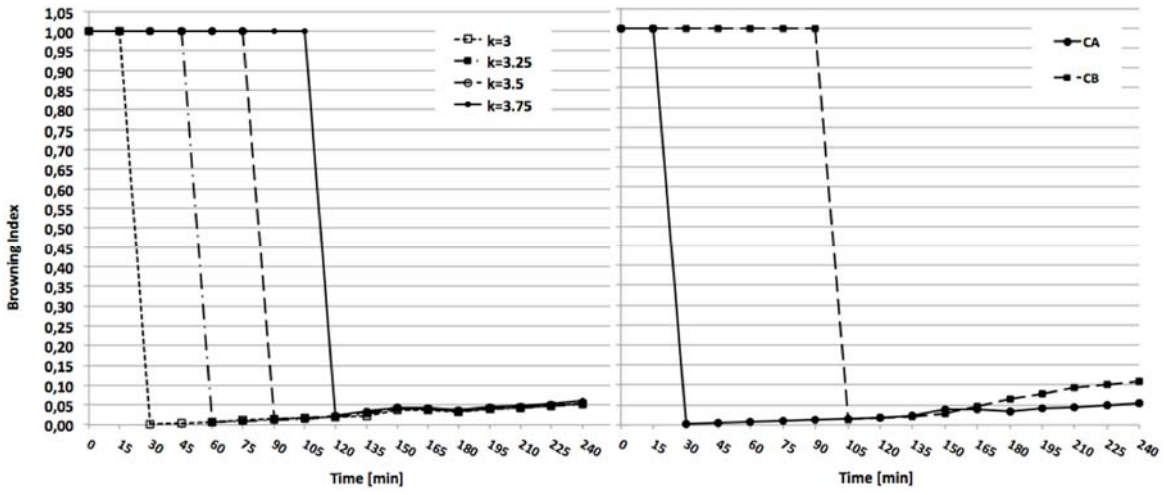

Figure 4: Trend of the browning index obtained (antioxidant concentration CA) with red component gain values of 3, 3.25, 3.5 and 3.75 (on left); trend of the browning index obtained with CA and CB antioxidant concentrations, adopting a red component gain value of 3 (on right).

4. Conclusions

This work showed how CVS can be profitably adopted in laboratory for quality evaluation of light pulp (apple) frozen fruit slices. Unlike other methods based colour measurement by CVS, the proposed image-processing algorithm implements a linear combination of RGB colour channels, which emphasizes the red component of browned areas on slices surface, with respect to the rest of the image, when browning occurs.

This approach allowed assessing the minimum browning time of defrosted apple slices as well as obtaining quantitative information about browning kinetics.
The CVS is able to detect browning phenomenon as soon as they occur even on very small surface (down to 15% of a apple slice surface). However, the algorithm sensibility can be tuned by change the gain applied to the red component of the linear combination. In this way, an appropriate minimum browning detection level can be tuned by operators who operate in quality control laboratories.
The proposed system is rather simple both in terms of hardware components, software platform and measurements management. It operates without operators' interventions and does not require preliminary operations on samples or calibration procedures.
The proposed system can be easily introduced in quality control laboratories of frozen fruit industries because it operates in automatic way and no preliminary procedures or calibrations are required.
Actually the CVS is employed, for intensive tests, in the same factory where experimental trials were carried out to support operators in quality control inspections.

Acknowledgements

This work was partially supported by the grants of the projects FoodVision and ColorEvolution (POR-FESR – Regione Piemonte).

References

Cabezas-Serrano A.B., Amodio M.L., Colelli G., 2013, Effect of solution pH of cysteine-based pre-treatments to prevent browning of fresh-cut artichokes, Postharvest Biology and Technology, 75, 17-23.
Jackman P., Sun D.-W., 2013, Recent advances in image processing using image texture features for food quality assessment, Trends Food Sci. Technol., 29, 35–43.
Kapur J. N., Sahoo P. K., Wong A. K. C., 1985, A new method for gray-level picture thresholding using the entropy of the histogram, Comput. Vision Graphics Image Process., 29, 273-285.
Kang S.P., Sabarez H.T., 2009, Simple colour image segmentation of bicolour food products for quality measurement, Journal of Food Engineering, 94, 21-25.
León, K., Mery, D., Pedreschi, F., León, J., 2006, Color measurement in L□a□b□ units from RGB digital images, Food Res. Int., 39, 1084–1091.
Mendoza F., Dejmek P., Aguilera J. M., 2006, Calibrated color measurements of agricultural foods using image analysis, Postharvest Biology and Technology, 41, 285-295.
Mery D., Pedreschi F., 2005, Segmentation of colour food images using a robust algorithm, Journal of Food Engineering, 66, 353–360.
Sun D.W. (2008). Computer Vision Technology for Food Quality Evaluation, Elsevier, Amsterdam, the Netherlands
Valous A. A., Mendoza F., Sun D.-W., Allen P., 2009, Colour calibration of a laboratory computer vision system for quality evaluation of pre-sliced hams, Meat Science, 81, 132-141.