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Simple colour image segmentation of bicolour food products for quality measurement

S.P. Kang *, H.T. Sabarez

Food Science Australia, P.O. Box 52, North Ryde, NSW 2113, Australia

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ABSTRACT

This paper introduces a colour image segmentation algorithm for bicolour food products. The algorithm has been developed for colour quality measurement in manufacturing processes. a^* and b^* components of *CIE* $L^*a^*b^*$ colour space are sampled from pixels in the food product region in an image. A polynomial equation is obtained from this colour data by using a least square fitting method. All pixels in the image are tested with this equation, and pixels having colour values close to the polynomial equation are regarded as ones in the food product region in the image. This algorithm is useful when multiple products are captured in an image and the food region needs to be segmented. The procedures of the algorithm and its application using French fried chips and dried apple slices are presented.

1. Introduction

Image segmentation is an important process in food image analysis in that it finds the right region of interest in an image. If the segmented section is not correct (e.g. include background, exclude significant portion of food area, etc.), it is difficult to produce meaningful results. Especially in food engineering, colour is one of the critical parameters for evaluating the product quality. Hence, the correct food area in an image must be segmented without background, yet including the entire food region.

Commercial colorimeters are available for food colour analysis, however, these devices measure only a small area. Consequently, computer vision systems have been recently developed for food colour analysis (Brosnan and Sun, 2002; Gökmen and Sügüt, 2007). In food image analysis using the computer vision system, the first step after image capture is segmenting the food product region in an image. Food image segmentation could be accomplished manually using commercial software packages such as Photoshop (Adobe Systems Inc., San Jose, United States) or MATLAB (The Mathworks Inc., MA, United States). Papadakis et al. (2000) used Photoshop manually selecting the region of interest of product images by moving the cursor along the product's boundaries. This manual method however requires enormous efforts to obtain the specific product boundary. As it is time-consuming and potentially yields inaccurate segmentation, it is not suitable for use in a commercial food processing line.

A number of image segmentation algorithms have been developed in the past to process images automatically (Du and Sun, 2004). The most commonly used method has been developed by Otsu (1979). His method converts a colour image to a binary image by thresholding the grey-level of the image data. Each pixel of the binary is set to either '0' or '1' and represents a region of interest in an image and background, respectively. However, histograms of grey-level images usually do not yield clearly distinct thresholds, hence there are inaccuracies in the selected regions after thresholding such as 1s in '0' region or 0s in '1' region. These unwanted pixels have to be removed using morphological operation before further processing (Sonka et al., 1993). Mendoza et al. (2006), Fernandez et al. (2005) and Riquelme et al. (2008) employed this method. However, if the grey-level of an object in an image was similar to the background, the object was difficult to be segmented. To improve thresholding results, Zheng et al. (2006), Kang et al. (2008) and Sun and Brosnan (2003) used RGB (red, green and blue) and HSI (hue, saturation and intensity) for the thresholding process instead of grey-level. Mery and Pedreschi (2005) developed a segmentation algorithm in MATLAB that determines a threshold using a statistical approach based on RGB and grey-level. Gökmen et al. (2007, 2008) used RGB colour space and manually selected three different colour sections also using a self-developed software routine in MATLAB. The colour data of three sections was used as mean colour values of each region to be segmented. Each pixel was sorted using Euclidian distances (Sonka et al., 1993) that pixels included to the closest colour section.

This paper presents such a generalised image segmentation algorithm for bicolour food products. The algorithm is based on *CIE* $L^*a^*b^*$, and is able to detect multiple products in images if the

* Corresponding author. Tel.: +61 2 9490 8849; fax: +61 2 9490 8499.
E-mail address: Seong.Kang@csiro.au (S.P. Kang).

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products in images are produced using same material and cooking method.

2. Materials and methods

2.1. Materials

As the materials for this study, French fried chips and dried apple slices were used.

2.2. Computer vision system

The images of these materials were captured using the computer vision system used in this study was the same as the one in Kang et al. (2008). This vision system is a box type enclosure. Two fluorescence tube lamps (TL-D Delux, 18 W/965, 6500 K, Philips) were attached at the top corner of the box, in parallel, at an angle of 45° to the product location. The internal size of the box was 700 mm (width) × 700 mm (length) × 500 mm (height). A colour digital camera (Olympus SP-500 UZ) captured images through a hole on the top surface. The calibrated camera settings for this experiment were; ISO: 200; shutter speed: 1/125; aperture: 3.5; resolution: 2816 × 2112; format: JPEG.

2.3. Segmentation

Since the segmentation algorithm presented in this paper was designed for quality measurement in food processing, this algorithm was developed in C++. The algorithm consists of two parts. Firstly, a polynomial equation for thresholding is generated from *CIE* $L^*a^*b^*$ colour space data of a sample image. Then, each image is binarized using the polynomial equation. In addition, each product in an image is separated from others for individual product analysis.

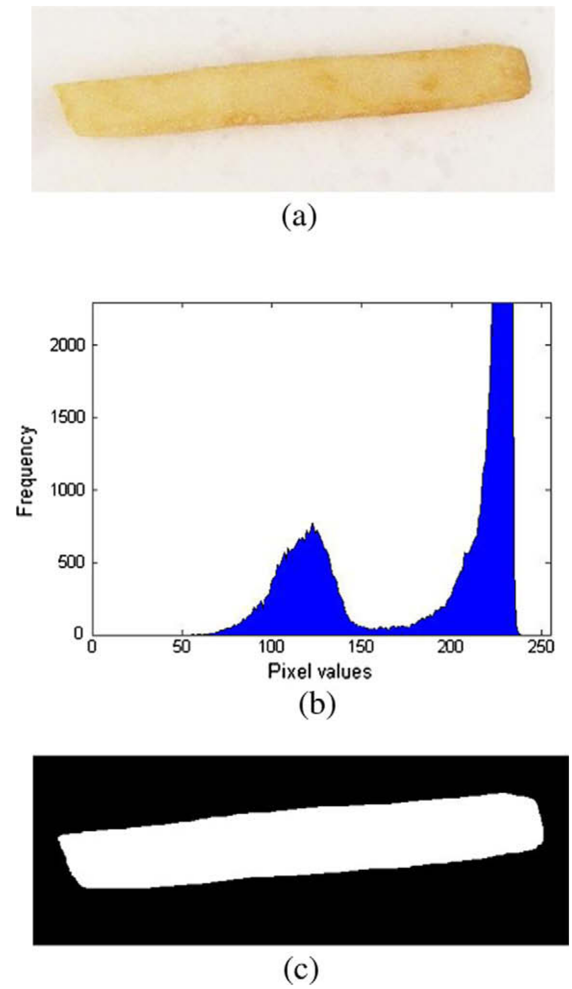


Fig. 1. A sample image: (a) is an original fried chip image, (b) is the histogram of blue component of RGB, and (c) is the result of segmentation using a blue colour threshold. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3. Results and discussion

3.1. General thresholding method

Generally, threshold values are determined by investigating histograms of grey-level or colour spaces. In order to carry out colour measurements of other images with the same kind of products, a threshold set might be changed to segment multiple images as well. For example, Fig. 1a shows a French fried chip image. Note that a white background was used in this figure instead of black because visual colour assessments of French fried chips in commercial applications are carried out on white. By investigating RGB and grey-level in Fig. 1a, it was found that the blue component was the most significant to differentiate the chip from the background. Fig. 1b shows the blue component histogram of RGB. This graph shows that Fig. 1a could be segmented simply by finding a threshold around 160. Fig. 1c shows the segmentation result by setting a threshold value to 160 of blue colour. The chip area was clearly separated from the background. However, this threshold value might not segment properly for other chip images. Fig. 2 shows an example when the same threshold value is applied to a different product image. As shown in Fig. 2a, although this chip was produced from same cooking conditions such as oil temperature, cooking duration, frying facility, batch, etc., overall colour of this chip is brighter than Fig. 1a. Due to the overall colour difference, the threshold value of Fig. 1a did not segment Fig. 2a properly as shown in Fig. 2b. To improve segmentation results for both images, more colour components need to be used. Thus, great effort is required to determine a general threshold for multiple images.

Fig. 2. A sample chip image with brighter colour than Fig. 1a: (a) original image and (b) the result of segmentation using the same method of Fig. 1.

3.2. Proposed thresholding method

Mendoza et al. (2006) reported that there is a colour change on a curved surface. Only a^* and b^* components of *CIE* $L^*a^*b^*$ colour surface remained unchanged. Kang et al. (2008) applied this fact in a mango colour change experiment. Hue angle was computed from a^* and b^* components of *CIE* $L^*a^*b^*$ and used for the colour analysis experiment. Whenever a mango image was captured, its position was slightly changed. However, the hue angle data was still reliable.

This paper introduces an algorithm using these two reliable colour components. Whitworth (2006) showed an example of thresholding results of a food image using a^* and b^*, but they did not show a successful result. There were undetected pixels in the food product region, and some background pixels were detected as products. Only if all the components of *CIE* $L^*a^*b^*$ are used, the products are segmented correctly. However, as reported by Mendoza et al. (2006), the L^* component is not robust at curved surfaces where light intensity changes. The segmentation algorithm introduced in this paper produces a polynomial equation of a^* and b^* to threshold images. The first step for obtaining the polynomial equation is collecting a^* and b^* data of the food product region. As the product used in this study is of bicoloured nature, the plots of the a^* and b^* values in an x–y plane are gathered in a specific region. Then, using the least square fitting method mentioned in Kreyszig (1993), a polynomial equation (i.e. $y = f(x)$) is obtained. Let b^* be the y-axis and a^* be the x-axis in two dimensional x–y plane as below.

Let Eq. (1) be a generic kth order polynomial.

$$y = f(x) = c_k x^k + \cdots + c_2 x^2 + c_1 x + c_0, \tag{1}$$

where $c_0, c_1, c_2, \ldots, c_k$ represents coefficients of the equation to be estimated. The order of the polynomial equation for a sampled data set with the coefficient of determination (R^2) that closest to 1.0 is selected as $f(x)$ for further processing. However, R^2 can be very low in some cases. If the polynomial equation passes through the middle of the distributed data plots, the equation can be used in the next process below.

Each pixel in an image is processed to convert it to a binary image using

$$M_{ij} = \begin{cases} 1, & \text{if } |f(a^*) - b^*| < T \\ 0, & otherwise, \end{cases} \tag{2}$$

where M_{ij} is the image matrix with horizontal and vertical pixel coordinates i and j. The origin of an image is at the top-left corner and the positive direction of i is right hand side and the positive

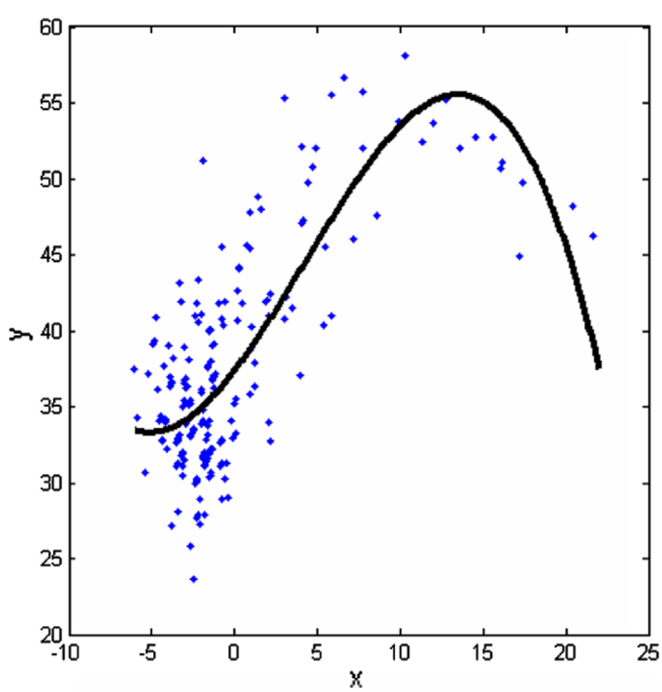
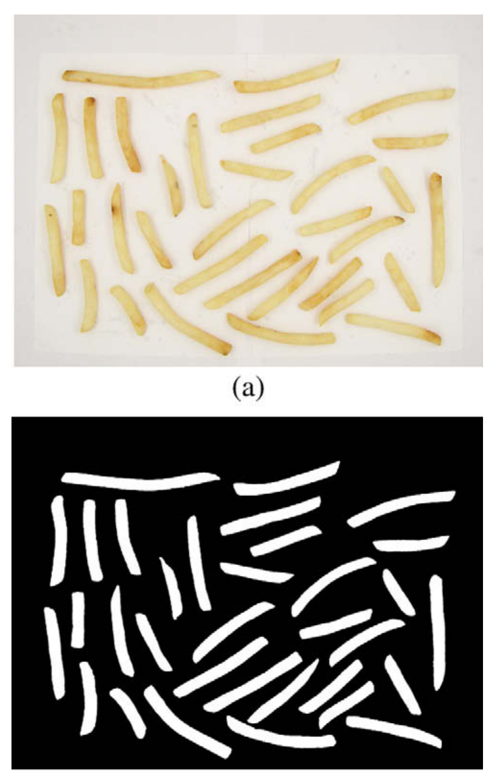


Fig. 3. Plot of a^* and b^* of *CIE* $L^*a^*b^*$ and the trend line; the dots represent plots of b^* against a^* of chip region pixels in Fig. 1a and Fig. 2a, and the line is obtained from the least square method. The equation of the line $y = -0.007x^3 + 0.0901x^2 + 1.218x + 37.37$ ($R^2 = 0.5721$).

(a) (b)

Fig. 4. Results of segmentation using a polynomial equation: (a) the segmentation result of Fig. 1a and (b) is the result of Fig. 2a.



(a)

(b)

Fig. 5. Results of multiple chips segmentation: (a) is the original image and (b) is the segmented image.

direction j is downward. T is a threshold for binarization and the difference between $f(a^*)$ and b^*. T should be set as a constant value that covers more than 90% of the distributed data plots (a^*, b^*) around the fitted line equation $f(a^*)$. If the difference of b^* and $f(a^*)$ of a pixel is less than T, the pixel is within the product area. Otherwise the pixels are located in the background. In addition, in some cases the positions of a^* and b^* in Eq. (2) could be interchangeable if the fitted line equation becomes more accurate.

Fig. 3 shows an example of this method using 240 sample plots of a^* and b^* from the product areas in the pictures including many chips. Using the above procedure, a polynomial equation was generated from the data plots of Fig. 3 as below,

$$y = -0.007x^3 + 0.0901x^2 + 1.218x + 37.37 \tag{3}$$

The line in Fig. 3 represents the plot of Eq. (3). Using this equation and setting T to 16, Fig. 1a and Fig. 2a are processed and the results are shown in Fig. 4a and b. Pixels containing 0s are plotted as black colour and 1s are white. Small holes in both images are removed using dilation and erosion (Sonka et al., 1993). Then, small spots in images like dark pixels caused while frying or oil sparks after frying are also removed. As shown in both images, the polynomial Eq. (2) successfully segmented two different types of product images. Thus, any product with the same material and the same cooking method will be segmented using this method.

3.3. Multiple objects segmentation

As mentioned earlier, in colour quality measurements in a food manufacturing process, processing samples one-by-one is not efficient. The colour vision system will be more useful if an image contains multiple samples. An example of multiple object segmentation is explained in Section 2.2. Fig. 5a shows 31 French fried chips. The image was processed using Eqs. (2) and (3) and the result is shown in Fig. 5b. The white area represents the product region, and the black is background. The pixels in the product region were successfully detected. Another example for analysing the image of dried apple slices is shown in Fig. 6. Fig. 6a is an image of dried apple slices. This figure was processed using same procedure as mentioned in Section 2.2. By sampling pixels in the apple slice region in Fig. 6a, a polynomial equation was obtained as shown in Fig. 6b. Each pixel was tested and the result was plotted in Fig. 6c. Note that, as reported by the research of Schanda (1998), colour measurement by the computer vision system used in this study is reliable at up to 10° observation angle. However, an observation angle greater than 10° is used in this paper to show the robustness of the segmentation algorithm with small colour variance resulting from changes in observation angle. This algorithm was tested with a number of fried chip images and dried apple slices. All the products in the experiment were successfully segmented.

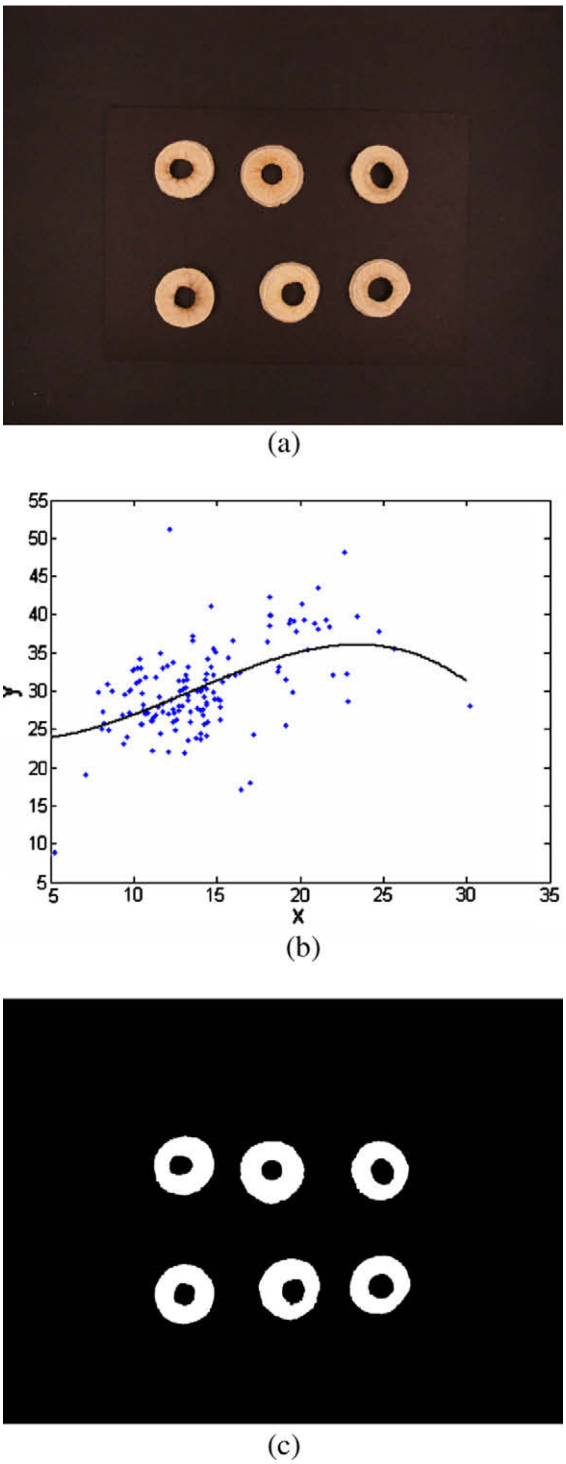


Fig. 6. An example of dried apple slices segmentation: (a) is the original image, (b) is the sampled data plots from the apple region in (a), and (c) is the segmented image. The equation of the line in (b) is $y = -0.003x^3 + 0.1199\,x^2 - 0.6773x + 24.68$ ($R^2 = 0.0802$).

4. Conclusion

A simple segmentation algorithm was introduced in this paper. The results of the algorithm using French fried chips and dried apple slices were presented. It has been shown that this algorithm is able to segment bicoloured food products produced by the same procedure such as cooking method, material, etc. If this algorithm is used with different products, a polynomial equation must be generated from sampled *CIE* $L^*a^*b^*$ data of an image. This algorithm is useful when colour quality measurement of multiple objects is required.

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