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NIR Computer Vision for Rapid Measurements of Some Physical Properties of Mangoes

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ABSTRACT

Quality assessment through quick sorting and grading of mangoes is today's need, for not only to enhance the post harvest management process but also to minimize the post harvest losses and to recover more economic and nutritional values. Near infrared (NIR) based computer vision (CV) which is very close to human vision was used for rapid measurements of some physical properties of mangoes (*Chausa*, *Dashehari*). Lab View s/w was used to process the image and development of algorithm steps for analysis of the image properties. Fruit's diameters were measured and compared with manual measurements using paired t-test, the 95% limits of agreement (Bland-Altman plot) and both measurements correlated using regression analysis. The results obtained were consistent and the correlations of the mean dimensions between both methods were found to be noticeably high. Coefficient of determination (R^2) for all diameters was found between 0.951 and 0.90. Various fruit's shape attributes important in design of harvest and post harvest equipment were also evaluated using NIR-CV technique. The present research, thus, could be the basis for the development of real time CV systems which would be near to human vision.

KEYWORDS

Assessment, human vision, mango, non-destructive, physical quality

INTRODUCTION

Fresh fruits and vegetables play an important role in sustaining the health of human beings by providing several vitamins, minerals, plant chemicals, fiber, etc. Several researches have proved that the diet with high fruits and vegetables protects from several serious diseases such as cancer, diabetes and heart disease (Patel and Kar, 2012). Mango fruit among them is well known for its luscious, juiciness, taste and flavor along with several medicinal values. Eating mangoes helps in boosting the immune system, lowering cholesterol and prevents many stomach related diseases by improving digestion. In addition, abundant vitamin A (carotene) in mango makes it a perfect fruit to improve eyesight. But the maintaining quality and freshness of mango fruit in the market is cause of concern. The traditional (manual) post harvest operations of mangoes which are very time-consuming delayed the reach of mango fruit in the market and consequently lead to various post harvest losses. Thus, to avoid such post harvest losses and maintain the freshness, real-time sorting and grading are very important to enhance the operation. There are various non destructive, real-time and image processing-based techniques available in the public domain. Most of the image processing techniques are based on image capturing using color cameras. Color cameras are more costly and a bit more time consuming than the NIR, monochrome imaging system. Near-infra-red (NIR) imaging-based commuter vision systems are very similar to human vision but exclude the color wavelengths. Most of the object, after removing the colour wavelength, looks similar to an image that has been converted to the black and white. In addition, NIR imaging system has very good sensitivity, high contrast in many difficult illumination situations, low cost in comparison to CCD cameras and due to special spectral characteristics, imaging with NIR camera has high quality (Patel *et al.* 2012a, b). Further, NIR imaging system has potential to collect spectra more than 80,000 per minute by using suitable s/w and by using strong statistical analysis tools pertinent information can be extracted from the resulting data. There are various applications of infrared imaging in the food industry, for instance, the investigation of properties of foodstuffs (such as firmness, soluble solids, acidity, etc.) and identification of foreign bodies in food products. Many physiological properties of food produce are highly correlated to the IR signals. The image analysis of thermograms is suitable for quality evaluation and shelf life study of fruits and vegetables. NIR imaging, therefore, offers a potential alternative technology for nondestructive applications (Patel *et al.*, 2012b).

Similarly, a near-infrared imaging system for determination of rice moisture was developed by Lin *et al.* (2006) and reported that the performance of NIR imaging system was almost the same as that of NIRS (near-infrared spectrometry). McClure (1987) determined moisture content in rice using the NIR system. Therefore, NIR imaging systems can be used for prediction of various properties and also for detecting the defects, etc. But, the main drawback of NIR imaging system is it's need for frequent calibration as it is very sensitive to moisture content in samples (McClure, 1987). Jirsa *et al.* (2007) investigated bakery characteristics of wheat dough and its final product by using the NIR imaging techniques and reported that the potential of NIR imaging technique can be used in the prediction of the protein

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content and zeleny sedimentation, also. The NIR imaging, thus, an indirect method, can also be applied in arable crops to detect and to locate the insect. However, it is unable to detect the low levels of infestation in the bulk samples between live and dead insects (Dowell *et al.* 1999). Ridgway and Chambers (1998) captured NIR images of infested wheat samples by NIR Videocon camera and detected insects using a comparison method. Davies *et al.* (2003) have also checked the potential of NIR imaging for detecting and locating the insects in cereal grain. In their study they have suggested a method of line segment detection with a minimum computation. Similarly, Schmilovitch *et al.* (2000) have applied NIR imaging in the appropriate spectral range to assess the selected physiological properties of mangoes cv. Tommy Atkins. Non-destructive techniques based on the NIR system, thus, can be applied for the measurement of food properties in very short times without sample preparation and can be implemented successfully throughout the food industry. Estimation of more than one quality parameters at the same time is the main advantage of using this technique (Lammertyn *et al.* 1998). Considering above facts, the main objective of computer vision (CV) based on near infrared (NIR) imaging, very close to human vision without color wavelength, was used in this research for measurement of some physical properties of mangoes.

MATERIALS AND METHODS

Chausa and *Dashehari*, the two commercial varieties of mango fruit were chosen on the basis of production and peel color more susceptible to image processing. The 60 ripe fruits were procured from the corresponding orchards selected on the basis of nearness to the laboratory (to avoid delay in transportation) and flowering amounts, and brought to the laboratory. First, length (L), breadth/width (W) and thickness (T) were evaluated using vernier calipers (least count: 0.01 mm; model no CD-6" CSX, Mitutoyo-Japan). Second, the six images (four by rotating 90^0, one from top and one from bottom) of fruits were acquired in a visible lighting regime using NIR camera after manual measurements. Complete information about NIR computer vision (NIR CV) has been depicted below.

Description of NIR computer vision system

An imaging (computer vision) system (Fig. 1) fabricated in the Division of Post-Harvest Technology, Indian Agricultural Research Institute, New Delhi (India) was used for this current research. This system is designed in such a way that the four cameras (visible color, visible monochrome, NIR and UV) can be attached and detached one by one and any camera among these can be used as per need. In this work NIR camera and visible lighting regime was applied and controlled with the nine fluorescent bulbs (50 watts, 220 Volts) fitted in cylindrically (Patel 2019 a, b, c). Constant electricity/voltage supply was maintained using the electronic ballasts and UPS (uninterrupted power supply) system (Fig. 1). The camera, which is placed at the top of the illumination chamber, acquires the image of the manually placed real mango fruit. The video signal is sent from the camera to the industrial computer, which is equipped with a frame grabber that captures the image. All images were stored in computer hardware memory in TIF (tag image file) format. The computer obtains the position of the centre of the detected objects and this information is used to process the element. The reported system, thus, is a combination of an illumination chamber, NIR camera, visible light, frame grabber, image processing and analysis s/w and computer h/w.

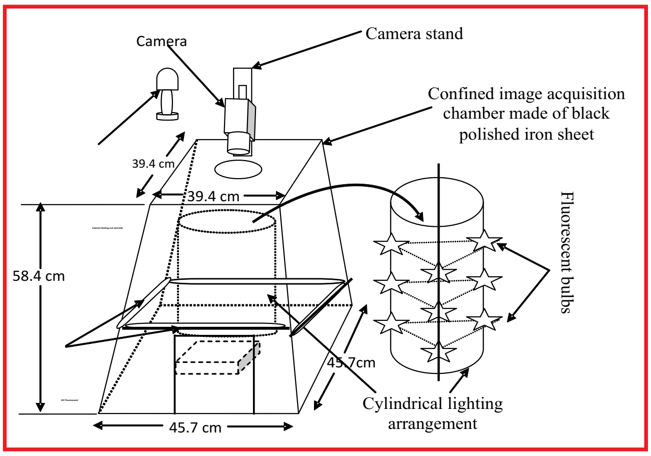


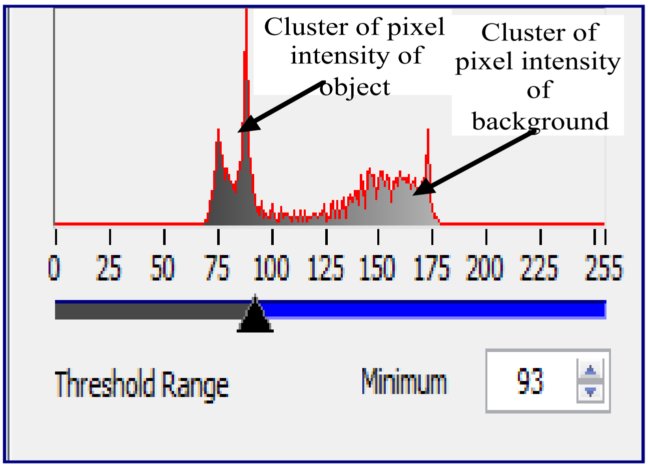
Fig. 1 : Schematic diagram of computer vision system Patel *et al.* (2019 a, b, c)

Computer features (H/W and S/W)

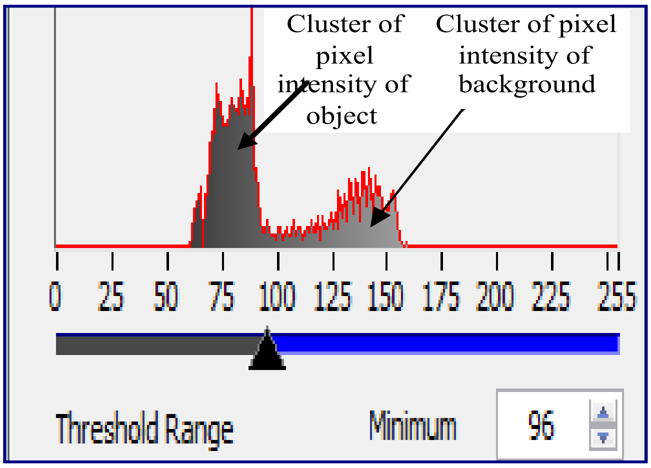
An industrial computer (PC type) was used in this research with an LED (light emitting device) screen for desk mounting. The NIR camera (Model: NIR-300GE; Made: Vosskohler GmbH, Germany) with resolution (320x 256 pixels), connected/interfaced through the Gigabit Ethernet port on the PC via Cat5e Ethernet cable, placed and fastened manually at the camera stand at the top of the illumination chamber at about 200 mm from the top of the fruit. Images of the manually placed real mango fruit on the sample holding platform were acquired stored in computer memory. The distance between the NIR camera and bottom/floor of the illumination chamber was 59 cm. IMAQ Vision that is a library of LabVIEW (National Instrument product, Austin, TX) software (version 10.0) was used for the image processing and analysis in this research work.

Processing of images

For the processing of NIR images of *Chausa* and *Dashehari* fruits algorithms (Fig. 2b) were developed. Initially, the images were sub-sampled to the size of 99×81 (for *Chausa*) and 81×58 (for *Dashehari*) pixel (m×n) to save the computational time. The sub sampled images were browsed and selected and brightness was enhanced applying values of brightness, contrast and gamma as 66, 45.50° and 0.41, respectively to make the image of both fruits clearer. To find out the exact color plane with the highest contrast level between object and background, histograms were developed before and after brightness enhancement. The histograms of intensity color of hue, intensity and saturation (HIS) color plane were developed and found to be suitable to use for thresholding of objects from the background (Fig. 2a).



(a) Chausa Fruits



(b) Dashehari Fruits

Fig 2a: Histogram displays threshold value of manual threshold set up looking for bright objects (i.e. fruit)

However, the proper bimodal histogram, however, was hard to obtain for all fruit's images (Fig. 2a). Dark objects (back ground) were looked at and the bright object (fore ground i.e. fruit) was separated from the background using manual threshold operation by adjusting maximum threshold range as 96 for *Chausa* cultivar and 93 for *Dashehari* cultivars (Fig. 2b). The Figure 2b displaces all operations of image processing and analysis used in the algorithms.

Particle analysis

Ten morphological features (area, perimeter, compactness, elongation, hydraulic radius, Heywood circularity, Max Feret and Waddell disc diameter, and type factor) of mangoes were calculated using particle analysis technique (in IMAQ vision s/w). By studying these attributes, the morphology of the outline and shape of the biological object was attempted to describe (Table 1). Except area, all attributes were evaluated considering image at 0^0 postures). However, for the total surface area (real world: mm^2), the area obtained from the image acquired at the 0^0 and 180^0 orientations/postures were only considered.

Table 1: Description of some shape attribute of mangoes evaluated non-destructively NIC (2000), Patel *et al.* (2019c)

Parameters	Description
Area	Number of pixels within the boundary of object.
Perimeter	The sum of the pixels that form the boundary of the sample. .
Max Feret Diameter (MFD)	The greatest distance possible between any two points along the boundary of the sample.
Waddell Disc Diameter (WDD)	The diameter of the disk with the same area as the particle. $$WDD = \frac{2\sqrt{Particle\ area}}{\sqrt{\pi}} \quad (6)$$
Elongation Factor	The ratio of the longest segment within an object to the mean length of the perpendicular segments. $$Elongation\ \ factor = \frac{Max\ \text{int}ercept}{Mean\ \ perpendicular\ \text{int}ercept} \quad (7)$$
Compactness Factor	The ratio of an object area to the area of the smallest rectangle containing the object. $$Campactness\ \ factor = \frac{Particle\ area}{Breadth \times width} \quad (8)$$
Heywood Circularit Factor	The ratio of an object perimeter to the perimeter of the circle with the same area. $$\frac{Particle Perimeter}{Perimeter of circle with same area as particle} = \frac{Particle Perimeter}{2\sqrt{\pi \times Particle\ \ Area}} \quad (9)$$
Type Factor	It is a complex factor relating the surface area to the moment of inertia. $$Type\ \ factor = \frac{(Particle\ area)^2}{4\pi\sqrt{I_{xx} \times I_{yy}}} \quad (10)$$ Where, I_{xx} and I_{yy} are moment of inertia with respect to gravity.

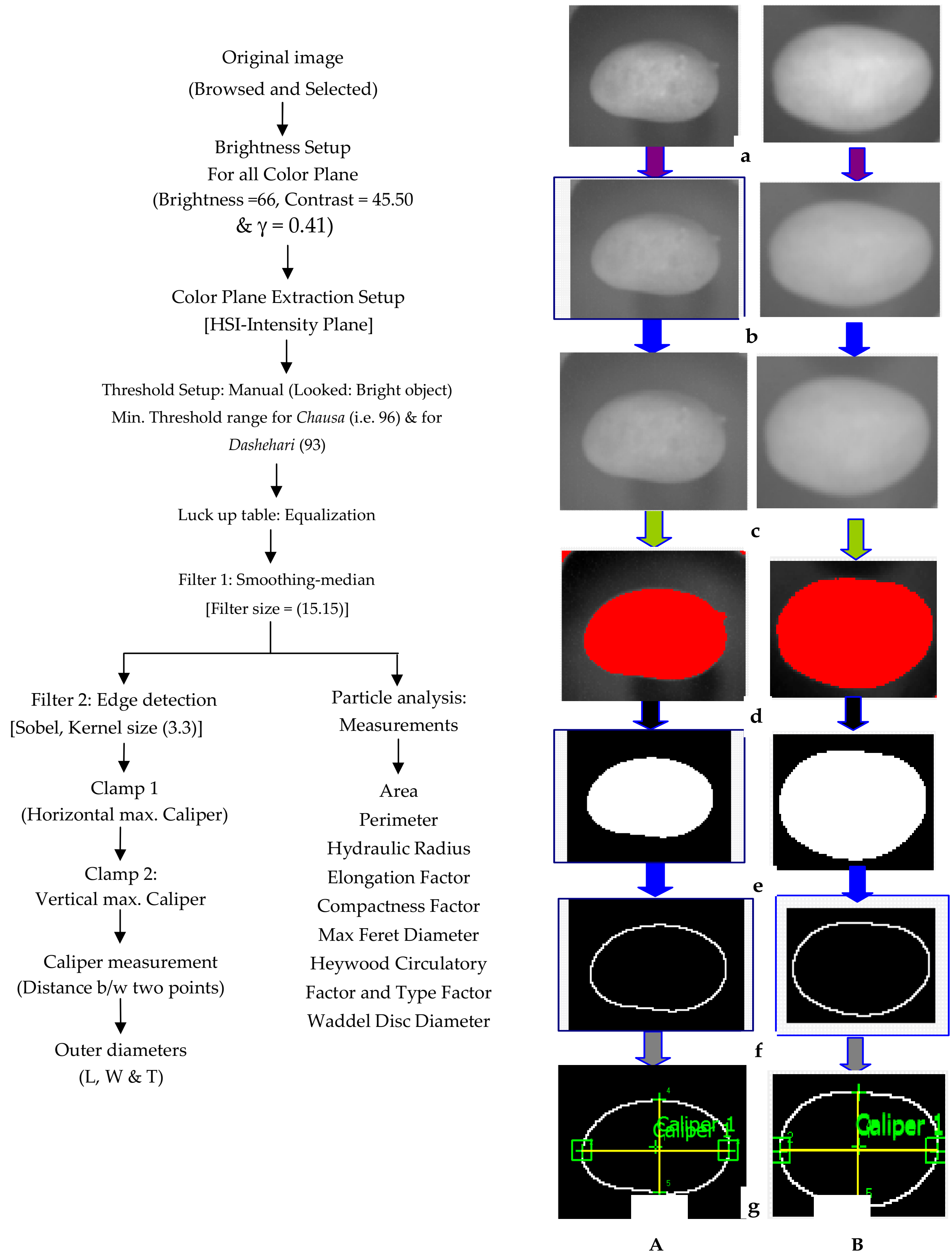


Fig. 2b: Flow diagram of algorithm for dimension and particle measurements of *Chausa* (A) and *Dashehari* (B) fruits using NIR CVS (a) Original NIR image, (b) image after brightness enhancement, (c) image after HSI-Intensity Plane extraction, (d) image after threshold, (e) filtered image, (f) the outline of image, and (g) image with length and breadth measurements.

Statistical analysis and calibration

Measurements of all properties were triplicated. Maximum, minimum, coefficient of variation (CV), etc. were obtained using Microsoft Excel (2003) software. Paired t-test and the mean difference confidence interval approach were used to compare outer IP diameters (L, W and T) of fruits obtained from NIRCVS with the actual diameters measured by DVC. The paired t-test was used for testing whether the difference between two measurements was significant or not. The important feature of this test is its ability to compare the measurements within each subject. Finally, the Bland-Altman approach was used to plot the agreement between the calculated and measured fruit dimensions (Bland and Altman, 1999). The statistical analysis, paired t-test and Bland-Altman plot, were all performed using Medcalc software (USA/Germany). For scale factor and camera calibration a rectangle wooden shape was taken. The image of this shape was captured using NIR camera considering all conditions (lighting, camera height, etc.) similar as during the image acquisition of mango fruit. To calculate the scale factor, the numbers of pixels in area (sq.cm) and length/or perimeter (m) of rectangle shape were counted. The scale factor was obtained after rationing the measured (pixels) and real area (sq.cm). The scale factors (k) for length, width and thickness of fruits of both cultivars were the same as 0.80. Similar validation methods were also employed by previous researchers such as Pauly and Shankar (2015), etc.

RESULTS AND DISCUSSION

Outer Diameters (L, W & T) of Mango's

The first effort was made for measuring the outer diameters of each fruit using image processing (IP) and calipers (manual) techniques. The descriptive statistics of the measurements displayed in Table 2. Lengths of fruits of *Chausa* and *Dashehari* cultivars computed with IP technique were found to be varied between 80.40 mm and 107.94 mm, and 75.27 mm and 114.78 mm along with the standard deviation 6.43 mm and 9.85 mm, respectively. The *Dashehari* fruits were investigated as the shortest as well as the longest fruit. Similarly, from the Table 2, the statistics of fruit's width and thickness measurements revealed that the *Dashehari* fruits were less bulky in shape than *Chausa*. In addition, very high sample variation was recorded among the IP length of *Dashehari* fruits. In contrast, the sample variation in IP width of *Dashehari* fruits was recorded lowest among the diameters. The lower and higher boundaries of measurements by IP (NIRCV system) and digital vernier calipers (DVC; manual) methods along with the average value were clearly presented in the Table 2. A complete comparison between the results obtained from both methods is discussed

Table 2 : Summary of disruptive statistics of external diameters of mangoes measured by NIR computer vision and manual method

Dimensions (mm)	Descriptive statistics					
	Mean	Standard error	Standard Deviation	Sample variation	Minimum	Maximum
			Chausa cultivar			
Measured by Image Processing						
Length	95.78	0.90	6.43	41.37	80.40	107.94
Breadth	56.43	0.52	3.68	13.52	47.73	52.54
Thickness	48.70	0.60	3.74	18.33	33.27	57.69
Measured by Vernier Calipers (manual)						
Length	100.02	0.94	6.70	44.91	85.80	113.92
Breadth	58.90	0.55	3.92	15.34	50.52	64.98
Thickness	50.64	0.64	4.59	21.06	33.59	58.69
			Dashehari cultivar			
Measured by Image Processing						
Length	97.54	1.31	9.85	60.03	75.27	114.78
Breadth	55.89	0.45	2.45	6.01	51.29	60.96
Thickness	50.73	0.39	2.96	8.75	45.69	55.70
Measured by Vernier Calipers (manual)						
Length	102.63	1.03	7.78	60.19	85.46	120.01
Breadth	57.66	0.47	2.55	6.51	51.87	63.95
Thickness	52.83	0.42	3.14	9.84	47.27	60.13

NIR computer vision vs. caliper (manual)

Results from NIR-CV/IP (Near Infrared-Computer Vision/ image Processing) were compared and verified with the results obtained in manual (i.e. DVC) measurement in this step. The results were correlated and displayed in Fig. 3 (a, d), (b, e) and (c, f) for length, width (breadth) and thickness of mangoes (*Chausa*, *Dashehari*), respectively. For *Chausa*, the coefficients of determination for fruit's length, width and thickness were determined as 0.951, 0.909 and 0.910 while for *Dashehari* fruits, these coefficients were found to be as 0.944, 0.904 and 0.897, respectively. The coefficient of determination, thus, obtained for both cultivars were found to be lower than 1 or nearly 1, which indicates

about 100 % fit of data, might be due to the flat shape (with two round surface) of mangoes. This round shape might have caused a difference in angle of placement on the fruit holder and thus difference in measurement. Similar findings have also been reported by Kilic *et al.* (2007) for the classification of beans using a computer vision system equipped with color (CCD) cameras. Paired t-test, the second comparison, was conducted between predicted (IP/NIR-CV) and actual (DVC) outer dimensions (L, W, T). Both methods were found statistically significant ($P<0.05$) and the obtained P-values were recorded less than 0.01 for both cultivars. The differences between two methods are not likely due to change and are probably due to the IV manipulation.

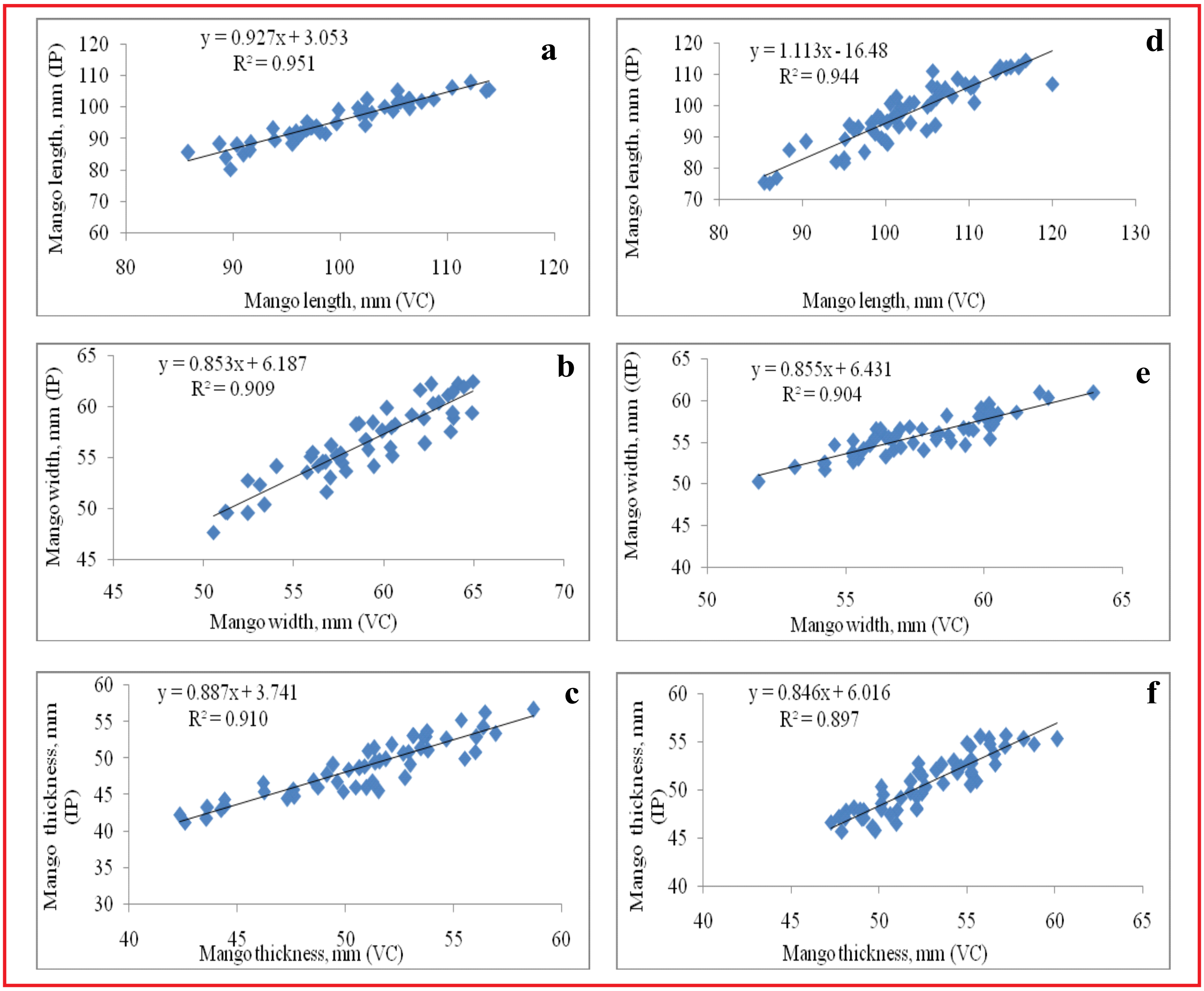


Fig. 3: Comparison of computed and measured outer dimensions (L, W, T) of *Chausa* (a, b, c) and *Dashehari* (d, e, f) fruits with image processing: IP (NIR-CV) and digital vernier calipers (DVC).

The significant difference between image analysis and the manual (caliper) method, thus, might be caused by the poor reproducibility of the latter. Nevertheless, the results obtained were consistent and the correlations of the mean dimensions between both methods were noticeably high. The mean difference between length (L), width (W) and thickness (T) measured by both methods are displayed in Table 3 along with standard deviation, standard error of difference and 95 % CI for the mean difference. The mean difference between outer dimensions (L, W, T) measured by calipers and IP methods for *Dashehari* cultivar were 4.82, 1.92 and 2.09 and for *Chausa* cultivar these were 4.17, 2.46 and 1.96, respectively.

Further, the Bland-Altman plot (Bland and Altman, 1986, 1999, 2007) known as difference plot, the third comparison was also conducted for compression of the results between the digital caliper and image processing methods are shown in Fig 4. The 95% limits of agreement [(0.10; 8.30), (-0.70; 5.70) and (-1.30; 5.30) for *Chausa* and (-1.40; 11.0), (-0.20; 4.00) and (-0.60; 4.80)] for *Dashehari* cultivar] contain 95% (3/51) of the difference scores. The mean difference (bias) of the measurements [length (a, d), width (b, e), and thickness (c, f)] of the fruits (*Chausa*, *Dashehari*) between IP and DVC methods were (4.2, 4.8), (2.5, 1.9) and (2.0, 2.1) mm, respectively. From these results, it can be stated that mango fruit's outer dimensions have affected significantly on the accuracy of

Table 3: Paired t-test analysis between vernier calipers and NIR CV technique used measurement methods of external diameters of mangoes

Dimension	Paired t-test	R^2	Standard Deviation (mm)	Mean difference (mm)	Std error of difference	95% CI for the mean difference (mm)	95% limits of Agreement (mm)
***Chausa* cultivar**							
Length	0.00	0.951	2.0777	4.1778	0.2909	3.59 : 4.76	0.10 : 8.30
Breadth	0.00	0.909	1.6375	2.4682	0.2293	2.01 : 2.93	-0.70 : 5.70
Thickness	0.00	0.910	1.6900	1.9659	0.2366	1.49 : 2.44	-1.30 : 5.30
***Dashehari* cultivar**							
Length	0.00	0.944	3.1551	4.8270	0.4179	3.99 : 5.66	-1.40 : 11.0
Breadth	0.00	0.904	1.0610	1.9276	0.1405	1.65 : 2.21	-0.20 : 4.00
Thickness	0.00	0.897	1.3927	2.0963	0.1845	2.26 : 2.82	-0.60 : 4.80

estimated dimensions (P<0.001). But, on the basis of consistent result and lower bias both methods can be used interchangeably. In these figures, the outlier indicates the 95% limit of agreement and the centre line shows the average differences.

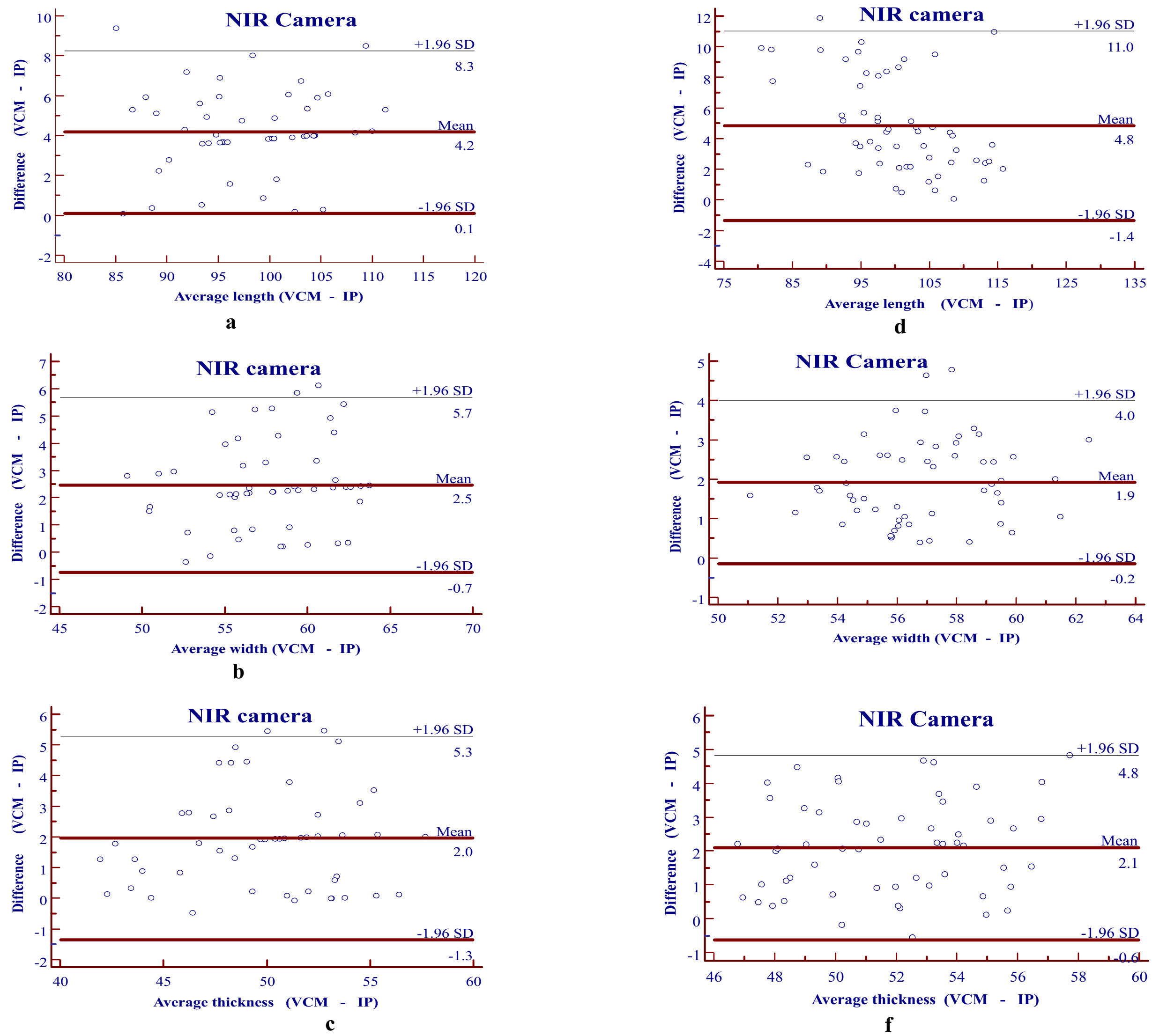


Fig. 4: Bland–Altman plot for the comparison of outer dimensions (L, W, T) of *Chausa* (a, b, c) and *Dashehari* (d, e, f) fruit's computed with IP (NIR-CV) and measured with digital vernier calipers (DVC); outer lines indicate the 95% limits of agreement and center line shows the average difference

Geometrical and shape attributes of mangoes

Various attributes of size/shape are evaluated automatically using LabView image processing s/w. these attributes were evaluated from the profile image of mango fruit acquired by NIR camera. Some attributes related to size/shape of the mango fruit of both cultivars are presented in Table 4. The mean value of fruit's elongation, compactness and type factors are slightly differing between the cultivars and can be used for the differentiation between them. *Dashehari* fruits were noticed longer and also slightly flatter than *Chausa* fruits.

The Heywood circularity factor, however, of the fruits of both cultivars was the same but the coefficient of variation (%) in Heywood circularity factor was different. Higher and lowest variations were noticed in the circularity (7.4 %) and compactness (0.08) factor for *Chausa* fruits. The range of variation (min & max) and standard deviation in shape attributes can also be noted from Table 4. The above results are almost close to the findings reported by Patel *et al.* (2019b) for *Chausa and Dashehari* cultivars using color camera-based computer vision systems. In addition, the other size/shape attributes such as area, perimeter, hydraulic radius, Max Feret's (MF) and Weddle Disk (WD) diameters were also evaluated automatically by NIMAQ software using particle analysis techniques are also presented in Table 4.

Table 4: Mean values, standard deviation (S.D.) and coefficient of variation (C.V.) of some geometric (size/shape) attributes of mangoes analyzed by NIR CVS.

Cultivars	Mean	Minimum	Parameters Maximum	S.D. (±)	C.V. (%)
***Chausa* cultivar**					
Elongation Factor	2.12	1.95	2.82	0.15	7.0
Compactness Factor	0.76	0.52	0.81	0.06	0.08
Heywood Circularity Factor	1.07	1.04	1.43	0.08	7.4
Type Factor	0.97	0.75	0.99	0.05	4.9
Perimeter (mm)	246.33	191.47	302.12	22.05	0.09
Hydraulic radius	17.02	11.68	19.24	1.56	0.09
Max Feret Dia. (MFD)	94.64	73.85	111.31	7.48	0.08
Waddle Disc Dia. (WDD)	72.93	57.83	80.96	4.99	0.07
Area (mm^2)	8392.77	6154.69	10007.81	1089.03	0.13
***Dashehari* cultivar**					
Elongation Factor	2.20	2.05	2.39	0.09	4.0
Compactness Factor	0.77	0.69	0.82	0.03	3.7
Heywood Circularity Factor	1.07	1.05	1.1	0.01	1.1
Type Factor	0.99	0.98	1.0	0.003	0.4
Perimeter (mm)	247.39	215.84	274.19	15.93	0.06
Hydraulic radius,mm	17.33	15.54	18.94	0.88	0.05
Max Feret Dia. (MFD),mm	97.29	82.96	109.62	6.95	0.07
Waddle Disc Dia. (WDD)	73.89	65.34	80.82	4.19	0.06
Area (mm^2)	8602.55	7048.44	10212.50	968.85	0.11

The mean values, standard deviation (S.D.), range (min, max) and coefficient of variation (C.V.) in the real world have been reported in Table 4. The mean, minimum and maximum values of the surface area of *Dashehari* fruits were found to be slightly higher than the *Chausa* fruits. But, the mean values of the fruit's perimeter and hydraulic radius of both cultivars were found almost to be the same. Variation in fruit's area perimeter and hydraulic radius, however, were noticed higher in *Chausa* (0.13 %, 0.09 % and 0.09 %) than in *Dashehari* (0.11 %, 0.06 % and 0.05 %) fruits, respectively (Table 4). Furthermore, Max Feret diameter (MFD) which measures the size of object in specified direction was found to be varied between 57.83 mm to 80.96 mm with mean value 94.64±7.48 mm for *Chausa* fruits and 82.96 mm to 109.62 with mean value 97.23±.6.95 mm for *Dashehai* fruits, respectively. In contrast to MFD, the WDD of fruits of both cultivars were found almost similar. Similar studies have also been reported by Momin *et al.* (2017) using color camera CVS for mangoes. They have reported that the geometry-based grading of mango using compute vision is simple, accurate and efficient and can be used to mechanize sorting and grading of mangoes.

CONCLUSION

The potential of NIR computer vision systems has been presented in this paper. This system is simple, efficient and almost accurate in the measurement of mango's geometrical and shape attributes. Using specific image processing and analysis software various morphological parameters can be analyzed and used for sorting/grading, differentiating between cultivars and for the designing of equipment for sorting/grading, loading/unloading, packaging and packages. As processing of NIR images is less time consuming, the NIR CVS could be more beneficial and cost effective than the color computer vision system in the mechanization of sorting and grading the mangoes after postharvest.

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