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Computer vision system in real-time for color determination on flat surface food

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Abstract

Artificial vision systems also known as computer vision are potent quality inspection tools, which can be applied in pattern recognition for fruits and vegetables analysis. The aim of this research was to design, implement and calibrate a new computer vision system (CVS) in real-time for the color measurement on flat surface food. For this purpose was designed and implemented a device capable of performing this task (software and hardware), which consisted of two phases: a) image acquisition and b) image processing and analysis. Both the algorithm and the graphical interface (GUI) were developed in Matlab. The CVS calibration was performed using a conventional colorimeter (Model CIEL* a* b*), where were estimated the errors of the color parameters: $e_{L^*} = 5.001\%$, and $e_{a^*} = 2.287\%$, and $e_{b^*} = 4.314\%$ which ensure adequate and efficient automation application in industrial processes in the quality control in the food industry sector.

Keywords: Computer Vision, RGB model, CIELab model, food quality control, Matlab.

1. Introduction

Color is one of the fundamental parameters defining the quality of a food. The assessment of this sensory parameter is crucial and is a preoccupation theme at food industry. In this context it's could estimate the sensory properties of food as the appearance and color of the surface, which are the first visually evaluated parameters and consequently consumer relationship in the acceptance or rejection of the product even before that this enters into the mouth (Du and Sun, 2004; Pedreschi *et al.*, 2006).

Currently, new tools are being used to measure changes in the color charac-

teristics in food, being one of this the computer vision technique projected as an alternative to the sensory evaluation. The efficient use of computer vision techniques for food colour and requires assessment requires of a calibration process based on absolute color common for color data as knowledge of the image characteristics that could correlate better with the quality product (Mendoza *et al.*, 2006).

The computer vision is relationship with the image processing and analysis, allowing the color segmentation, quantification and classification of elements of interest. The utilization of computer vision as an instrument for

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estimating the changes of the color characteristics on food is extremely advantageous when it is used to replace the panellists responses for images taken with a video-camera and after processed and analysed by computer algorithms. Make this reduces the cost, time and subjectivity of color measurements, making the estimation most reliable and scientific (Brosnan and Sun, 2004).

The combining of a digital camera and its image processing by software to replace the traditional measurement instruments have been widely used to provide a cheaper and versatile form to measure the color of many foods (Arce-Lopera *et al.*, 2013; Ariana *et al.*, 2006; Blasco *et al.*, 2009; Blasco *et al.*, 2007a; Lefcote *et al.*, 2006; León *et al.*, 2006; López-García *et al.*, 2010; Lunadei *et al.*, 2012; Mendoza *et al.*, 2006; Pedreschi *et al.*, 2006; Pedreschi *et al.*, 2011; Quevedo *et al.*, 2009; Unay and Gosselin, 2007; Xiaobo *et al.*, 2007; Xing *et al.*, 2007; Xul and Zhao, 2009; Yam and Papadakis, 2004).

Description RGB (Red, Green and Blue) of a color refers to the color composition in terms of the intensity of the light primary colors: red, green and blue. It is a color model based on the additive synthesis, which allows represent a color by mixing of the three primary colors of the light. Most digital camera models using the RGB color model where each sensor capture the light intensity in the red level (R), green (G) or blue (B) of the light spectrum (Hunt, 2004).

The CIE $L^* a^* b^*$ (CIELAB) is chromatic model normally used to describe all the colors that the human eye can perceive. It was developed specifically for this purpose by the *Commission Internationale d'Eclairage* (Illumination International Commission), reason why is abbreviated CIE. Asterisks (*) following each letter are part of the name, as they represent L^* , a^* and b^* .

The three parameters in the model represent the lightness of color (L^* , $L^* = 0$ black yields and $L^* = 100$ indicates white

yields), its position between red and green (a^* , negative values indicate green while positive values indicate red) and its position between yellow and blue (b^* , negative values indicate blue and positive values indicate yellow). This color model is three-dimensional and can only be adequately represented in three-dimensional space (Hunter Labs, 1996).

Moreover, the publication of computational approaches that convert RGB color units to $L^* a^* b^*$ use an absolute model with known parameters (Mendoza *et al.*, 2006; Segnini *et al.*, 1999). In this research, the parameters are estimated through a calibration process. However, the model parameters vary from case to case because RGB units depend on external factors (n (camera sensor sensitivity, lighting and sizing).

Although few studies on inspection of processed fruit apply computer vision, probably due to its lower economic interest respect of the fresh fruit and the greater complexity of the processing of these. However, the status of current inspection systems opens new possibilities for the creation of complex and robust algorithms capable of running in real-time inspection lines.

Therefore, it is important to start to develop appropriate decision algorithms and methods that allow accelerate and optimize industrial processes, particularly the case of fruits. In this regard, it is of interest to use digital video-cameras with communication to computers for the color valuation in real-time allowing the processing and analysis of their images with the use of special programs, so that the integrated system interprets information of manner equivalent to the human eye. Thus, measure the number, length, width, area, color, etc. of a particular food would be trivial.

Thus, this study had as aim to design, implement and calibrate a computer vision system for real-time to measurement the color on flat surface food.

2. Materials and Methods

2.1. CVS design

The CVS consisted in a cubic box of black interior walls, illuminated and support for digital camcorder connected to a computer for remote control of the same. The lighting system is composed for four Philips fluorescent tubes, daylight, 18 W (length 60 cm) With a color temperature of 6500 K, corresponding to daylight and a color index (Ra) approximately 95%. The four tubes were placed horizontally, forming a square on the camera to be created by illuminating light nucleus homogeneous where the samples will be situated. The shooting cube has its black interior walls and the surface where the sample is located is of black rubber, with the aim to avoid alterations produced by shine on the camera and samples (Pedreschi *et al.*, 2006). The capture system, Sony Handycam HDR-CX11E, video-camera has a stand position vertically to 22.5 cm forming with the samples a 45° angle between the axis of the camera and light sources. The images were captured at high resolution (720x480 pixels). The camera was connected to a computer Core i3.

2.2. CVS implementation

2.2.1. Routine algorithm

The extraction of the color characteristics of the imaging was performed on a graphical user interface (GUIDE) created in MatLab. The software consists of a multi-step GUIDE (Figure 1) described below.

A. Real-time image

Once conditioned the sample within the device built for artificial vision, we proceed to activate the camera and after enter at the GUIDE to display the live image of the sample.

B. Image Capturing

Wait ten minutes for the light is evenly distributed throughout the interior of the equipment including the sample for the computer vision, then click on the option to capture the GUIDE.

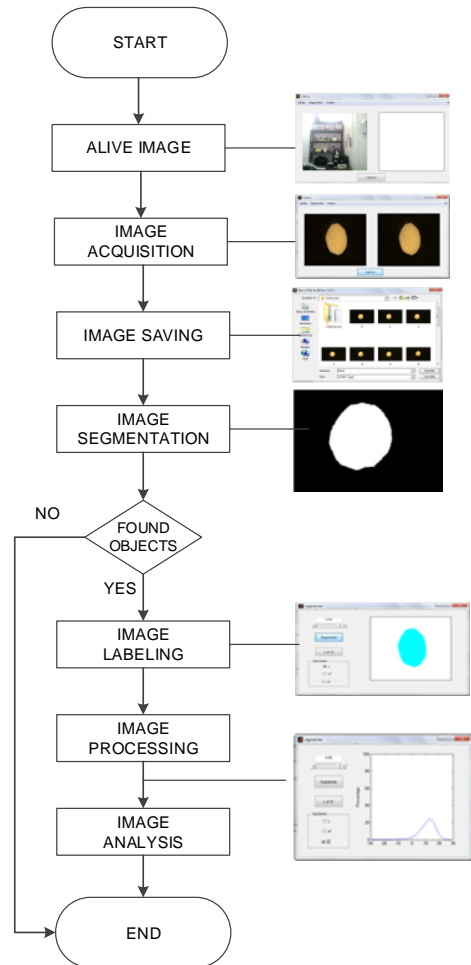


Figure 1. Routine for image processing and analysis.

C. Image saving

To save the captured image to make click on the option to record and moves a window through which you can access the folder where you want to save the image.

D. Image segmenting

When you already have the image saved, it is need insulate or separate objects of interest in the scene. It is intended, thus, to divide an image into different regions, automatically detecting the edges of the elements. The operation of segmenting an image depends on the image itself and the information we look for within it. With this objective make click on the option of the GUIDE segmenting and automatically throw us a segmented image ready to process, should be detailed in the upper

segment button can change the threshold value, in this case threshold (Th), for converting a binary image.

E. Image labelling

To differentiate the segmented image objects are assigned a different value of the pixel, according to its pixel value.

F. Image Processing

The image processing is the conversion of RGB color units to $L^* a^* b^*$ (segment labelling) values necessary for graphics and analysis respectively. To convert the RGB color space of the image to CIELab color space is necessary to do it in two phases. The first phase involves the conversion from RGB to XYZ (Poynton, 1996) and the second of XYZ color space CIELab. As a first step it must to normalize RGB to rgb values (values between 0 and 1) using equations 1, 2 and 3 for each value of R, G and B respectively.

$$\text{si } \frac{R}{255} > 0.04045 \quad r = \left(\frac{R+0.055}{1.055} \right)^{2.4}; \text{ si } \frac{R}{255} \leq 0.04045 \quad r = \frac{R}{12.92} \quad (1)$$

$$\text{si } \frac{G}{255} > 0.04045 \quad g = \left(\frac{G+0.055}{1.055} \right)^{2.4}; \text{ si } \frac{G}{255} \leq 0.04045 \quad g = \frac{G}{12.92} \quad (2)$$

$$\text{si } \frac{B}{255} > 0.04045 \quad b = \left(\frac{B+0.055}{1.055} \right)^{2.4}; \text{ si } \frac{B}{255} \leq 0.04045 \quad b = \frac{B}{12.92} \quad (3)$$

Subsequently this values were converted the rgb values to XYZ RGB values using the matrix M for a D65-2° illuminant-observer as shown in Equation 4. Was used the D65-2° illuminant-observer because is a standard recommended by the Commission Internationale d'Eclairage (CIE) and best suited to the lighting that was used (Blasco *et al.*, 2007b).

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = 100 * [M] \begin{bmatrix} r \\ g \\ b \end{bmatrix} \quad (4)$$

where:

$$[M] = \begin{bmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2126 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{bmatrix} \quad (5)$$

Thus, developing equation 4 and using matrix 5, are obtained X, Y and Z values by equation 6.

$$\begin{aligned} X &= 100 * r * 0.4124 + 100 * g * 0.3572 + 100 * b * 0.1805 \\ Y &= 100 * r * 0.2126 + 100 * g * 0.7152 + 100 * b * 0.0722 \\ Z &= 100 * r * 0.0193 + 100 * g * 0.1192 + 100 * b * 0.9505 \end{aligned} \quad (6)$$

Subsequently we obtain the values of x, y, z, using equations 7.8 and 9 respectively.

$$x = \frac{X}{X_n} \quad (7); \quad y = \frac{Y}{Y_n} \quad (8); \quad z = \frac{Z}{Z_n} \quad (9)$$

Where X_n, Y_n, Z_n are tri-stimulus values of the white specific object using in this case illuminant D65 (daylight) and the observer with the values shown in Equation 10.

$$X_n = 95.047; Y_n = 100; Z_n = 108.883 \quad (10)$$

After were calculated the values: varX; Vary varZ, using equations 11, 12 and 13.

$$\text{si } x > 0.008856 \quad \text{var } X = (x)^{1/3}; \text{ si } x \leq 0.008856 \quad \text{var } X = (7.787 * x) + (16/116) \quad (11)$$

$$\text{si } y > 0.008856 \quad \text{var } Y = (y)^{1/3}; \text{ si } y \leq 0.008856 \quad \text{var } Y = (7.787 * y) + (16/116) \quad (12)$$

$$\text{si } z > 0.008856 \quad \text{var } Z = (z)^{1/3}; \text{ si } z \leq 0.008856 \quad \text{var } Z = (7.787 * z) + (16/116) \quad (13)$$

Subsequently were calculated the values of L^*, a^* and b^* in the CIELab color space, following Equation 14 to calculate the lightness L^* , equation 15 for the value of a^* and equation 16 for the value of b^* .

$$L^* = (116 * \text{var } Y) - 16 \quad (14)$$

$$a^* = 500 * (\text{var } X - \text{var } Y) \quad (15)$$

$$b^* = 200 * (\text{var } Y - \text{var } Z) \quad (16)$$

2.2.2. Graphical of the image characteristics

The way to show the variability of the data from the analysed image is done by a distribution chart (histogram frequency) representing the vertical axis (or Y axis) the proportion of data from the analysed image (normalized frequency) having a value of $L^* a^* b^*$, which is indicated on the horizontal axis (or X axis). To obtain this graph make click on the option $L^*, a^* b^*$ of the GUIDE. It should be noted that both the computer and the computer vision GUIDE developed for this research should be used with flat surfaces.

2.3. CVS calibration

In order to calibrate the CVS were measured 30 colored cardboard which were obtained the values of $L^* a^* b^*$ with Konika Minolta cr400 Colorimeter in parallel the same with the CVS,

subsequently was measured the error CVS respect to the colorimeter. The normalized average error for each estimate parameter $L^* a^* b^*$ was obtained by comparison with measurements made with a colorimeter using equations 1 and 2 (Leon *et al.*, 2006).

$$e_{L^*} = \frac{1}{N} \sum_{i=1}^N \frac{|L_i^* - \hat{L}_i^*|}{\Delta L}; \quad e_{a^*} = \frac{1}{N} \sum_{i=1}^N \frac{|a_i^* - \hat{a}_i^*|}{\Delta a}; \quad e_{b^*} = \frac{1}{N} \sum_{i=1}^N \frac{|b_i^* - \hat{b}_i^*|}{\Delta b} \quad (17)$$

These errors were calculated with a mean of N measurements for $i = 1, \dots, N$, and normalized according to the scale size worked. As the measurements at intervals of $L^* a^* b^*$ were $0 \leq L^* \leq 100$, $-120 \leq a^* \leq +120$ and $-120 \leq b^* \leq +120$, the scale used is $\Delta L = 100$ and $\Delta a = \Delta b = 240$. To evaluate the performance of the model used for mean error of three measurements b^* it is calculated as follows:

$$\bar{e} = \frac{e_{L^*} + e_{a^*} + e_{b^*}}{3} \quad (18)$$

3. Results and discussion

3.1. CVS Design

For image acquisition process is take fundamental importance the type of lighting used. After evaluating different types of lighting, it decided to develop a system based on fluorescent tubes, as are valid for applications where visible light is important, for example, color sorting. The lighting directionally placed vertically with

an angle of 45° , which avoids direct reflections towards the camera on flat sample. Fernandez *et al.* (2005) used this setting to illuminate apple slices in where were controlled and evaluated its dehydration by tracking of its color and shape. A similar system later was used by Pedreschi *et al.* (2006) to illuminate potato chips in a system designed to measure the kinetics of color changes under different frying temperatures. The operation mode of the CVS designed is shown in Figure 2.

In this study was used the CIELab color system where the values of the X, Y and Z depend on the measurement geometry, illuminant and cameras based in charge-coupled devices (CCD); Therefore, if any of these parameters changes, also changing the values of $L^* a^* b^*$.

It is important highlight that the RGB color space is depending of the device in other words different devices produce different RGB values for the same pixels in a scene. For this reason, there have been developing diverse intents for standardization of values, as the called RGB color space. Another commonly used color space in food inspection, nearest to the human color perception is the HSI. Blasco *et al.* (2007a) compared five color spaces for identifying external defects in citrus and obtained the best results with the HSI.

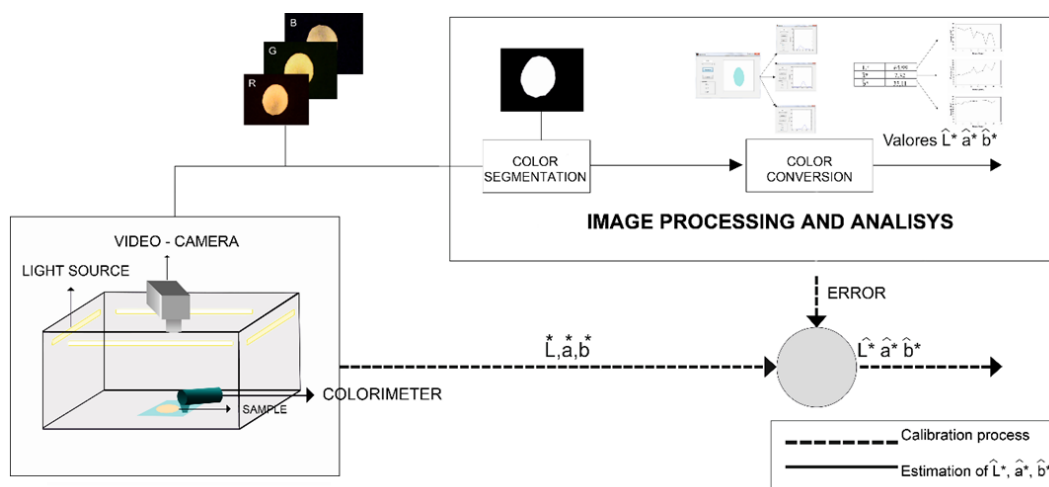


Figure 2. Scheme for converting RGB images to units $L^* a^* b^*$ using CVS.

Xiaobo *et al.* (2007) used both RGB and HSI for Fuji apples classified into four color categories. For his part, Abdullah *et al.* (2006) converted RGB coordinates into RGB coordinates, where was used the H component to classify the star-fruit (*Averrhoa carambola*) in four maturity categories.

However, both RGB and HSI color spaces are not uniform. This means that the Euclidean distance between two points located in different color regions in these areas do not produce the same difference of perception of a standard observer. To try to solve this problem, were defined uniform spaces as the CIELab and Hunter Lab, which are usually used for the color comparison (Leon *et al.*, 2006). Mendoza *et al.* (2006) compared different color spaces such as sRGB, HSV and $L^* a^* b^*$ in terms of their suitability for color quantization on curved surfaces, proving to be more appropriate $L^* a^* b^*$.

Often, it is important to determine the color of the fruit to set subsequent post-harvest treatments, for example, it is common the mandarins recollect when still have a green color and subject it to a de-greening treatment. In these cases, the fruit is stored in a chamber with humidity specific and ethylene concentration determined.

The duration of treatment depends on the color of the fruit at harvest time, expressed as one standard color index (Jimenez-Cuesta and Martinez-Javega, 1981). In another investigation, Fathi *et al.* (2011) used image analysis to measure the influence of different osmotic treatments on the color of the kiwis. For this purpose they converted the original coordinates RGB to $L^* a^* b^*$ to evaluate the color differences. According Xul and Zhao (2009), often the color of the skin also shows signs of internal injuries in apples.

3.2. CVS implementation

The implementation was done using a digital video-camera connected to a computer that governs the entire CVS. The processing of each picture begins with the segmentation process. To image segmenting P was used the band relationship between the green and

blue (G / B) of the RGB value of each pixel, so that those pixels whose values are above the threshold are considered samples and the remaining background.

This relationship was established because the samples analysed (case study, yacon slices minimally processed) have very low blue values and green high values, while the background has always low values of both values, thus facilitating discrimination. After receiving the segment of interest these pixels were converted to RGB color units for subsequently converting to space $L^* a^* b^*$. To convert the RGB color space to another color space is necessary previously to convert the original values to XYZ space. This step represents a loss of precision because the RGB space is limited in the number of colors (limited spectrum). Moreover, there are many arrays for conversion from RGB to XYZ. This is because there is a dependency of the RGB space in which we are working (Adobe RGB, Apple RGB, CIE RGB, RGB NTSC, PAL/SECAM RGB, sRGB, etc.).

Typically, video-cameras work in RGB space, so we use arrays for that color space. One of the important points to consider when applying these matrices in the conversions are illuminant-observer chooses to use. This platform has used fluorescent tubes which have a color temperature of 6500 K, so to make the formulas have been used conversions including D65 (6500 K) illuminant and the observer 2°.

3.3. Algorithm for image processing

This work has implemented image analysis algorithms to estimate the color and therefore also have developed a GUIDE simple for observing the development of the color analysis on flat surface food. Since the tests carried out show good results it is recommended the composed setting that simplifies the inspection system. However it should be improved in the future, focusing on lighting, optimizing algorithms and if possible using hardware with more processing power. The Matlab commands used in this study are presented in Table 1.

Table 1
CVS Programming in MatLab

Step	MatLab command	Description
1	Im = imread ('name.format');	Read the RGB image and stores it in the array im
2	img = rgb2gray (im);	Change the image to grayscale and stores it in img
3	[NFIL ncol] = size (img);	Determines the size of the image
4	for i = 1: NFIL, for j = 1: ncol, if img (i, j) <85, img (i, j) = 250, end, end, end	Change the background color
5	Th = 0.90;	Determine the threshold (Th), for this is used imtool
6	imbw = im2bw (img, Th);	Binarize the image using Th and is stored into imbw matrix
7	IMGC = imcomplement (imbw);	Generate the complement of the binarized image
8	IMGC = imfill (IMGC, 'holes');	Fill existing holes
9	[Imge n] = bwlabel (IMGC);	Tag and stored the image in the image matrix
10	stats = regionprops (imge, 'all');	Gets statistical information and stores it in the stats array
11	Area = zeros (1, n);	Determine the area
12	for i = 1: n; Area (i) = stats (i).Area; end k = 0, for i = 1: n, if max (Area) == stats (i).Area k = i;	Create zeros matrix
13	Cn = stats (k).Centroid;	Get the centroid
14	Deq = stats (k).EquivalentDiameter; hold on, plot (Cn (1), Cn (2), '* r'), hold off; break% stop process, end, end	Gets the equivalent diameter
15	POSP = stats (k).PixelList;% save POSP POSP; [NFIL ncol] = size (PPD), for i = 1: NFIL, x (i) = POSP (i, 1), and (i) = POSP (i, 2);	Obtains information about the image position
16	R (i) = Im (y (i), x (i), 1), G (i) = Im (y (i), x (i), 2), B (i) = Im (y (i), x (i), 3); end	Obtains values of R, G, B
17	image (label2rgb (imge));	Displays the new image labelled
18	IMAR = double (R) / 255; imag = double (G) / 255; IMAB = double (B) / 255;	Save the image in the matrices labelled: RR, GG, BB
19	[NFIL ncol] = size (IMAR); for i = 1: NFIL, for j = 1: ncol if (IMAR (i, j) > 0.04045); IMAR (i, j) = ((IMAR (i, j) + 0.055) / 1.055) ^ 2.4; else ; IMAR (i, j) = IMAR (i, j) / 12.92; end, end, end, for i = 1: NFIL, for j = 1: ncol if (imag (i, j) > 0.04045), imag (i, j) = ((imag (i, j) + 0.055) / 1.055) ^ 2.4; else Imag (i, j) = imag (i, j) / 12.92; end; end end; for i = 1: NFIL, for j = 1: ncol if (IMAB (i, j) > 0.04045); IMAB (i, j) = ((IMAB (i, j) + 0.055) / 1.055) ^ 2.4; else; IMAB (i, j) = IMAB (i, j) / 12.92; end; end; end; IMAR = IMAR * 100; imag = imag * 100; IMAB = IMAB * 100;	Determines the matrix size and conditions the first part of the conversion from RGB to XYZ
20	X = IMAR * 0.4124 + Imag * 0.3576 + IMAB * 0.1805; Y = IMAR * 0.2126 + Imag * 0.7152 + IMAB * 0.0722; Z = IMAR * 0.0193 + Imag * 0.1192 + IMAB * 0.9505;	Performs the second part of the transformation from RGB to XYZ, constants for the Observer = 2 °, Illuminant = D65
21	var_X = X./95.047; var_Y = Y./100.000; var_Z = Z./108.883;	Transforms from XYZ to Var_X, var_Y, var_Z, using Observer = 2 °, Illuminant = D65
22	[NFIL ncol] = size (var_X);	Determine the matrix dimension
23	for i = 1: NFIL, for j = 1: ncol; if (var_X (i, j) > 0.008856); var_X (i, j) = var_X (i, j) .^ (1/3) else var_X (i, j) = (7787 * var_X (i, j)) + (16/116); end; endn end; for i = 1: NFIL, for j = 1: ncol if (var_Y (i, j) > 0.008856); var_Y (i, j) = var_Y (i, j) .^ (1 / 3); else var_Y (i, j) = (7787 * var_Y (i, j)) + (16/116); end, end, end, for i = 1: NFIL, for j = 1: ncol if (var_Z (i, j) > 0.008856); var_Z (i, j) = var_Z (i, j) .^ (1/3) else var_Z (i, j) = (7787 * var_Z (i, j)) + (16/116); end, end, end	Determine the values: var_X (i, j), var_Y (i, j), var_Z (i, j)
24	L = (116. * Var_Y) -16; a = 500. * (var_X-var_Y); b = 200. * (var_Y-var_Z);	Obtain L*, a*, b* values

3.4. CVS calibration

Figure 3 shows the measurements taken to the colored cardboard, their results in L^* , a^* , b^* obtained by the CVS and a conventional colorimeter. A CVS must be designed to give objective and reproducible color of a food product at any time. Small differences are observed between the values of the color parameters obtained by the colorimeter and the CVS. Also observed that the model used for the conversion of units of color RGB to L^* , a^* , b^* , obtained from images generated by computer vision, are reliable. Figure 3 clearly shows the relationship between the two devices, with relatively low average errors (and $e_{L^*} = 5.001\%$, and $e_{a^*} = 2.287\%$, and $e_{b^*} = 4.314\%$ for L^* , a^* and b^* , respectively). An error of less than 10% is indicative that the model explains in acceptable form the variation of the experimental data (Pulido *et al.*, 2004) which guarantees good results in future tests.

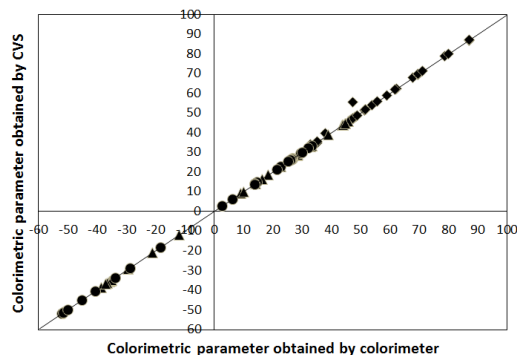


Figure 3. Comparison among colorimetric parameters obtained by CVS and colorimetric parameters obtained by colorimeter [L^* (◆), a^* (▲), b^* (●)].

4. Conclusions

The present work allows developing a new tool for measuring of color on flat surface foods. This system allows obtain sensory information sensory over color objectively and thus take advantage of traditional systems proposed nowadays, allowing a more accurate and rapid characterization of these.

The image processing and analysis algorithms implemented in the VCS enabled to estimate of the parameters of the CIELAB color model with errors: $e_{L^*} = 5.001\%$ and $e_{a^*} = 2.287\%$ and $e_{b^*} = 4.314\%$, values relatively low to ensure good results.

It is recommends to integrate the configuration composed of a digital camera, which, as has been widely described, simplified the inspection system. It should word widely in lighting and optimization algorithms. The integration of an artificial neural network, with chromatic and morphological parameters in the VCS for classification of processed or fresh foods would improve considerably, allowing estimate the food shelf life about minimally processed foods.

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