Measurement of the colour index of early-season citrus fruits using computer vision

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Abstract
Aspect and colour of food surface is one of the first quality parameters evaluated by consumers and it is a key factor in the acceptance of a particular product for the consumers. In the Mediterranean area, early-season citrus fruit reach acceptable internal maturity standards for marketing, while the skin of the fruit is still green. A degreening treatment is widely used as a postharvest practice to improve the external colour. This treatment depends on the initial colour of the fruit. Therefore, an application where the inspection of the colour is needed is the assessment of these citrus fruits in order to determine accurately the colour of the citrus at harvest. The classification to determine if the fruit needs to be treated for degreening is based on the citrus colour index (CCI). In this work, the potential for the in-line CCI assessment of an industrial computer vision system is studied and compared with two other devices; a characterized computer vision system and a spectrocolorimeter used as reference in the analysis of colour on food. The results obtained prove that the industrial computer vision system predicts the colour index of citrus with a good reliability (R^2 = 0.975) and is effective for classification of the fruit according to its colour.

Key words: colour analysis, citrus fruits, degreening, machine vision

1. Introduction

Colour is one of the most important attributes of agrifood products, since consumers associate it with freshness and is critical in the acceptance of a particular product among others (Campbell *et al*., 2004). Producers strive to prevent products with defective colorations from reaching the market (Abdullah *et a*l., 2004; Hatcher *et al*., 2004), as well as ensuring that individual products are packed in batches with a similar colour (Blasco *et al*., 2009). In this sense, it is also important to measure how post-harvest treatments affect the colour of fruits (Cubero *et al*., 2010). An application where the inspection of the colour is needed is the assessment of citrus fruits. Fruits are manually harvested, then loaded in boxes and transported to a packing house, where the fruit is sorted. In the early season, this sorting is aimed at classifying by colour, because fruit is treated separately (orange fruits go directly to the market, orange-green suffer a 24 hour degreening process and green fruit suffer a 72 hour degreening). The Citrus Colour Index (CCI) in the citrus industry is used to determine the harvesting date or to decide if citrus fruits should undergo a degreening treatment (DOGV, 2006). Table 1 summarized the recommendations for the treatment of degreening of orange and tangerines (Jimenez-Cuesta *et al*., 1981). Colorimeters are electronic devices for colour measurement that express colours in numerical coordinates. However, colorimeters are limited to the measurement of small regions of a surface or when the object has a homogeneous colour (Gardner, 2007). Instead, still or video cameras can provide images in which the colours of the pixels are determined individually being more suitable for cases where the surface has a heterogeneous colour (Yam and Papadakis, 2004). In this work, a computer vision system has been specifically developed for the inspection of the external quality of citrus fruits. The potential for in-line colour assessment of the industrial computer vision is compared with a reference colour acquisition device to know the accuracy of this new sorting system. However, industrial machine vision systems for in-line inspection are not as reliable as high quality still cameras are in terms of image quality and colour fidelity (Berns, 2000). Therefore, a characterized high quality image acquisition system has been included in the study in order to set the true potential of an automatic imaging system to reproduce the colours of the fruit. In brief, in this work, the potential for the in-line ICC assessment of an industrial computer vision system is studied and compared with reference methods.

Table 1. Recommendations for the treatment of degreening of oranges and tangerines (Jimenez-Cuesta *et al*., 1981).

CCI	**Mandarins**	**Oranges**
CCI < -13	Not necessary	Not necessary
-13 > CCI < -5	72 h with ethylene	Not necessary
-5 > CCI < +3	48 h with ethylene 72 h without ethylene	72 h with ethylene
CCI > +3	24 h with ethylene 48 h without ethylene	48 h with ethylene 72 h without ethylene
CCI > +7	Not required	Not required

2. Material and methods

2.1. Fruit used

Experiments were carried up with a set of 120 oranges of Navelina cultivar. Fruit were chosen randomly from the production line of a packing house with a colour from green and yellow with some green spots to orange. Each fruit was labelled and colour was measured with the three devices. A total of 60 samples were used to perform the regression model while other 60 were used to test the model.

2.2 Imaging systems

Three colour measured systems have been used to acquire data. The first one was composed by a spectrocolorimeter CM-700d, used as reference since this is a device commonly used in the industry to measure colour. The second one was composed by a high resolution still camera (system A) in order to know the goodness of an image-based colour estimation method under laboratory conditions. Finally it was used an industrial computer vision system working in-line (system B) to determine if the measurement of colour can be automated. To test the systems, the CCI of each fruit was calculated from six measurements acquired by the spectrocolorimeter, and also from four images of each fruit acquired with the vision systems. A regression model was fitted between the spectrocolorimeter values and the both image systems, in order to check the relations between these types of measurements.

2.3. Feature selection

The spectral reflection curve of the six points of each orange was taken using the spectrocolorimeter, and the average curve of these points was calculated. This average curve was integrated wavelength by wavelength through the visible range, with illuminant spectral emission D65 and standard observer 10º. The areas under the resulting curves yield the values of X, Y and Z coordinates (Hutchings, 1999). The XYZ coordinates were used to calculate the HunterLab parameters (*L, a, b*) and with them, the corresponding CCI using the equation 1.

$$CCI = \frac{1000 \cdot a}{L \cdot b} \quad (1)$$

The images of the fruit were acquired using the system A and system B. The colour of the pixels in the image was codified in RGB colour space and converted to XYZ coordinates and HunterLab parameters. The conversion was performed off-line by calculating the CCI of all possible RGB values in the image, being these values stored in a Look Up Table (LUT). This table is preloaded in the memory of the computer; therefore during the in-line processing it is possible to obtain the HunterLab value of each pixel just by consulting the LUT. The mean of all the RGB values of the pixels belonging to the fruit were calculated and the resulting values were transformed using the LUT in the CCI values. The results were called PIXIC. The CCI of the fruit was calculated as the mean of the CCI of the four partial images of the fruit.

2.4 Test

The values of CCI estimated for each fruit by system A and system B were compared with those obtained using the spectrocolorimeter by means of a quadratic regression and performing a classification.

Three tests were carried on during this work:

1. To assess the image analysis algorithm that provides most accurate prediction of the CCI.
2. To determine the behaviour of systems A and B towards the spectrocolorimeter.
3. To compare the colour classification achieved by the systems A and B against the classification done by the spectrocolorimeter using the standard classification thresholds to determine if the fruit needs to be treated for degreening (table 1).

The statistical analysis of data was performed through analysis of variance (ANOVA) using SPSS© 17.0 (IBM Corporation, USA).

3. Results

Figure 1 shows the CCI estimated using the three different methods. The values of CCI obtained for the different devices for each fruit have similar trends. The spectrometer shows higher values in general than the A system. However, the B system presents, in absolute values, higher CCI scores than the other two systems.

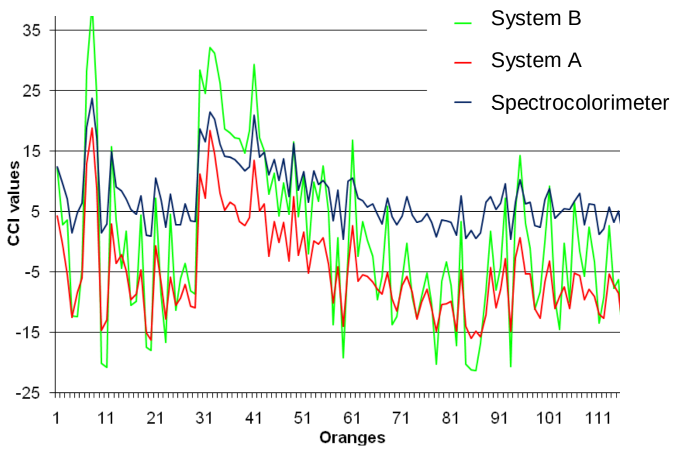

Figure 1. CCI estimated by the three different devices

To determine behaviour of the A and B systems towards the spectrocolorimeter, regression models were built and analyzed using SPSS. Tables 2 and 3 show the multiple regression analyses. The quadratic regression was significant in the case of the system B, with a p-value = 0.00, but the statistical significance of the quadratic term for the system A was doubtful (p-value =0.082). The A and B systems use the same procedure for getting the colour information from the fruit, which could be a reason to present the same behaviour towards the spectrocolorimeter. Therefore we assume that also for the system A the term is statistically significant.

Table 2. Multiple regression analysis of the system A

	Unstandardised Coefficients		**Standardised Coefficients**		
	B	**Std. Error**	**Beta**	**t**	**Sig.**
Laboratory system	0.613	0.011	0.989	53.932	0.000
Laboratory system^2	0.002	0.001	0.032	1.755	0.082
Constant	10.293	0.136		75.678	0.000

Table 3. Multiple regression analysis of the system B

	Unstandardised Coefficients		**Standardised Coefficients**		
	B	**Std. Error**	**Beta**	**t**	**Sig.**
Industrial system	0.340	0.007	0.959	46.594	0.000
Industrial system^2	0.002	0.000	0.083	4.008	0.000
Constant	8.228	0.144		57.073	0.000

The quadratic regression model was used for recalculating the CCI values (PIXIC) obtained using the imaging systems, thus obtaining new values so-called “PIXIC transformed”. Figure 2 shows the same values of Figure 1 after the transformation, being evident how they fit better after applying the model.

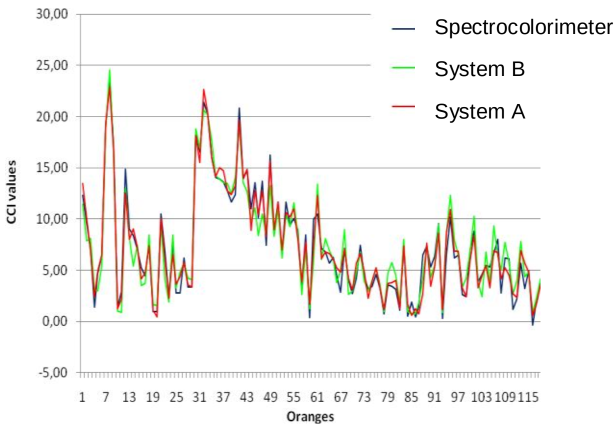

Figure 2. CCI estimated by the three different devices after applying the quadratic regression model

Figure 3 shows the scatterplot between the spectrocolorimeter (observed or real values) and the predicted values from the system A and the system B, respectively

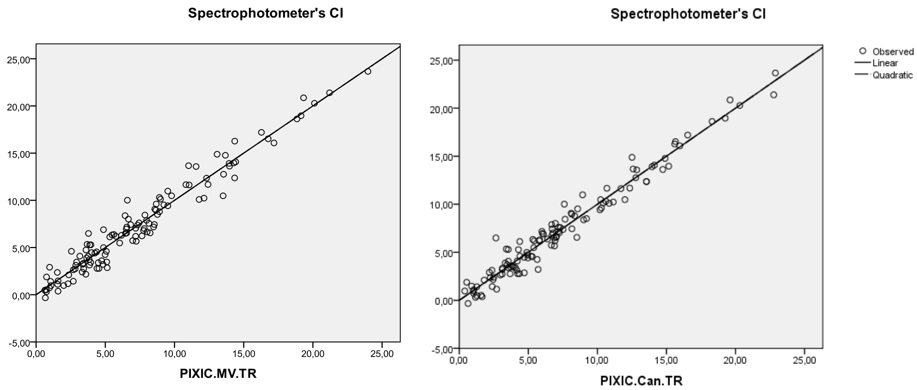

Figure 3. Scatterplot between the spectrocolorimeter and the system A (right) and between the spectrocolorimeter and the system B (left).

To compare the different methods in terms of fruit classification, the fruit was sorted using the "PIXIC transformed" values and the CCI obtained using the spectrocolorimeter. Three categories were set using the recommendations for the treatment of degreening of oranges (Table 1). The range of the values was: CCI < 3 (group 1), 3 < CCI < 7 (group 2), 7 < CCI (group 3). A tolerance of ±0.5 was considered after a personal communication with a expert in post-harvest, from the IVIA, who states that, in the practice, there are no perceptible differences in colour for variations of even one unit in the CCI. The confusion matrixes for both imaging systems are shown in tables 4 and 5. As expected, system A obtains better results than the system B, particularly in the case of the middle category which represents those fruits whose colour is changing and has more heterogeneous distribution of the colour. Fruit in group 1 had normally some green and yellow spots randomly distributed which can cause a decrement of the classification performance. On the contrary in the other groups the colours were more uniform. Classification is better when oranges have matured, because the colour tends to become homogeneous. In both cases, it was obtained more than 84 % success compared with the spectrocolorimeter, being the average higher than 92 %.

Table 4. Confusion matrix between system A and spectrocolorimeter (%) (Average 94.2 %)

Spectro. / System A	CCI < 3	3 < CCI < 7	7< CCI
CCI < 3	84.0	16.0	0.0
3 < CCI < 7	2.3	95.4	2.3
7 < CCI	0.0	1.9	98.1

Table 5. Confusion matrix between system B and spectrocolorimeter (%) (Average 92.6 %)

Spectro. / System B	CCI < 3	3 < CCI < 7	7< CCI
CCI < 3	84.0	16.0	0.0
3 < CCI < 7	0.0	90.7	9.3
7 < CCI	0.0	1.9	98.1

4. Conclusions

Two computer vision systems have been developed and tested to automate the measurement of the colour of citrus fruits in the industry aimed at sorting the fruit depending on the need of degreening.

High correlations have been found between the spectrocolorimeter and the image systems A and B. Compared with the spectrocolorimeter, the results obtained with system A were slightly better than the achieved using the system B, but in both cases a good R^2 value was obtained. The capability of the imaging systems to sort the fruit in the same categories than the spectrocolorimeter achieved average values higher than 92 %. These results are promising and demonstrate the feasibility of a computer vision system to inspect the colour of citrus fruits in field conditions while the fruit is being harvested, being a valuable advance for this industrial sector.

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