Development of a computer vision system to estimate the colour indices of Kinnow mandarins

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Abstract Maturity of a citrus fruit is generally expressed by a numerical value called citrus colour index (CCI). The success of methods employed in estimating the maturity depends on the cultivar and climatic conditions of growing regions. In this work, an image processing based method using CIELAB color model has been developed to estimate the CCI of Kinnow mandarin fruits. A polynomial transformation based camera characterization method was employed to reduce the number of transformations required for RGB to $L^*a^*b^*$ colour space transformation, which resulted into a colour difference of 2.191 with CIELAB ΔE^* 2000 colour difference formula. In order to analyse the performance of this method, linear regression and partial least square (PLS) models were built on a dataset of 271 Kinnow fruit images wherein spectrophotometer was used for the validation of computed CCI values. The proposed method achieved a high adjusted R^2 value of 0.9660 using PLS regression, which ascertain the feasibility of image processing based system in estimating the maturity of

Kinnow fruits. Additionally, a correlation analysis between colour coordinates and physicochemical properties was conducted to analyze the relation between the fruit's external peel colour and its internal characteristics.

Keywords Computer vision system · Citrus colour index · Colour characterization · Colour difference · Physicochemical parameters · Kinnow mandarins

Introduction

Kinnow mandarin (*Citrus reticulata Blanco*), hybrid variety of (*King* × *Willow leaf*) is a major harvested citrus fruit across north India. Every cultivar of citrus varies from one another in many aspects such as colour, texture, taste, harvesting time, nutritional value, etc. The shelf life of a mandarin fruit depends on the maturity level of fruit during harvesting time. Kinnow fruits are non-climacteric in nature and their ripening process takes place only before the harvest. Various studies on physicochemical properties of fruits i.e. total soluble solids (TSS), titratable acidity (TA), firmness (F), pH and colour parameters reveal the detailed ripening process and post-harvest handling of a particular cultivar. TSS/acid ratio is known worldwide as a commercial indicator of internal maturity of citrus fruits (Lado et al. 2014).

Maturity evaluation based on colour information is ideal when there is a strong correlation between the internal maturity and external peel colour of fruit. The skin colour of Kinnow mandarin at commercial stage is normally deep orange/reddish. Colorimeters and spectrophotometers express colour as numerical coordinates. However, they are capable to measure only a small field of view and work best

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on objects which have homogeneous colours (Vidal et al. 2013).

Recently, image processing and computer vision systems (CVS) have achieved greater success in evaluating the quality of fruits and vegetables. Various colour spaces are used to create, visualize and represent colours in two or three-dimensional space. The $L^*a^*b^*$ or CIELAB is the most popular colour space as it is perceptually uniform and device independent colour model (León et al. 2006).

Many applications are developed recently to explore the feasibility of CVS in evaluating colour of food products. A novel fruit recognition method based on biogeography-based optimization (BBO) and feedforward neural network (FNN) was developed by Zhang et al. (2016). This method achieved an overall accuracy of 89.11% by using colour, texture and shape features. Zhang et al. (2017) designed an image based fruit category classification method using 13-layer convolution neural network (CNN) to classify fruits into 18 categories. They achieved an overall classification accuracy of 94.94% by adopting three data augmentation techniques. An 8-layer deep convolutional neural network was implemented by utilizing parametric rectified linear unit to classify 18 categories of fruits. The developed algorithm was able to achieve an overall accuracy of 95.67% (Wang and Chen 2018).

For citrus fruit maturity estimation, a mobile platform consisting of computer vision system to pre-sort the fruits during harvesting was developed by Vidal et al. (2013). The system was successful in obtaining a reliable R^2 of 0.925 working in real time field conditions. A mobile equipment capable of estimating maturity index and size of citrus fruits was developed by Cubero et al. (2014). A prediction model built with quadratic regression achieved a reliable $R^2 = 0.993$ for size and $R^2 = 0.918$ for colour index.

Estimation of harvesting period, based on just ‘time’ information may fail due to varying climatic conditions. Moreover, the usage of chemical agents can slow down or accelerate the ripening process. Currently, the maturity index of Kinnow fruit is calculated by visual inspection of experts. The current state-of-the-art shows, there is lack of quantitative indicator to standardize the stages of Kinnow ripening. Therefore, it is essential to establish an indicator that reflects the real ripening stage while grading and packing.

Materials and methods

Samples collection

The Kinnow fruit samples were collected from an orchid based in Abohar, Punjab, India during the last week of every month starting from October until December 2016. Each group of samples contained around 90 fruits, making the total sample size to 271. The colour of collected fruits ranged from homogeneous deep green to typical deep orange/red colour. Necessary care was taken to include all the variability in terms of colour, texture and size during the sample collection.

Image acquisition

In order to achieve uniform lighting and avoid bright spots found on the acquired fruit images, a precise image acquisition system was developed according to Gómez-Sanchis et al. (2008), which incorporates two components: CanonEOS 1300D CMOS colour camera and an image acquisition chamber. The fruits were placed on a uniform black background and their distance from camera was 15 cms. Detailed specifications of the camera and description of the image acquisition chamber is provided in section A1 of Online Resource 1.

Image segmentation

Chroma keying technique, which replaces a specific colour element (Chroma) with a newly estimated colour values (Malone 2010), was used to segment the fruit portion from the acquired images. In our experiments, it was observed that average blue component (B) values of the acquired images were considerably low as compared to the average of red (R) and green (G) components. Hence, the blue component (B) was chosen to identify the background mask.

$$blueness = B - \max(R, G) \quad (1)$$

Based on histogram analysis, a threshold was selected to create a binary mask. Subsequently this estimated blueness of image (mask) was applied on fruit images to set the background pixel values to ‘zero’ using the following equation:

$$mask = blueness < threshold \quad (2)$$

Pixels, whose intensity values lesser than the threshold were considered as background pixels.

Camera characterization

RGB values acquired by typical digital cameras are device and illumination dependent. Conversion from RGB to an independent colour space requires complex transformations. The process of characterization, which reduces the required number of transformations and maps RGB colour to independent colour space such as CIE XYZ, was implemented according to Cheung et al. (2004). Polynomial transformations up to third order were explored. CIE XYZ to $L^*a^*b^*$ transformations were carried out as per (León et al. 2006) by using D65 illuminant and 10° observer.

Colour difference

Human perception of observing the colour difference is defined by the metric ΔE^* . It ranges from 0 to 100 (Schuessler 2014). Currently, CIELAB ΔE^* 2000 is the most accurate colour difference formula. ΔE^* is implemented as per Sharma et al. (2005) and is calculated as:

$$\Delta E_{00}^* = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2} + R_T \frac{\Delta C'}{K_C S_C} \frac{\Delta H'}{K_H S_H} \quad (3)$$

where ΔL^* = difference in brightness/lightness (positive—lighter, negative—darker), Δa^* = difference on red/green axis (positive—red, negative—green), Δb^* = difference on blue/yellow axis (positive—yellow, negative—blue), ΔC^* = difference in chroma values (positive—bright, negative—dull), ΔH^* = difference in hue value, $K_L K_C K_H$ = parametric weighing factors

$$S_L = 1 + \frac{0.015(\bar{L}' - 50)^2}{\sqrt{20 + (\bar{L}' - 50)^2}}, S_C = 1 + 0.045\bar{C}' \text{ and } S_H = 1 + 0.015\bar{C}' T$$

On a pair of colour values L_1^*, a_1^*, b_1^* and L_2^*, a_2^*, b_2^* , colour difference is computed as:

$$\Delta E_{00}(L_1^*, a_1^*, b_1^*, L_2^*, a_2^*, b_2^*) = \Delta E_{00}^{12} = \Delta E_{00}^* \quad (4)$$

Physicochemical properties

After image acquisition, fruits were peeled off and pulp portion was juiced to determine the physicochemical properties. The *pH* of fruit juice was measured by Testo 206 pH2 handheld pHmeter and *TSS* by Bellingham and Stanley RFM840 refractometer at room temperature (25 °C). *TSS* and *pH* of each fruit was measured thrice and

average value was considered for further analysis (Pace et al. 2011). Konica Minolta CM-3600d spectrophotometer was used to measure the rind colour at six random places to cover the whole fruit surface. CIE $L^*a^*b^*$ values were computed using the standard CIE-76 formula. Before measuring the colour, spectrophotometer was calibrated with white ($L^* = 98.97$, $a^* = -0.09$, $b^* = 0.38$) and black ($L^* = 25.12$, $a^* = -0.41$, $b^* = -1.05$) reference tiles. The CCI values obtained from $L^*a^*b^*$ values of spectrophotometer were used as reference to measure the correctness of CCIs produced by CVS (Cubero et al. 2014).

Colour index estimation

Fruits those are harvested early before the actual season may attain an acceptable level of internal maturity and sugar-to-acid ratio before their external surface colour turns into a marketable deep orange/red colour. In citrus degreening, ethylene is used to degrade the existing green-pigmented chloroplasts. Estimating exact amount of ethylene treatment required for degreening process is difficult. Duration of ethylene treatment depends on the initial colour and the variety of fruit (Ladaniya 2008). In order to quantify the surface colour, CCI or maturity index (MI) is used in food processing industries across the world. CCI estimation methods that contain b^* component in the denominator are suitable for tomatoes, citrus or any other fruits which don't contain violet tint (Carreño et al. 1995). Therefore, in this work, two industry standard methods, $CCI = a/b$ (Little 1975) and $CCI = 1000 \times a/L \times b$ (Jimenez-Cuesta et al. 1981), were used for estimating CCI values of Kinnow fruits. Two images of a fruit (opposite sides) were considered to calculate the CCI. Background was removed using chroma keying technique as described in Eqs. (1) and (2). The average RGB values of these two images were calculated independently and mean of these averaged values were used for conversion to CIE XYZ values using the camera characterization process mentioned in “Camera characterization” section.

Statistical analysis

Correlation analysis of physicochemical parameters and analysis of variance (ANOVA) studies were conducted on all 271 Kinnow samples using R programming software (R Development Core Team 2016) with 95% confidence interval. The *pH* of mandarin fruits varies in between 3 to 5 and minimum *TSS* content of a marketable Indian Kinnow is 8 °Bx (Ahmad and Siddiqui 2015). In CIE $L^*a^*b^*$ colour space, coordinate values vary in intervals of $0 \leq L^* \leq 100$, $-120 \leq a^* \leq 120$ and $-120 \leq b^* \leq 120$ (León et al. 2006). The L^* component represents luminosity. Positive values of

parameter a^* indicate red colours while its negative counterpart denote green colours. Similarly, negative values of parameter b^* refer bluish colours and positive values represent yellowish colours. The detailed regression analysis was performed in MATLAB (R2013a; The Mathworks, Inc., Natick, MA, USA), wherein a probability value $p < 0.05$ was considered as statistically significant difference.

Results and discussion

Physicochemical studies

TSS is a practical indicator of fruit's internal maturity (Lado et al. 2014). The average values of *TSS* and *pH* measured were 7.17 ± 0.2 , 10.27 ± 0.2 , 12.42 ± 0.3 and 2.99 ± 0.1 , 3.13 ± 0.1 , 3.23 ± 0.1 respectively for the months of October, November and December. Although, there was considerable rise in *TSS* but no significant increase in *pH* values among the collected fruits. An increasing trend of *TSS* and *pH* since the beginning of season, indicated the continuous rise in sweetness and decline of acidity (Fig. S.2 of Online Resource 1). The 0Bx and *pH* values of Kinnow fruits collected in October were lower than the acceptable standard. Although, the fruits collected in November and December had acceptable *TSS* and *pH* values but presence of green patches on their skin justify the requirement of degreening treatment.

Figure 1 shows an increasing trend of b^* which indicates accumulation of carotenoids as the season progressed. Transformation of negative to positive values of a^* indicate reduction in chlorophyll content (greenness) and increase of carotenoids. Similarly, surge in L^* specify the decrease of total pigments content (Vélez-Rivera et al. 2014). The carotenoid content varies drastically among the cultivars of citrus. Mandarins have highest content of carotenoid. The deep orange/reddish colour of mandarins is mainly due to cryptoxanthin (Goldenberg et al. 2018). The lower L^* , a^* and b^* values obtained by CVS in comparison to spectrophotometer specify lower illumination inside the image acquisition chamber. Camera characterization results obtained by second and third order polynomial transformations were in liaison with spectrophotometer values.

Colour difference studies

Magnitude of difference in $L^*a^*b^*$ values obtained by spectrophotometer and CVS indicates the effectiveness of the developed system. Smaller is the difference, higher is the reliability of the developed system. For the linear transformations, mean and maximum colour differences

(ΔE^*) obtained were 4.2878 and 18.1929 respectively. Whereas, the mean colour difference obtained for second order was 2.191 and for third order transformation was 1.9885, which ascertain the reliability of the developed CVS. Ideal colour representation should have zero ΔE^* . Any value of ΔE^* between 3 and 6 is acceptable in commercial reproduction of colours (DataColor 2011). In this experiment, the obtained mean colour difference for both second and third order transformations was less than 3. However, since third order transformations need higher processing time, second order transformations are preferred for estimating the CCI of Kinnow fruits.

Correlation among physicochemical parameters

Detailed experimental results show that *TSS* had a strong correlation with the colour parameters. Among the colour coordinates, a^* achieved the highest correlation of 0.878 with *TSS* signifies the deviation of greenish to reddish colour with sugar content. The high correlation of 0.952303 among L^* and b^* indicates the phenomena of colour transformation from dark green to light green/light yellow. Similarly, parameters a^* and b^* share a strong correlation of 0.889738 among each other. It was observed that *pH* had the average correlation of 0.454043 with other parameters making it the least significant physicochemical attribute.

Regression and validation analysis

The effectiveness of the proposed CVS was evaluated by developing linear and partial least square regression (PLS) models. The dataset of 271 Kinnow fruits was randomly divided into training set of 180 fruits and test set of 91 fruits. Three models were built by applying linear, second and third order polynomial transformations on $L^*a^*b^*$ values for each CCI method chosen. The root mean squared deviation (RMSE) and standard error (SE) for $CCI = a^*/b^*$ were lower compared to the value obtained with $CCI = 1000 \times a^*/L^* \times b^*$. The *p* values obtained for all models were nearly zero, consolidating the confidence in the obtained results shown in Table 1.

Similarly, ANOVA test was conducted to realise any significant difference between means of CCIs obtained by CVS and spectrophotometer. Table 2 includes the Adjusted R-squared (R_{adj}^2) and cross-validated mean square error (*CvMSE*) values obtained for the developed models.

It was observed that models developed using $CCI = a^*/b^*$ had lower sum of square, *CvMSE* values and higher *F* ratio, R_{adj}^2 values in comparison to $CCI = 1000 \times a^*/L^* \times b^*$, makes it more feasible and reliable method. No significant difference was observed

Fig. 1 Variation of colour coordinates: **a** L^* component **b** a^* component **c** b^* component

between the values of R^2_{adj} obtained with both the employed regression techniques as well as among the second and third order transformations of each technique. As third order polynomial transformations consume high computing time, the model developed using $CCI = a^*/b^*$ with second

order polynomial transformation is more ideal for estimating the CCIs of Kinnow fruits. The high $R^2_{adj} = 0.9660$ achieved using PLS regression model shows the confidence in the developed CVS. However, both colour index

Table 1 Comparison of CCI estimation methods using regression and ANOVA analysis

CCI Estimation Formula	Model	Parameter	Estimate	Standard Error	<i>T</i> statistic	<i>P</i> value	RMSE
$CCI = 1000 \times a/L \times b$	Linear transform	CONSTANT	3.6876	0.090729	40.644	5.3457e–92	1.22
		CVS-CCI	0.030593	0.00084398	36.249	4.2188e–84	
	Second order transform	CONSTANT	– 0.48182	0.10219	– 4.7151	4.8614e–06	0.874
		CVS-CCI	1.0747	0.020522	52.367	4.5069e–110	
	Third order transform	CONSTANT	– 0.43176	0.088742	– 4.8653	2.5048e–06	0.768
		CVS-CCI	1.0623	0.018312	58.012	1.5012e–117	
$CCI = a/b$	Linear transform	CONSTANT	2.5358	0.042666	59.432	2.4973e–119	0.567
		CVS-CCI	0.56101	0.011377	49.311	1.0099e–105	
	Second order transform	CONSTANT	– 0.1883	0.055102	– 3.4173	0.00078379	0.485
		CVS-CCI	1.0381	0.017711	58.616	2.6029e–118	
	Third order transform	CONSTANT	– 0.17039	0.053296	– 3.1969	0.0016438	0.471
		CVS-CCI	1.0373	0.017525	59.19	4.998e–119	

Table 2 Adjusted R-squared and *CvMSE* values obtained for CCI estimation methods

		$CCI = 1000 \times a/L \times b$			$CCI = a/b$		
		Linear	Second order	Third order	Linear	Second order	Third order
Linear regression	R^2_{adj}	0.88	0.939	0.949	0.931	0.951	0.952
	<i>CvMSE</i>	15.1582	0.7919	0.7417	6.535	0.2418	0.2225
PLS regression	R^2_{adj}	0.9150	0.9573	0.9585	0.9478	0.9660	0.9675
	<i>CvMSE</i>	9.6145	0.6854	0.6276	4.871	0.2158	0.1985

methods exhibited high correlation with the external colour development of Kinnow fruits.

Although, peel colour based maturity estimation is followed worldwide but the climatic conditions such as temperature and amount of sun light largely affect the external colour (Ladaniya 2008). The method $CCI = a^*/b^*$ performed better as it is more suitable to fruits which have increasing trend of redness (Little 1975).

Conclusion

Maturity estimation is a complex task as it depends on internal physiological and the external peel color transformations. A computer vision system to estimate the maturity index of Kinnow mandarins was developed. Camera characterization process was carried out using polynomial transformations. In order to estimate the maturity indices, the current industry standard $CCI = 1000 \times a^*/L^* \times b^*$ and $CCI = a^*/b^*$ methods were explored. This study reveals that the model developed using $CCI = a^*/b^*$ with second order polynomial transformation is more ideal for estimating the maturity indices

of Kinnow fruits. Measured physicochemical properties had good correlation with the changing peel colour of the fruits. A high $R^2_{adj} = 0.9660$ achieved with partial least square regression model exhibits confidence in the developed CVS based method.

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