Application for the estimation of the standard Citrus Colour Index (CCI) using image processing in mobile devices

S. Cubero[1], F. Albert[2], J.M. Prats-Moltalbán[3], D.G. Fernández-Pacheco[4], J. Blasco[1], N. Aleixos[2*]

[1]Centro de Agroingeniería. Instituto Valenciano de Investigaciones Agrarias (IVIA). CV-315, km 10,7 – 46113 Moncada (Valencia), Spain

[2]Departamento de Ingeniería Gráfica, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain. Email: naleixos@dig.upv.es

[3]Grupo de Ingeniería Estadística Multivariante, Departamento de Estadística e IO Aplicadas y Calidad, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain

[4]Departamento de Expresión Gráfica, Universidad Politécnica de Cartagena, Cartagena 30202, Spain

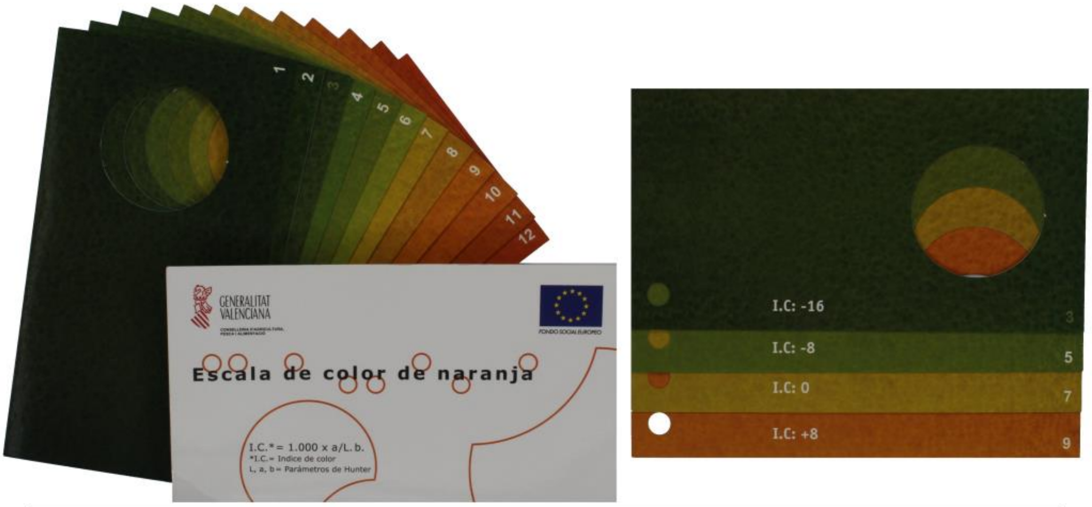
Abstract The collection of oranges normally begins before they have reached the typical orange colour. Moreover, citrus fruits are subjected to certain degreening treatments that depend on the standard citrus colour index (CCI) at harvest. In order to facilitate the measure of this index, a free application that uses image processing techniques has been developed for Android-based mobile devices using the built-in camera of the device. The image analysis process is performed on all the images from the live input of the camera to obtain the CCI of such fruit using the open source OpenCV library. For this purpose, the RGB (red, green and blue colour coordinates) average value of a pre-selected area of the input image is calculated and then converted to HunterLab colour space to finally calculate the CCI. Several tests were carried out in the field with the fruit in the trees and under laboratory conditions with different varieties of oranges (Navel, Bonanza, Cram and Navelina) at different stages of maturity, and using different Android devices. The results were obtained for each device and condition in relation to the colour measured by a camera and compared with the performance of a panel of workers who evaluated the colour using the traditional methods. Best R^2 values obtained were 0.854 for outdoors conditions and 0.881 when measurements were done indoors.

Keywords: mobile device, colour analysis, citrus fruits, Colour Citrus Index estimation, in-field conditions

1. Introduction. State of the art

Colour is one of the main attributes that consumers associate directly with the freshness or maturity of agricultural food products, so it is a key factor in their preferences over other products (Campbell et al., 2004). A practical application where the inspection of the colour is also needed is the marketing of citrus fruits. Fruits are harvested manually, loaded in boxes and transported to packing houses, where they are sorted in batches. In the early season, when the citrus fruit is received in the packinghouse, this sorting focuses on classifying by colour because it normally needs a degreening treatment using ethylene, whose duration depends on the colour they present at harvest (Porat, 2008). The standard parameter used to determine the colour of citrus fruits is the citrus colour index (CCI), being used in the citrus industry to determine the harvesting date and to decide which fruit should undergo a degreening treatment and the type of the treatment (Jimenez-Cuesta et al., 1981).

The common way to determine the CCI in the industry is by using colorimeters, which are specific electronic devices for colour measurement that express colours as numerical coordinates. However, although colorimeters give accurate colour measures and are small handy devices, they are expensive and only provide information of a very small area of the fruit surface (Gardner, 2007), which may not be representative of the colour information of the whole fruit surface, especially when the fruit has not a uniform colour. In this sense, calibrated colour cameras can achieve similar results to colorimeters (Vidal et al., 2013). Another extended way to estimate the CCI is the set of cards simulating the colour and texture of the fruit at different stages of maturity developed by the Centro de Tecnología Postcosecha of the Instituto Valenciano de Investigaciones Agrarias (IVIA) and provided by the Consellería de Agricultura Pesca y Alimentación of the Generalitat Valenciana for oranges (Fig. 1) and mandarins, which allows a visual comparison of the citrus surface to the printed colour inside a circular window and so estimate the CCI of such fruit that is printed on each colour card (DOGV, 2006).



Card number	1	2	3	4	5	6	7	8	9	10	11	12
CCI	-24	-20	-16	-12	-8	-4	0	+4	+8	+12	+16	+22

Figure 1. Set of coloured texture cards used to estimate visually the CCI of oranges

A way to automate this measurement is to acquire images of the fruit using digital cameras and then analysing the colour using image processing software. This method allows estimating the colour of a bigger region or even the entire fruit, being especially suitable in those cases where the surface has a heterogeneous colour since the colours of the pixels are determined individually (Cubero et al., 2011; Lorente et al., 2012). Automated estimation of colour using image processing presents several advantages regarding the visual inspection such as accuracy, objectivity and repeatability. However, one of the major drawbacks when measuring colour using images is that, normally, the colour is provided in red, green and blue colour coordinates (RGB) since this is the native colour space for most image acquisition devices. However, this colour space is device-dependent, and it is not a perceptual colour model. On the contrary, other colour models like CIELAB or HunterLab are defined in such a way that the distances among colours in the colour space are related with the differences in the human perception regardless of the position of the colours, so they are very well suited for colour comparison and appropriate for measuring or representing the colour of fruits (Mendoza et al., 2006; Arzate-Vázquez et al., 2011; Lang and Hübert, 2012).

In most cases, it is necessary to obtain comparable measurements of the colour by using colour indices, which combine the colour coordinates in one single ratio easier to be understood and handled by operators (Quevedo et al., 2013; Cavazza et al., 2013; Cárdenas-Pérez, et al., 2017). The CCI is estimated using a ratio whose definition is based on

HunterLab colour coordinates and the colour of application ranges from green to orange. This index determines the need of degreening treatments and the commercial maturity stage, two important issues, that differ and depend on the variety (Lado et al., 2014).

However, a common vision system needs an external acquisition device (the camera) and the image processing software, that is normally implemented to be run on a computer, which prevents to obtain the data instantaneously or to be used in the field, and it is clearly less practical than the traditional portable texture set of cards or colorimeters. An alternative is the implementation of the computer vision system in a mobile device like a smartphone. Currently, a smartphone is a relatively inexpensive hand-held computer with very high processing capability. In addition, the integration of built-in high resolution sensors and cameras in these devices makes them practical solutions for many tasks in agriculture and farming. For example, research has been recently conducted on mobile devices to calculate solar radiation parameters (Molina-Martínez et al., 2011), real-time livestock monitoring (Hwang et al., 2013) or prediction of oil palm content (Pamornnak et al., 2015).

The capability to acquire and process images allows these devices to be used to obtain objective and accurate information on the tasks that have traditionally been based on the experience of trained workers. For instance, Intaravanne et al. (2012) used the built-in camera of a smartphone to capture images of bananas and estimate their ripeness depending on the measurement of the colour. In the work developed by Gómez-Robledo et al. (2013), it is presented an application to evaluate the soil colour implementing a Munsell soil-colour model. This application used the built-in camera inside a controlled lighting chamber to capture and store the images that are later processed. Gong et al. (2013) presented an android-based application with the aim of predicting the yield of citrus orchards by first acquiring and storing the images and later processing them. The colour information captured by mobile devices was used to study the structure of coffee branches and determine the number of fruits by Ramos et al., (2017) and Avendano et al., (2017).

A summary of the works that use smartphone-based sensors in agriculture is presented by Pongnumkul et al. (2015). In this review they report that works that use the built-in smartphone cameras take pictures or videos which are later sent and stored as a whole on servers or on the cloud for future reference or further inspection sending back the results to the mobile-phone, or take pictures or videos to be image-processed further in the very device. They also state that it is necessary to endow these applications with highly intuitive interfaces, concluding that many applications still do not concern this aspect.

As we can see from the works mentioned above, the user needs to capture and to store the images first, and then has to start the app developed to analyse them (in the smartphone or in an external server), since the apps do not work with the live input of the camera, that is, do not work on-line. The approach presented in here offers a simple and intuitive user interface and provides a portable, handy and economical innovation for the estimation of the CCI, working as a real on-line vision system, providing real-time results and allowing the user avoiding the management of the stored images since the analysis has been performed on the live camera input.

It has been tested using different configurations of the camera and under different environmental conditions, especially outdoors where the image processing is always more complex due the changing lighting conditions (Sabzi et al., 2017; Sengupta and Lee, 2014). The results were obtained for each device and condition in relation to the colour measured by a calibrated image acquisition system and compared with the performance of a panel of workers who evaluated the colour using the traditional methods, in order to determine whether this kind of devices can be potentially accurately used when working both in a packinghouse or outdoors under natural conditions, thus being a helpful tool to the grower for crop and commercialisation management.

2. Materials and Methods

The algorithms of colour estimation have been implemented for Android mobile devices using the open-source BSD-licensed library OpenCV (https://en.wikipedia.org/wiki/BSD_licenses), the open software development kit (SDK) for Android (http://developer.android.com/sdk/terms.html), and the programming environment Eclipse (http://www.eclipse.org/org/documents/epl-v10.php) using Java language. Android is the most widespread operating system for mobile devices (Puder and Antebi, 2013) and permits to use and program open-code using a free license. Two sets of devices were used, the first one (Table 1) was composed of four devices (2 phones and 2 tablets) that were used to carry out the preliminary tests of the app during the development in the season 2014/15, and the second set was composed of seven smartphones with different hardware characteristics (Table 2) and was used to for the final test and validation of the app in real operating conditions during the next season (2015/16).

Table 1. Devices used to develop and calibrate the app

Device type	Tablet	Tablet	Smartphone	Smartphone
Model	Samsung Tab 2 (GT-P5110)	Ampe A78 Dual Core	Samsung S III (GT-I9300)	Samsung S III Mini (GT-I8190)
Android version	4.0.3	4.2.2	4.1.2	4.1.2
Display	10.1”	7”	4.8”	4”
Resolution display	1280 x 800	1024 x 600	720 x 1280	480 x 800
Built-in camera	3 MP	2 MP	CMOS 8 MP	CMOS 5 MP
CPU*	ARM Cortex-A (2 x 1 Ghz)	RK3066 (2 x 1.6 Ghz)	ARM Cortex-A9 MPcore (4 x 1.4 Ghz)	ARM Cortex-A9 (2 x 1 Ghz)
GPU**	PowerVR SGX540	ARM Mali-400 MP	ARM Mali-400	ARM Mali-400

**Central Processing Unit*
***Graphics Processing Unit*

Table 2. Smartphones used to validate the app

Device number	1	2	3	4	5	6	7
Model	BQ Aquaris M5	Cubot S200	LG Optimus L4 (Tri E470)	LG Nexus 5	Samsung S3	Samsung S3 Mini (GT-I8190)	Sony Xperia P
Android version	5.1.1	4.2.2	4.1.2	6.0.1	4.3	4.1.2	4.1.2
Display	5"	5"	3,8"	5"	4,8"	4”	4"
Resolution display	1080x1920	720 x 1280	320 x 480	1080x1920	720 x 1280	480 x 800	540 x 960
Built-in camera	CMOS 13 MP	CMOS 12.78 MP	CMOS 3.15 MP	CMOS 8 MP	CMOS 8 MP	CMOS 5 MP	CMOS 8 MP
CPU*	Snapdragon 615 Octa Core (8 x 1.5 Ghz)	ARM Cortex-A7 (4 x 1.3 Ghz)	ARM Cortex-A9 (1 x 1 Ghz)	Snapdragon 800 Quad Core (4 x 2.3 Ghz)	ARM Cortex-A9 Mpcore (4 x 1.4 Ghz)	ARM Cortex-A9 (2 x 1 Ghz)	ARM Cortex-A9 (2 x 1 Ghz)
GPU**	Adreno 405 550 MHz	ARM Mali-400 500 MHz	PowerVR SGX531	Adreno 330 550 MHz	ARM Mali-400 500 MHz	ARM Mali-400 500 MHz	ARM Mali-400 500 MHz

**Central Processing Unit*
***Graphics Processing Unit*

3. Description of the application

The interface is developed to facilitate the operation of colour measurement by the grower. When the application runs, the device display is configured in landscape mode with two well-differentiated zones: the left part being to capture the images and display the results; and the right area of the screen to configure the app (Fig. 2). To facilitate the colour measurement in all conditions, the app can operate in two modes, by comparison with a colour reference card or of colour estimation by real-time image processing.

The first method contains the preview of the standard coloured texture cards (Fig. 1) for visual comparison with the sample. Two sets of cards can be selected for oranges and mandarins. When it is active, the texture card corresponding to the selected texture preview is superimposed to the image zone and the obtained CCI is given by the indicative value of the card (Fig. 2b). This method simply substitutes the current physical colour cards by virtual cards thus facilitating the opportunity of taking measurements with the advantage of recording the results. However, as the number of cards is limited, the method presents limitations and the colour of the sample must be approached to the most similar card, which has a lack of accuracy. Alternatively, in the second method, the app estimates the colour of the sample in real-time presenting the measurement of the colour using the CCI and also different colour coordinates (if selected).

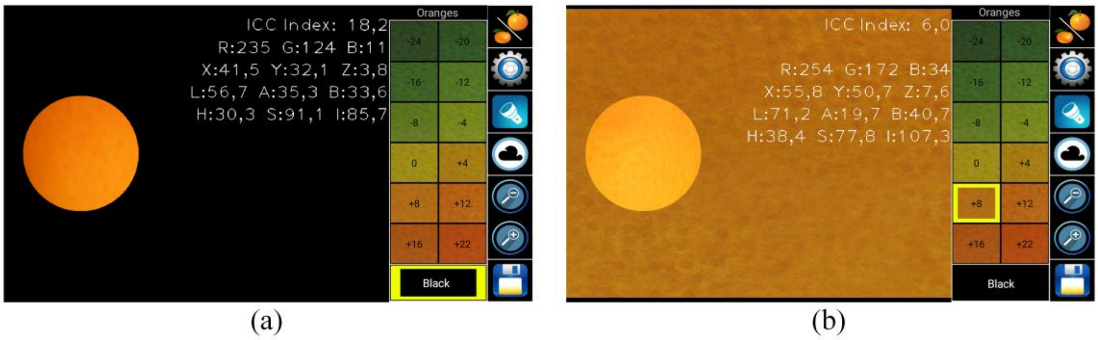


Figure 2. Interface of the application: (**a**) Information from image analysis is available; and (**b**) Set of coloured textures active for alternative visual comparison

The camera is the key device feature in this application but, depending on the model, the characteristics of the optics, the sensor, and their configuration and performance can vary. An important feature to properly measure the colour is the white balance (WB) that is the process of removing unrealistic colour casts, so that objects which appear white to the human eye are rendered white in the photo. Proper camera WB has to take into account the colour temperature of the light source. By default, the auto mode for the WB is set. However, depending of the illumination of the scene it is possible to choose other particular WB modes to obtain accurate CCI measurements. In addition, the lantern can be turned on to capture the images if necessary. Other settings allow setting the size of the measuring spot or the estimated colour information of the fruit in real-time that will be displayed in the screen while capturing the images.

The application shows a circular mask area as region of interest (ROI) in which the colour data is measured and is located close to the built-in camera position at most devices. Thus, in the case the lantern is activated, the captured scene is properly illuminated. The circular ROI can be enlarged or reduced as desired to obtain accurate measurements depending on the distance to the sample or if the application is used in the field or indoors. If illumination is good, a bigger area can be measured.

Once the application is running, the camera shows the live image inside the ROI, and presents the colour information from the sample in real-time. The process to obtain the CCI in real-time begins with the calculation of the average RGB value from all the pixels of the ROI. Then, this value is converted to XYZ colour coordinates using equations described by Mendoza et al. (2006), and finally XYZ are converted into Hunter Lab values using the equations corresponding to the illuminant D65 and observer 10º described in HunterLab (1996). Once this conversion is performed, the CCI is calculated using equation (1), where *L*, *a*, *b* are the coordinates of the Hunter Lab colour space:

$$\mathrm{CCI} = \frac{1000 \times \mathrm{a}}{\mathrm{L} \times \mathrm{b}} \qquad (1)$$

The CCI could probably be more accurately calculated by averaging the CCI value of each individual pixel but the conversion process for each pixel is time consuming for a real-time process and the results were proved virtually to be the same by Cubero et al. (2014) and Vidal et al. (2013). Apart from the colour index, colour information of the ROI in different colour spaces is also given if they are selected from the preferences menu. The colour spaces provided are RGB, XYZ, CIELAB and HIS (hue, intensity and saturation coordinates). In addition, the information about CCI and other colour spaces can be saved along with the image of the fruit and a screenshot of the device showing all data and configuration. Figure 3 shows the flowchart of the vision-based algorithm of the application developed.

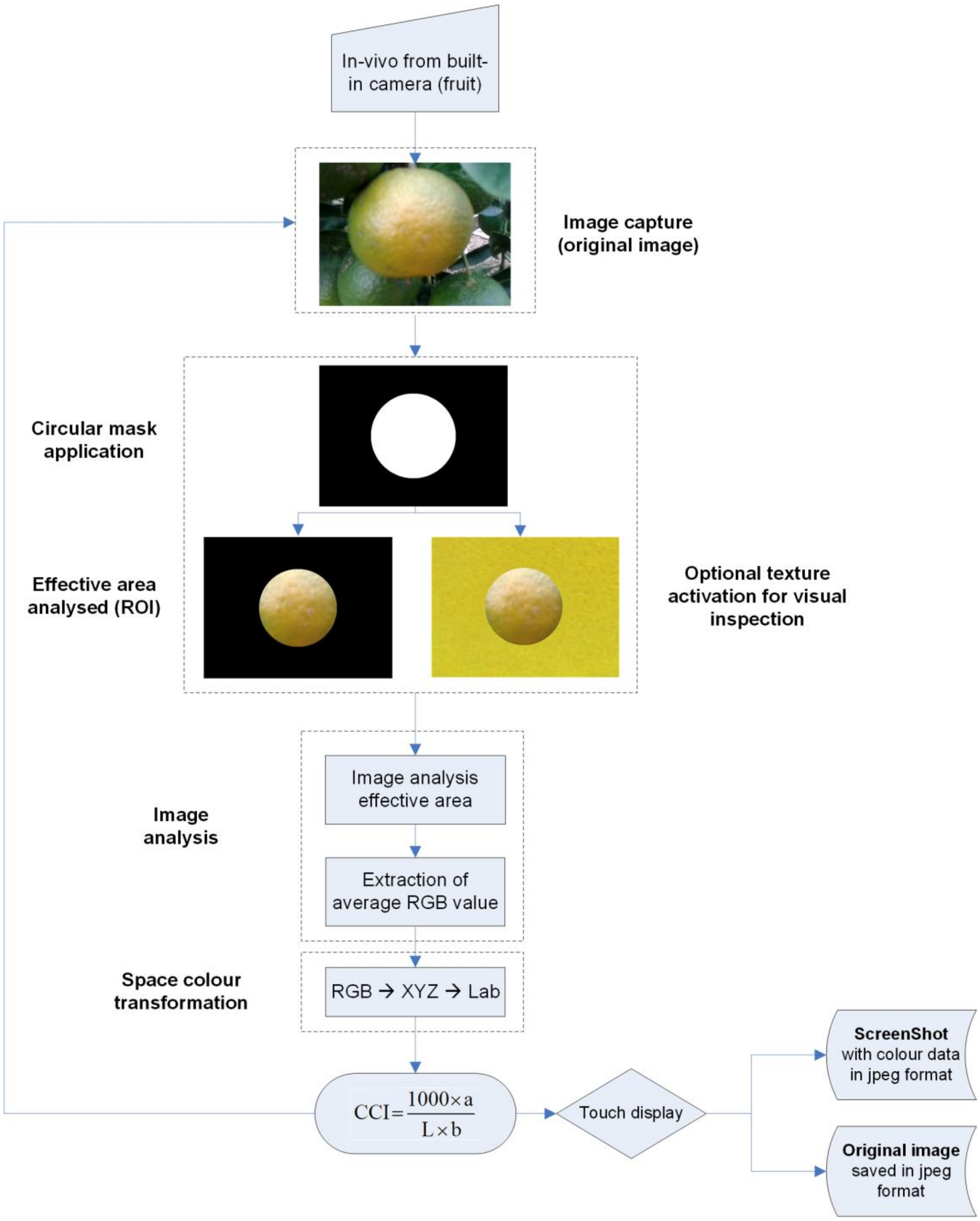


Figure 3. Flowchart of the vision-based algorithm of the mobile application developed

4. Development and calibration

4.1 Fruit used in the experiments

A total of 55 oranges of different varieties (Navel, Bonanza, Cram and Navelina) at different stages of maturity were used for the tests. Fruits were chosen between November 2014 and

March 2015 from experimental parcels at IVIA. The colour of the selected fruits ranged from uniform dark green to uniform orange including yellowish green to greenish orange to cover most of the possibilities that can be found in the field. All measurements were carried out in different sunny days between 11:00 AM and 01:00 PM. Each fruit was labelled and the colour was measured with the four mobile devices under both field conditions (in the tree before harvest) and indoor conditions (collected fruits).

To obtain the reference colour of each fruit, all oranges were photographed using a digital single lens reflex (DLSR) camera (EOS 550D, Canon Inc, Japan) used to acquire high quality images with a size of 3456 x 2304 pixels and a resolution of 0.03 mm/pixel. This reference images were taken by placing each sample inside an inspection chamber containing the camera and the lighting system. The camera was placed at a distance of 20 cm from the samples. Illumination was achieved using four lamps that contained two fluorescent tubes each (Biolux L18W/965, 6500 K, Osram AG, Germany). The angle between the axis of the lens and the sources of illumination was of approximately 45º since the diffuse reflection responsible for the colour occurs at 45º from the incident light. However, the samples have a curved shape that can still produce bright spots affecting the colour measurements. In order to minimise the impact of these specular reflections, cross polarisation was used by placing polarising filters in front of the lamps and in the camera lenses. The fluorescent tubes were powered using high frequency electronic ballast to avoid the flickering effect of the alternate current and produce a more stable light. The application EOS utility (Canon Inc, Japan) was used to capture the images of each fruit. This software allows tuning all the camera parameters like the ISO, shutter speed or resolution as well as capturing the images without handling the camera. A colour calibration was performed to the images obtained with this camera using a standardised colour chart (ColorChecker SG Chart, X-Rite Inc, USA). The colours of the patches in the colour chart were correlated with those provided by the maker achieving a determination coefficient R^2 higher than 99.9 %.

In addition, a semi-trained panel composed of nine experts measured later the colour of the fruits visually using the standard colour cards. Figure 4 shows representative samples of the colour of the fruit used in all the experiments.

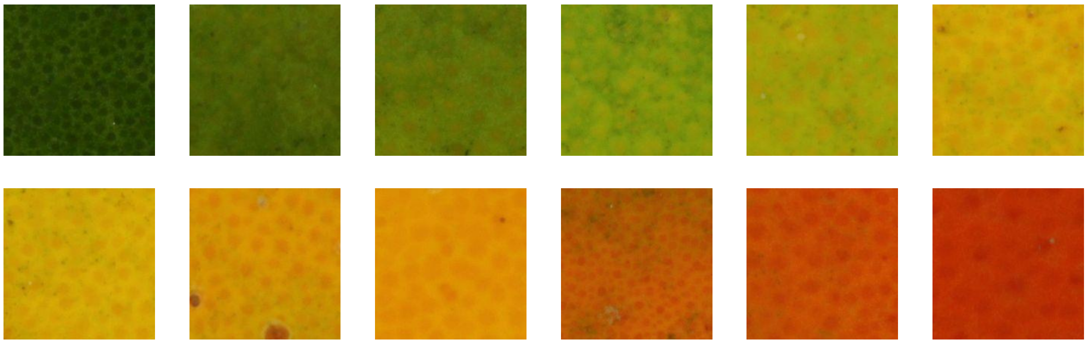


Figure 4. Representative samples of the colour of the fruit used for the experiments

4.2 Description of the tests

In order to achieve the previous stated objectives, several tests were carried out:

1. The CCI of each fruit was measured using all four mobile devices in the field, with the fruits in the trees before harvesting (Fig. 5a). This is important to know the performance of the application when working in field conditions to be used as a tool to aid in the decision of the harvesting moment. The CCI was estimated using different WB modes such as auto, cloudy, fluorescent, and with the flash activated.
2. Later, each fruit was harvested and labelled and its CCI was measured in the laboratory with all four mobile devices under controlled illumination using the same WB options than in the field (Fig. 5b).
3. The colour of all fruits was later measured using the reference DLSR camera. Four measurements were acquired; two in the equatorial part, one near the stem-end and another near the blossom-end. The RGB colour coordinates of the fruit were converted to Hunter Lab values following the same algorithm developed for the app.
4. Finally, the CCI of each fruit was estimated by the semi-trained panel of nine workers (inspectors) who annotated their judgement using the traditional current standard texture colour cards.

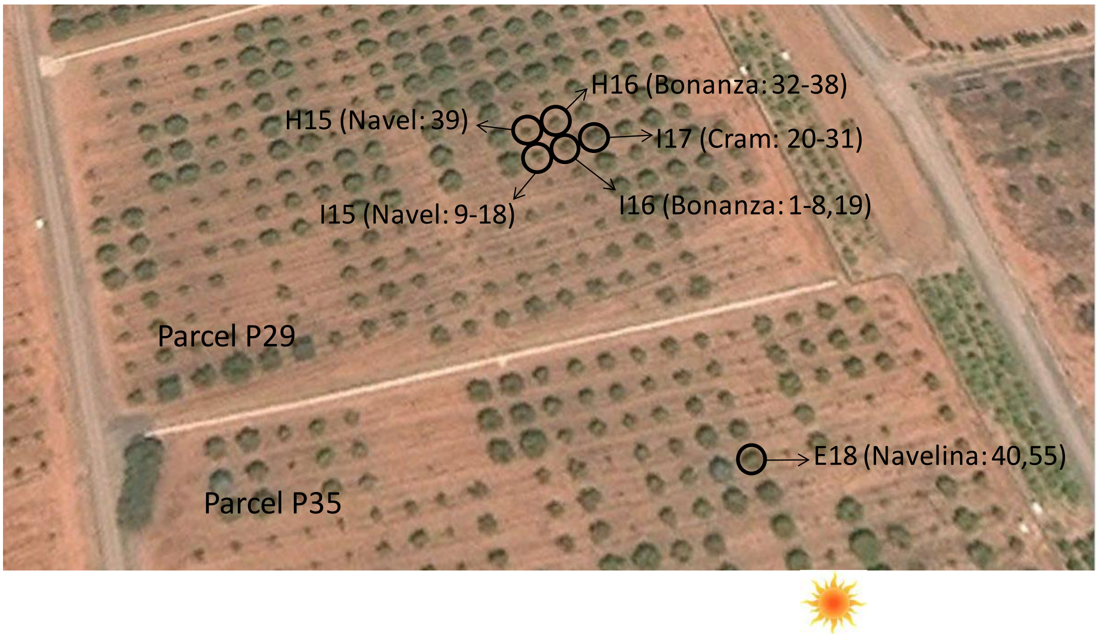
(a) (b)

Figure 5. Different test conditions: (**a**) under field conditions; and (**b**) under controlled illumination conditions

Then, for each fruit, the CCI was measured with the mobile devices under field conditions and under laboratory conditions with three different white balance modes, using the DLSR camera and by the semi-trained panel. The CCI values calculated by using the mobile devices in different conditions were compared to those obtained using the reference and the panel. The statistical analysis of data was performed through multiple regression models (Montgomery, 2005) using Statgraphics Centurion (StatPoint Technologies, USA) statistical software. Results achieved during development were used to improve the application and perform the validations tests.

5. Validation

Both, the images captured during development and the results obtained allowed incorporating a number of improvements to make the app more robust and the colour measurement more accurate under different conditions. To validate the app, the tests performed for development were repeated in the field and laboratory in the next season between November 2015 and March 2016 to cover all colour range during the natural maturation process of the fruit. The experiments were the same than those performed for the calibration but using all devices listed in the Table 3. The colour of 230 different oranges was measured with each device in the same trees in the field in different days between 11:00 AM and 01:00 PM under sunny conditions, and indoor simulating the illumination of a packinghouse. In the test performed to calibrate the app, all the images were captured using automatic WB, but to validate the application, the images were captured using different WB modes like AUTO, CLOUDY, FLUORESCENT, and with the FLASH activated. Figure 6 shows the trees selected from the experimental parcels at the IVIA (top image) and the relative position of the fruits in the trees with the position and orientation of each tree regarding the location of the sun (bottom image) in order to cover different conditions regarding the sun location.



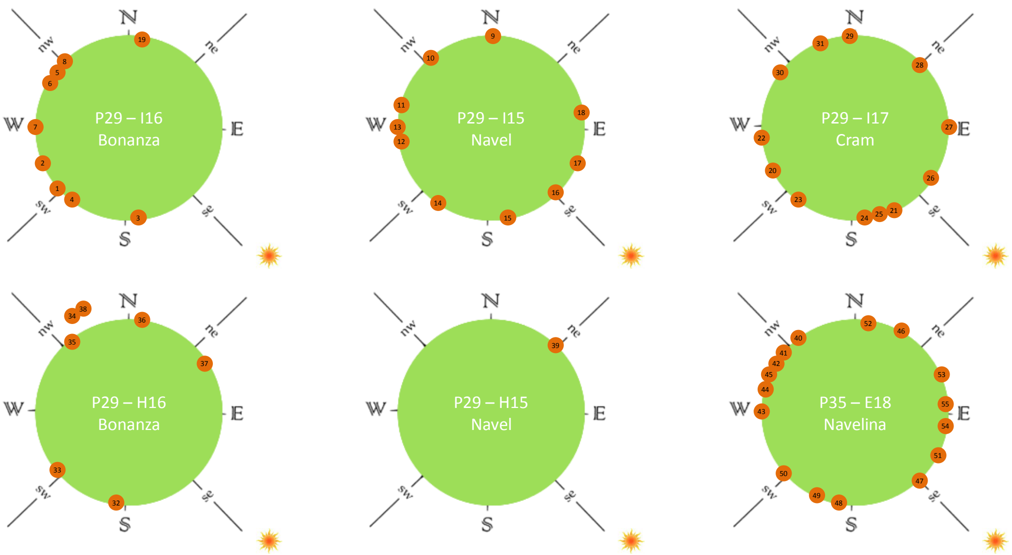


Figure 6. Top image: trees surveyed at the experimental parcels at the IVIA including the position of the sun; and bottom image: location and relative orientation of the fruits in the trees

6. Results and discussion

6.1 Performance under different conditions with all the devices

One way for assessing the reliability of the method proposed when working with different cameras and under different conditions is to compare the value of the coefficient of determination R^2 of the Multiple Regression models between each of the tested built-in cameras (smartphones) and the reference DLSR camera. This coefficient provides the ratio between the models explained variability and the total variability of the data, *i.e.* the proportion (percentage) of the CCI values that can be predicted by the model. This is achieved by computing different regression models, using the CCI values of the reference camera as dependent variables, and the CCI values of the different smartphones as independent variables. In all cases, linear and non-linear terms (up to fourth polynomial) were included in the models, using one or the other depending on the statistical significance (for a Type I risk of 0.05) of the coefficients, in a backward elimination sequential procedure. The R^2 values for the different devices analysed are presented in Table 3, for each device and WB mode tested, and for each of the two conditions (outdoors and indoors). The results achieved by the FLORESCENT WB mode are not presented because in all cases the results achieved were poor. In order to assess for statistical significant differences between devices, environmental conditions and white balance modes, analysis of variance (ANOVA) was carried out on these R^2 values. Table 4 shows the results of the corresponding analysis.

Table 3. R^2 values achieved for the different built-in cameras analysed under outdoors and indoors conditions

	Outdoors			**Indoors**		
Device	**AUTO**	**FLASH**	**CLOUDY**	**AUTO**	**FLASH**	**CLOUDY**
1	0.796	0.854	0.739	0.813	0.831	0.791
2	0.715	0.737	0.585	0.876	0.842	0.728
3	0.684	0.703	0.721	0.881	0.838	0.872
4	0.725	0.795	0.679	0.818	0.834	0.844
5	0.737	0.798	0.232	0.830	0.820	0.401
6	0.708	0.766	0.278	0.774	0.753	0.484

7	0.723	0.698	0.697	0.806	0.743	0.715

Table 4. ANOVA of the R^2 values achieved for the different built-in cameras analysed

Source	**Sum of Squares**	**Df***	**Mean Square**	***F-ratio***	***P-value***
Main effects					
A: Device	1845.520	6	307.586	28.65	0.0000
B: Environment	880.551	1	880.551	82.01	0.0000
C: WB mode	2272.650	2	1136.330	105.83	0.0000
Interactions					
AB	218.408	6	36.401	3.39	0.0341
AC	3001.250	12	250.105	23.29	0.0000
BC	131.895	2	65.947	6.14	0.0146
Residuals	128.843	12	10.737		
Total (corrected)	8479.120	41			

**Degrees of freedom*

From these results, the most relevant findings are that when the app is used indoors R^2 values are higher and it performs better than in the field, which is quite expected since the illumination conditions are more stable for the former condition. However, interaction effects appear between the device, the environments and the white balance mode, which means that they are interconnected, and that different conclusions can be drawn depending on, i.e., the environment where the pictures are obtained.

Figures 7 and 8 show the different interaction plots, which are afterwards analysed to derive the most relevant achievements. From these figures, it can be seen (Fig. 7) that, although the measurements taken under indoors environment present higher R^2 values, these differences are reduced when working with the flash activated. Actually, within the outdoors conditions, it can be seen that mode FLASH presents statistically significant differences with mode AUTO, probably because this way, the colours are homogenised, the light directly coming from the sun is attenuated and the shadows are cleared. On the contrary, in the indoor conditions these differences cannot be stated. Finally, CLOUDY mode obtained poorer results, especially in the field, which can be explained by the existing sun conditions when the images were taken. It should be noted that CLOUDY mode was selected because, under indoor conditions, it seemed to be better visually matching the colors of oranges than with other modes, which in the light of the results obtained was clearly incorrect.

Analysing each device independently, from Table 3, it can be seen that device 1 (BQ Aquaris M5) shows the best results when working in the field, especially when the flash is activated, equivalent to those obtained under well-controlled indoors conditions. When the fruit was inspected under conditions similar to those found in a commercial packinghouse, the results were better, performing best the device 3 (LG Optimus L4). However, no large differences were found among the first four devices. In this case, the best results were achieved using the auto WB, except in some cases so the recommendation is to set this mode on. Comparison between conditions and devices can be seen in the interaction plots shown in Figures 7 and 8.

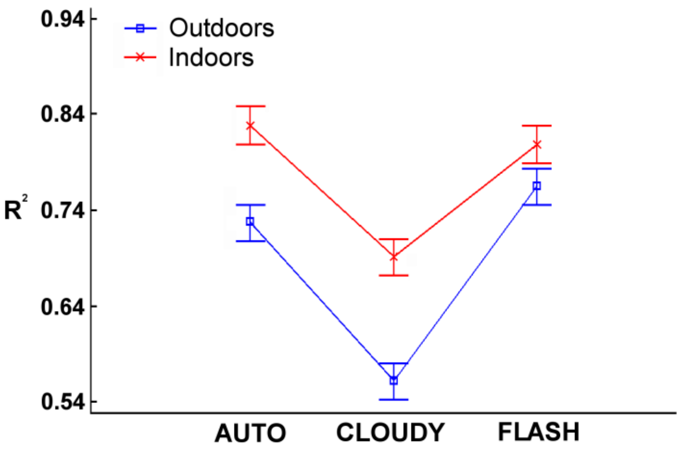


Figure 7. Interaction plot for the WB mode and the two environmental conditions

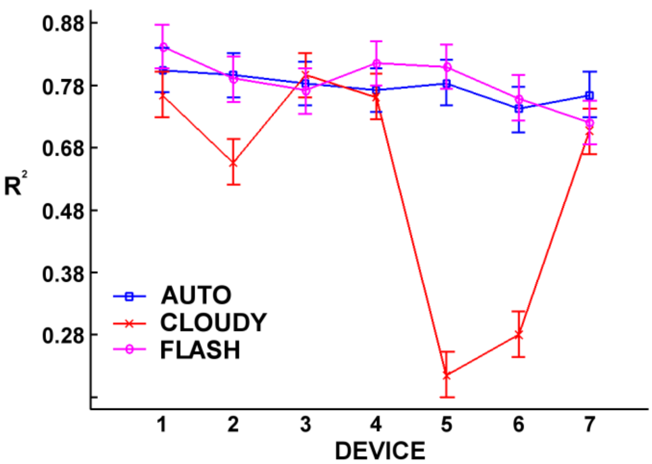


Figure 8. Interaction plot for the Device and WB mode

Summarising, when the app is used in the field to estimate the colour of the oranges in the trees, device 1 shows the best performance. Actually, no statistical significant differences appear between the different modes used although for illustration purposes the mode with the flash activated is depicted in Figures 9 and 10, showing the relation between the values predicted with the device and the reference camera, both in the field (Fig. 9) and indoors (Fig. 10).

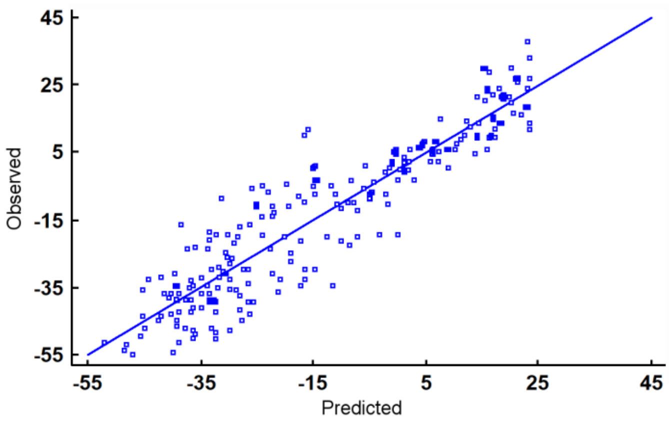


Figure 9. Observed vs predicted CCI values for Device 1 and FLASH mode in outdoors conditions (R^2 value 0.854)

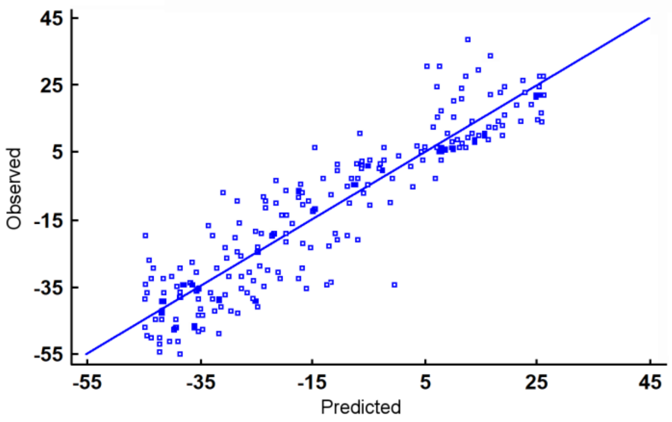


Figure 10. Observed vs predicted CCI values for Device 1 and FLASH mode in indoors conditions (R^2 value 0.831)

These results give confidence on the ability of the built-in cameras of smartphones to reproduce the CCI values obtained with a reference camera, taking into account the huge variability and heterogeneity of the colours of the citrus fruits, especially when they are turning from green to orange, and when CCI values of the reference camera were obtained under well-controlled laboratory conditions.

Since FLASH mode shows the most robust results (i.e. the ones with minor statistical differences in their means for all devices, no matter if the camera is working outdoors or indoors), the following analyses were carried out using this WB mode.

6.2 Comparison to human performance

The current method to evaluate the colour of the citrus before or at harvest is based on the subjective estimation of workers by comparison with printed colour patterns. In order to compare the CCI values estimated by different workers to those computed by the mobile devices, the same dataset was also analysed by nine experts. ANOVA was carried out to compare the results of all devices (R^2) with this new application configured to use the FLASH WB mode in both indoors and outdoors conditions.

6.2.1 Comparison of the human performance with all devices in outdoors conditions

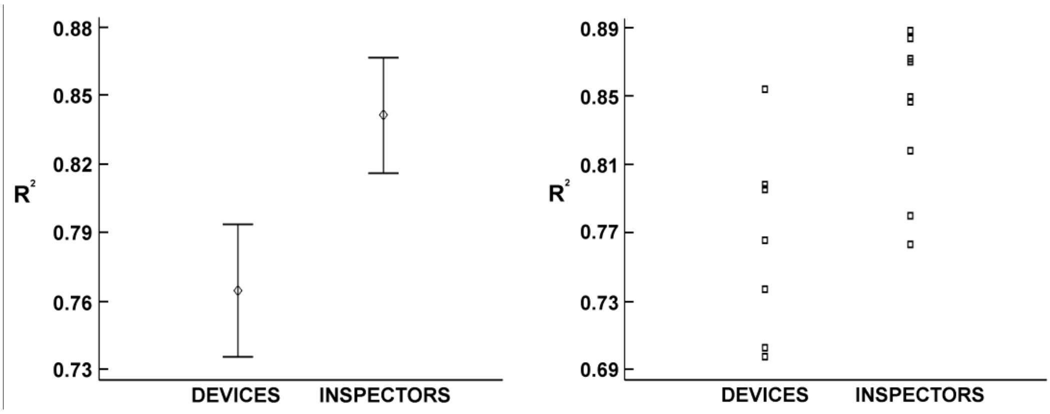
Table 5 presents the ANOVA table, and Figure 11a the least significant difference (LSD) comparison between the devices working outdoors and the human inspection. It can be seen how the inspectors provide a better relation with the reference camera, i.e. higher R^2 values, with a high statistical significance (very low *p-value*).

Table 5. ANOVA table for R^2 values achieved for the two types of judges analysed: Devices vs Inspectors, outdoors conditions.

Source	**Sum of Squares**	**Df***	**Mean Square**	***F-ratio***	***P-value***
Judge	231.648	1	231.648	9.12	0.0092
Residuals	355.787	14	25.4134		
Total (Corrected)	587.436	15			

**Degrees of freedom*

Nevertheless, when inspecting the Scatter plot in Figure 11b, it can also be seen how the R^2 values from both the devices and the inspectors overlap considerably. Furthermore, the estimation performed by the inspectors was carried out under well illuminated indoors conditions, while the image measurements were taken under changing natural conditions with the sun illuminating the fruits from different positions, so a fair comparison between them would be that in indoors.



(a) (b)

Figure 11. Comparison between the devices working outdoors and the human inspection. (**a**) LSD plot for judge; and (**b**) Scatter plot for judge (Devices vs. Inspectors)

6.2.2 Comparison of the human performance with all devices in indoors conditions

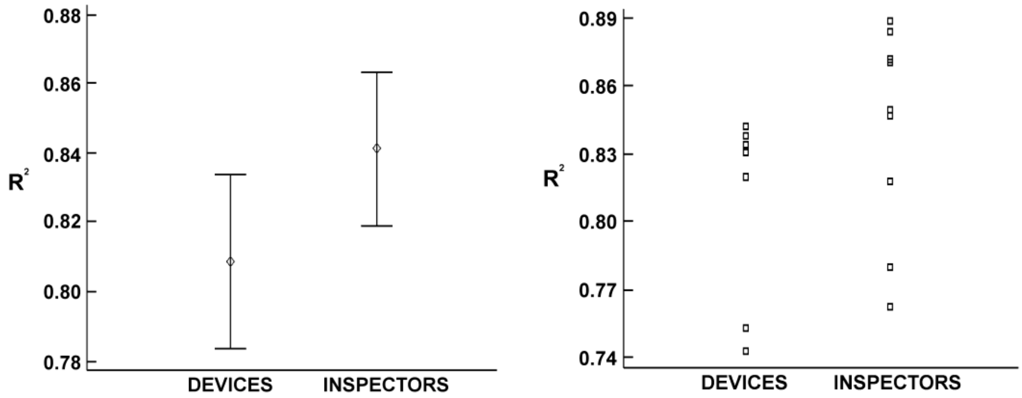
When repeating the analysis for the indoors conditions, no statistical significant differences can be assessed between devices and inspectors, as the p-value in Table 6 is higher that the alpha or Type I risk used (5 %), defined as the risk of rejecting the Null hypothesis when in fact it is true. This can be also derived from the fact that the two LSD intervals in Fig. 12a overlap.

Table 6. ANOVA table for R^2 values achieved for the two types of judges analysed: Devices vs Inspectors, for indoors conditions

Source	**Sum of Squares**	**Df***	**Mean Square**	***F-ratio***	***P-value***
Judge	41.9971	1	41.9971	2.16	0.1634
Residuals	271.641	14	19.4029		
Total (Corrected)	313.638	15			

**Degrees of freedom*

Finally, when taking a look at the scatter plot in Fig. 12b, it is possible to see the high degree of overlapping between judges, so in the end it is possible to say that, when working in the same conditions, if there is no interaction between judges and environmental conditions (indoors or outdoors), both types of estimations are equivalent.



(a) (b)

Figure 12. Comparison between the devices working indoors and the human inspection. (**a**) LSD plot for judge; and (**b**) Scatter plot for judge (Devices vs. Inspectors)

This agricultural app presents certain benefits. It represents a clear advance on the current visual methods since it introduces objectivity in the colour estimation and substitutes the current dated colour cards, which are limited to a few number of discrete CCI values compared to our developed tool capable of obtaining more accurate continuous values. Other clear advantages are, for instance, the possibility of saving the images for later checking, the creation of historical reports, the immediate availability for the grower and potential integration with other tools, and besides its low cost, portability and availability of mobile technology, being intuitive even for non-specialised personnel. On the other hand, high amount of possible natural conditions reduces the performance of the app when it is used in the field, making necessary more research to analyse and discard nonsense colours, bright spots and discriminate between illuminating conditions to make appropriate colour corrections that are expected in further versions. In summary, the results are acceptable in comparison with the method currently used in the industry or by the growers, representing a clear advance over the current state of the art, since it eliminates the subjectivity but more research improvements are needed to the image segmentation and CCI estimation reach human performance.

6 Conclusions

A real portable computer vision system that allows measuring the colour index of citrus fruits automatically, while the fruit is being harvested or under any other process, has been developed to work with built-in smartphone cameras and successfully tested. The main advantages are the universal availability of such systems, the portability of this sort of technology and the simplicity of use of the app, allowing estimating the colour condition of the fruit (citrus) in the field by means of a real vision system and thus the amount of degreening processes needed.

The system developed has been implemented on the Android operating system and requires a minimal interaction of the user, providing a live image of the fruit while it is being inspected. This is a key feature, since no smartphone-based application developed provides this feature, thus allowing any non-expert user to get use to this application easily.

The development of the app was done during one season and it was validated in the next season with different fruit. Three validations were done, the first and second one to compare the CCI values from the mobile devices operating under natural (outdoors) and controlled (indoors) conditions respectively, to those obtained by the reference camera. The measurements in the field are negatively influenced most probably by the changing illumination conditions, and this fact lowers the correlation to the reference. The third has compared CCI values from the mobile devices to those estimated by an expert panel using the colour cards under the same controlled conditions. R^2 values of 0.854 and 0.881 were obtained for outdoors and indoors conditions although the results were influenced by the quality of the mobile device. The obtained results are promising and demonstrate the feasibility of a smartphone integrated computer vision system to inspect the colour of citrus fruits in real time in outdoor conditions while the fruit is being harvested, which is a valuable step forward for this industrial sector.

Acknowledgements

This work was partially funded by INIA and FEDER funds through research project RTA2015-00078-00-00.

References

Arzate-Vázquez, I., Chanona-Pérez, J.J., Perea-Flores, M.J., Calderón-Domínguez, G., Moreno-Armendáriz, M.A., Calvo, H., Godoy-Calderón, S., Quevedo, R., Gutiérrez-López, G. (2011) Image processing applied to classification of avocado variety Hass (*Persea americana* Mill.) during the ripening process. Food and Bioprocess Technology, 4, 1307-1313

Avendano, J. Ramos, P.J. Prieto, F.A. (2017) A system for classifying vegetative structures on coffee branches based on videos recorded in the field by a mobile device. Expert Systems with Applications, 88, 178-192

Campbell, B.L., Nelson, R.G., Ebel, C.E., Dozier, W.A., Adrian, J.L., Hockema, B.R. (2004) Fruit quality characteristics that affect consumer preferences for satsuma mandarins. HortScience, 39, 1664-1669

Cárdenas-Pérez, S., Chanona-Pérez, J., Méndez-Méndez, J.V., Calderón-Domínguez, G., López-Santiago, R., Perea-Flores, M.J., Arzate-Vázquez I. (2017) Evaluation of the ripening stages of apple (Golden Delicious) by means of computer vision system. Biosystems Engineering, 159, 46-58

Cavazza, A., Corradini, C., Rinaldi, M., Salvadeo, P., Borromei, C., Massini, R. (2013) Evaluation of pasta thermal treatment by determination of carbohydrates, furosine, and color indices. Food and Bioprocess Technology. 6, 2721-2731

Cubero, S., Aleixos, N., Albert, F., Torregrosa, A., Ortiz, C., García-Navarrete, O., Blasco J. (2014) Optimised computer vision system for automatic pre-grading of citrus fruit in the field using a mobile platform. Precision Agriculture, 15, 80-94

Cubero, S., Aleixos, N., Moltó, E., Gómez-Sanchis, J., Blasco, J. (2011) Advances in machine vision applications for automatic inspection and quality evaluation of fruits and vegetables. Food and Bioprocess Technology, 4, 487-504

DOGV (2006) Diari Oficial de la Comunitat Valenciana, 5346, 30321-30328

Gardner, J.L. (2007) Comparison of calibration methods for tristimulus colorimeters. Journal of Research of the National Institute of Standards and Technology, 112, 129-138

Gómez-Robledo, L., López-Ruiz, N., Melgosa, M., Palma, A.J., Capitán-Vallvey, L.F., Sánchez-Marañón, M. (2013) Using the mobile phone as Munsell soil-colour sensor: An experiment under controlled illumination conditions. Computers and Electronics in Agriculture, 99, 200–208

Gong, A., Yu, J., He, Y., Qiu, Z. (2013) Citrus yield estimation based on images processed by an Android mobile phone. Biosystems Engineering, 115, 162-170

HunterLab. 1996. Applications note, Hunter Lab Color Scale. https://support.hunterlab.com/hc/en-us/article_attachments/201440625/an08_96a2.pdf. Accessed October 2017.

Hwang, J., Jeong, H., Yoe, H. (2013) A study on the real-time livestock monitoring system using mobile platform. International Journal of Smart Home, 7, 137-144.

Intaravanne, Y., Sumriddetchkajorn, S., Nukeaw, J. (2012). Cell phone-based two dimensional spectral analysis for banana ripeness estimation. Sensors and Actuators B: Chemical, 168, 390-394

Jiménez-Cuesta, M.J., Cuquerella J., Martínez-Jávega, J.M. (1981) Determination of a color index for citrus fruit degreening. In Proc. of the International Society of Citriculture, 2, 750-753.

Lado, J., Rodrigo, M.J., Zacarías, L. (2014). Maturity indicators and citrus fruit quality. Stewart Postharvest Review, 14, 2:2

Lang, C., Hübert, T. (2012) A colour ripeness indicator for apples. Food and Bioprocess Technology, 5, 3244-3249

Lorente, D., Aleixos, N., Gómez-Sanchis, J., Cubero, S., García-Navarrete, O.L., Blasco, J. (2012) Recent advances and applications of hyperspectral imaging for fruit and vegetable quality assessment. Food and Bioprocess Technology, 5, 1121-1142

Mendoza, F., Dejmek, P., Aguilera, J.M. (2006) Calibrated color measurements of agricultural foods using image analysis. Postharvest Biology and Technology, 41, 285-295

Molina-Martínez, J. M., Jiménez, M., Ruiz-Canales, A., Fernández-Pacheco, D. G. (2011). RaGPS: A software application for determining extraterrestrial radiation in mobile devices with GPS. Computers and Electronics in Agriculture, 78, 116-481

Montgomery, D. C. Design and analysis of experiments, 6th ed. Tempe: Wiley, 2005

Pamornnak, B., Limsiroratana, S., Chongcheawchamnan, M. (2015) Oil content determination scheme of postharvest oil palm for mobile devices. Biosystems Engineering, 134, 8-19

Pongnumkul, S., Chaovalit, P. and Surasvadi, N. (2015) Applications of Smartphone-Based Sensors in Agriculture: A Systematic Review of Research. Journal of Sensors, 2015, Article ID 195308, 18 pages.

Porat, R. (2008) Degreening of citrus fruits Tree Forest Science and Biotechnology, 2, 71-76

Puder, A., Antebi, O. (2013) Cross-compiling Android applications to iOS and Windows Phone 7. Mobile Netw. Appl., 18, 3–21

Quevedo, R., Valencia, E., Alvarado, F., Ronceros, B., Bastias, J.M. (2013) Comparison of whiteness index vs. fractal Fourier in the determination of bloom chocolate using image analysis. Food and Bioprocess Technology, 6, 1878-1884

Ramos, P.J, Prieto, F.A., Montoya, E.C., Oliveros, C.E. (2017) Automatic fruit count on coffee branches using computer vision, Computers and Electronics in Agriculture, 137, 9-22

Sabzi, S., Abbaspour-Gilandeh, Y., Javadikia, H. (2017) Machine vision system for the automatic segmentation of plants under different lighting conditions. Biosystems Engineering, 161, 157-173

Sengupta, S., Lee, W. S. (2014) Identification and determination of the number of immature green citrus fruit in a canopy under different ambient light conditions. Biosystems Engineering, Special Issue: Image Analysis in Agriculture, 117, 51-61

Vidal, A., Talens, P., Prats-Montalbán, J. M., Cubero, S., Albert, F., Blasco, J. (2013) In-Line Estimation of the Standard Colour Index of Citrus Fruits Using a Computer Vision System Developed For a Mobile Platform. Food and Bioprocess Technology, 6, 3412-3419