

## COLOUR INSPECTION OF APPLE WITH MACHINE VISION

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**Summary.** The objectives of this paper were to develop a machine vision system for colour analysis of apples and evaluate the performance of the colour vision system to assess apple maturity. In this study, colour was evaluated using two systems; *RGB* and *HIS*. The results show that histograms of chrominance are a specific characteristic of a given variety. After reaching maturity, fruits exhibit a different distribution of chrominance values. The range of variability of chrominance values for immature apples averaged twice as high than that for mature apples, except in case of Jonagold and Golden Delicious varieties. The chrominance value may be a measure of the degree of fruit maturity during harvest period. Chromaticity attributes, *r* and *g*, may be used to predict harvest and consumption maturity of apples.

**Key words:** apple, colour space, image processing

## INTRODUCTION

Colour is one of the most significant factors relating food quality to maturity and surface defects [Dobrzanski *et al.* 2002]. The appearance of fruits affects acceptance by producers and consumers. Inspection of fruits is an important procedure for marketing and processing accomplished during harvest and storage. Apples are commonly graded into three categories, according to European standards [Anonymous, 1989], on the basis of their external quality to determine their market value. Manual inspection's lack of consistency, subjectivity and variability in grading have encouraged efforts for automated apple inspection. A machine vision system can be an ideal tool for assessing colour by image processing. The application of a machine vision system and image processing can provide more informative, quantitative colour assessment with greater reproducibility.

Some investigators have applied image processing techniques to colour identification for fruits. [Thomas and Connolly 1986] compared human colour perception and the capabilities of the image processing using RGB colour components from machine vision. [Morrissey 1988] stated that an HIS system was more efficient in colour inspection than human colour perception. [Tao *et al.*, 1995] used a CCD colour camera with frame grabber to generate a 512\*512\*8 bit of red, green and blue image of the sample. A lighting chamber was designed to provide uniform diffuse illumination

of apples without any reflection. They concluded that the vision system achieved over 90% accuracy for inspection of potatoes and apples with hue histograms and multivariate discriminate techniques. [Paulus and Schrevers 1997] reported on an image analysis system consisting of an RGB video camera with software where each pixel point was characterized by its red, green and blue value, varying between 0 and 255. [Miller 1995] developed an algorithm to measure colour dispersion.

[Molto *et al.* 2002] used linear discrimination analysis to segment pixels into three and four classes. A discriminate function sorted the apple as accepted or rejected. The accuracy was good for apples.

[Zou Xiaobo *et al.* 2007] developed a machine vision system to automatically grade apple fruit colour, which consisted of a colour CCD camera equipped with an image grab device, a bi-cone roller device controlled by a stepping motor, and a lighting source. Four images, one for every rotation of 90°, were taken from each apple. Seventeen colour feature parameters were extracted from each apple in the image processing. By applying the step decision tree algorithm in combination with the organization feature parameter method, high grade judgment ratios were achieved in the classification of 'Extra', and 'Reject' colour grades.

[Blasco *et al.* 2003] used the segmentation procedure, based on a Bayesian discrimination analysis, which allowed fruits to be precisely distinguished from the background. Thus, determination of size was properly solved. The colours of the fruits estimated by the system were well correlated with the colorimetric index values that are currently used as standards.

The objectives of this paper were to; (1) develop a machine vision system for colour analysis of apples and (2) evaluate the performance of the colour vision system to assess apple maturity.

## MATERIAL AND METHODS

Six apple cultivars used in this study were; Gala, Fiesta, Sampion, Jonagold, Ligol, and Golden Delicious. The apples were picked every five days on six dates beginning before harvest and continuing after it, at the Albigowa Orchard Experiment Station. When apples reached ripeness, they were placed into cold storage for 5 months. Prior to testing, fruit were removed from storage at least 15 hours before measurements to allow them to reach room temperature (20 °C).

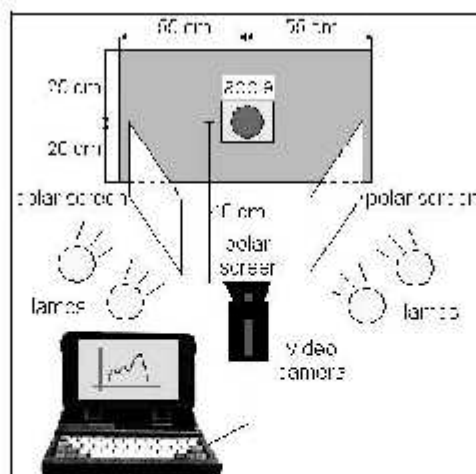


Fig. 1. Machine vision system

Images were acquired using one CCD camera (Model SSC-DC58AP, RGB Sony) equipped with 25 mm lens, a computer with MultiScan program for image analysis, and lighting with a diffuse light from two halogen lamps [Fig.1]. Apples were oriented vertically in the stem-calyx direction and then they were rotated to obtain eight images. Images were digitized using a frame grabber and viewed on the monitor. The camera was located on the side of the sample at a distance of 400 mm.

For determining the harvest readiness of the apples, the following measurements were taken; firmness, sugar content and starch index. The firmness tests were performed directly after the optical measurements. The Magness-Taylor test was carried out with a Zwick Machine using a cylindrical plunger 11 mm in diameter travelling at a constant speed of 2 mm/s into the peeled apple at the distance of 8 mm. The force vs. deformation curves were recorded for each apple. The maximum force and the slope of curve from the origin to 2.0 mm of displacement were used as a measure of fruit firmness. Apple juice was extracted after firmness measurements and its sugar content was measured with a refract meter of RR 12 to an accuracy of 0.25% Bricks.

Colour was represented as an RGB composite and also as an HIS system of hue, saturation and intensity. Hue value was calculated using the following formula for red, green and blue values:

$$H = \left( 90^\circ + \tan^{-1} \left\{ (2R - G - B) * \left[ \sqrt{3}(G - B) \right]^{-1} \right\} + (180^\circ \text{ if } G < B) \right).$$

Two coordinates, *r* and *g* were used as two-dimensional chromaticity coordinates. This analysis based on normalized colours is insensitive to changes in luminance, but is sensitive to changes in chrominance. The normalization was conducted by taking the percentage ratio of the number of pixels of each hue within the object range to the total area of the object. The procedure was applied to the inspection of all fruits.

## RESULTS

The diagrams showing relationships between the parameters *R* and *G*, for the tested varieties during harvest and storage periods are presented in Figures 2 and 3. These relationships are described with the use of quadratic polynomial equations. The harvest period was characterized by more than twice higher variability than the storage period. A concentration of points of *R* versus *G* was recorded within the range of the *R* parameter variation from 120 to 200 during harvest period and from 150 to 200 - in storage period. Mutual relationships between these parameters show the dynamics of changes taking place during fruit ripening. A good alternative for maturity determination is the use of the relationship between *R* and *G*. Meanwhile this calculation is not yet optimised according to the threshold of maturity.

Relationships between chromaticity attributes, *g* and *r*, for the tested varieties during harvest and storage periods are presented in Figures 4 and 5. These relationships are of linear character and are very similar for both the tested periods. The share of red colour ranged from 18 to 40 % during harvest, whereas during storage it was nearly twice as high. These parameters may be utilized for the study of mutual relationships between green and red colour. The advantage of the transformation to the attributes of *g* and *r* is that the correlation is very high. Determination coefficient ranged from 0.95 to 0.97.

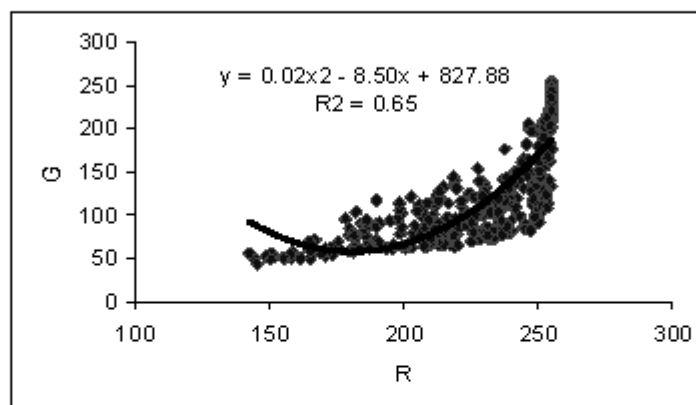


Fig. 2. Relationship between colour composites  $G$  and  $R$  of the tested varieties at harvest time

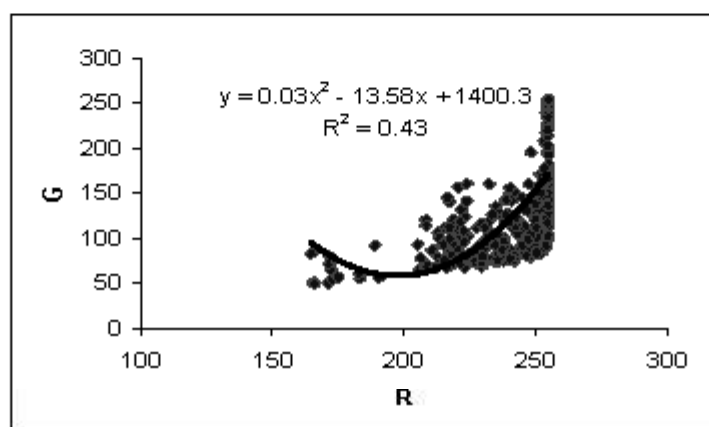


Fig. 3. Relationship between colour composites  $G$  and  $R$  for the tested varieties at storage

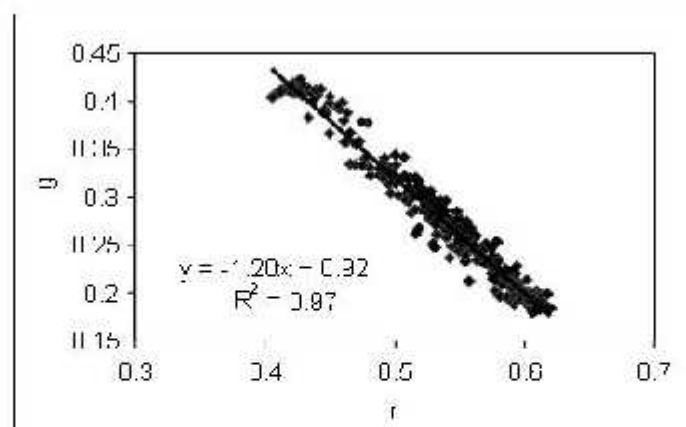


Fig. 4. Relationship between chromaticity coordinates  $g$  and  $r$  for the tested varieties at storage

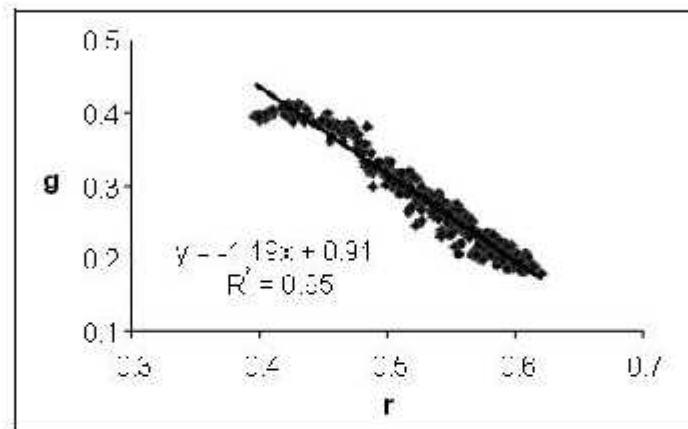


Fig. 5. Relationship between chromaticity coordinates  $g$  and  $r$  for the tested varieties at harvest time

The histograms of  $RGB$  colours for the tested varieties during harvest and storage are presented in Figures 6 and 7. The values of the  $G$  parameter varied from 50 to 100 during harvest time, whereas during the storage period the variability range of that parameter was twice higher and reached a maximum of 200. A large concentration of coloration intensity occurred for the  $R$  parameter. The dynamics of coloration intensity changes and the range of that variability may be closely observed from  $RGB$  histograms. Applying this histogram to the thresholding, the regions of interest could be separated.

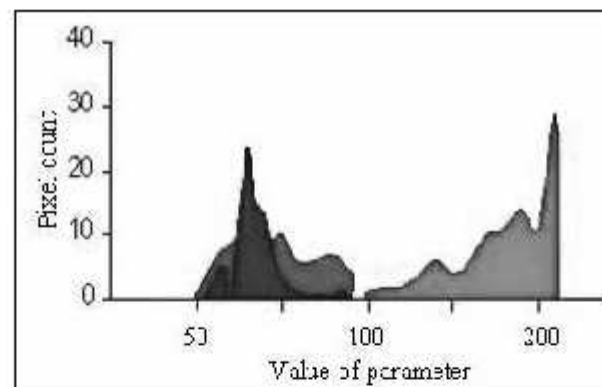


Fig. 6. The  $RGB$  colour histogram of the tested apple within harvest

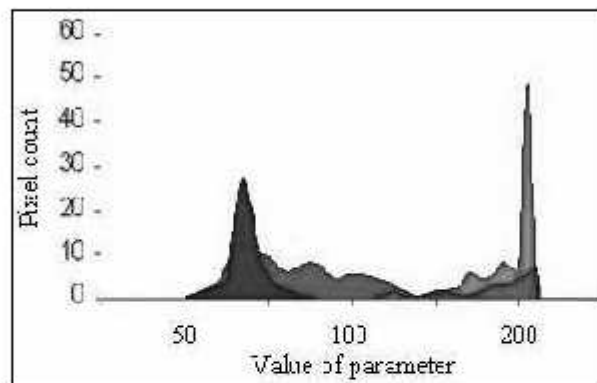


Fig. 7. The RGB colour histogram of tested apple within storage

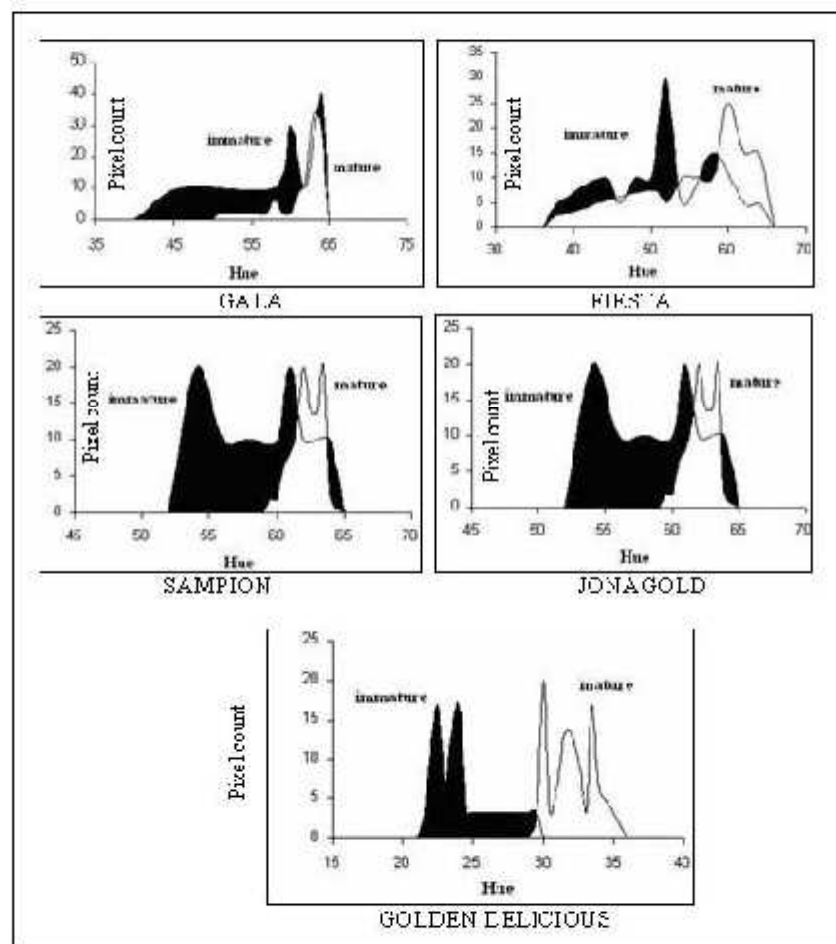


Fig. 8. Hue histograms of mature and immature apples for the tested varieties within harvest

Histograms of chrominance of the tested varieties of apples at harvest are presented in Figure 8. On average the recorded values of chrominance were lower for apples picked from trees before they reached their harvest maturity, than those for fruit collected at a later time, after they reached their harvest maturity. Depending on the pixel number the character of variability distribution for chrominance values differed significantly for the tested varieties. The Golden Delicious variety had clearly the lowest mean value of chrominance and relatively high concentration of its values at levels 22, 24, 32 and 34. The chrominance values of the remaining varieties were higher by an average of 24. Moreover, the Golden Delicious and Jonagold varieties exhibited the lowest range of variability of chromaticity values, as compared to the remaining varieties, i.e. 14 and 29, respectively. It shows that histograms of chrominance are a specific characteristic of a given variety. Study of chrominance shall permit a determination of harvest characteristic of the variety.

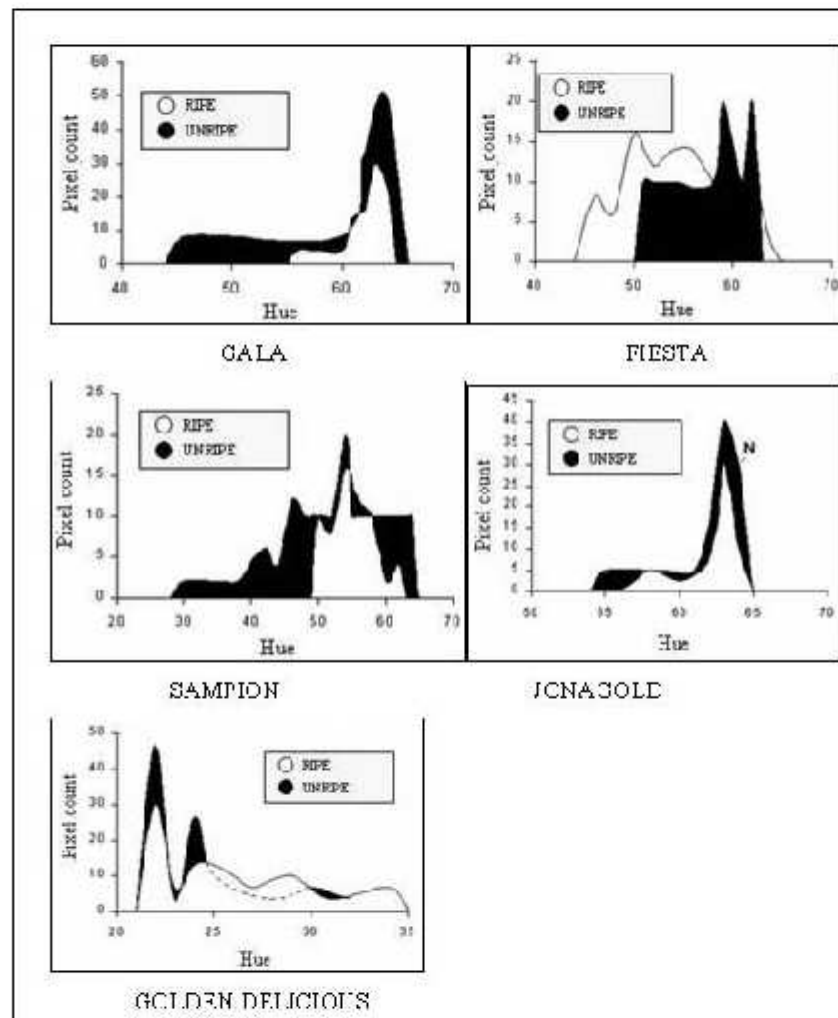


Fig. 9. Hue histograms of ripe and unripe apples for the tested varieties within storage

Histograms of chrominance of ripe and unripe apples in the tested varieties during storage period are presented in Figure 9. They show that, after reaching maturity, fruits exhibit a different distribution of chrominance values. The range of variability of chrominance values for immature apples averaged twice as high as that for four varieties of mature apples (not for Jonagold and Golden Delicious). A significant observation from the data is that only Fiesta and Ligol (data not presented) varieties may be graded into ripe and unripe apples on the basis of chrominance values. For the remaining varieties, another discriminating characteristic is needed. Therefore, the application of apple chrominance histograms for apple grading based on maturity works for some but not all varieties.

The measurement date had a significant effect on fruit chrominance during harvest period as shown in Figure 10. During storage that effect was not significant, except for Fiesta and Ligol varieties. These results mean that the chrominance value may be a measure of the degree of fruit maturity during harvest period but less useful during storage.

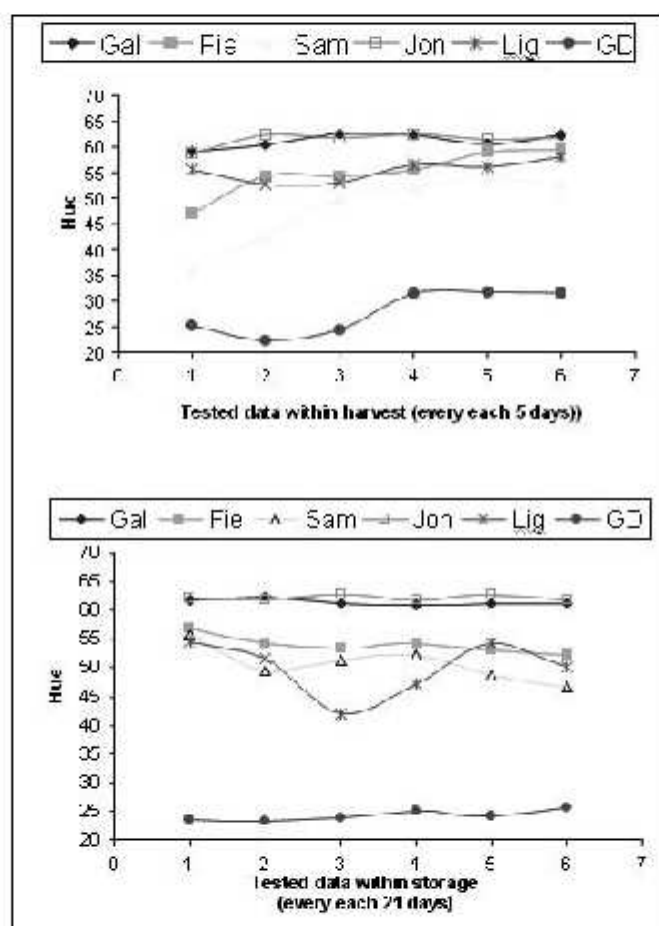


Fig.10. Effect of tested data on the value of hue for tested varieties (Gal – Gala, F – Fiesta, S – Sampon, J – Jonagold, L – Ligol, GD – Golden Delicious)



Chromaticity attributes,  $r$  and  $g$ , analyzed for apples at various stages of harvest and maturity are shown in Tables 1 and 2. The values of  $r$  and  $g$  were found to differ significantly among varieties. These indices may be measured on either the blushed side or non-blushed side. Chromaticity attributes,  $r$  and  $g$ , may be used for the assessment of harvest and maturity of apples as shown by the diagram (Fig. 11) for Gala and Golden Delicious varieties.

Table 1. Average values of  $r, g$  chromaticity coordinates for red and green in mature apples

Variety	Data	Whole apple		Blush of apple	
		$r$	$g$	$r$	$g$
<i>Gala</i>	8.09.03	0.603	0.195	0.624	0.169
<i>Fiesta</i>	8.09.03	0.546	0.268	0.580	0.207
<i>Sampion</i>	12.09.03	0.527	0.285	0.562	0.241
<i>Jonagold</i>	22.09.03	0.598	0.211	0.608	0.194
<i>Ligol</i>	29.09.03	0.547	0.260	0.574	0.205
<i>Golden Delicious</i>	29.09.03	0.460	0.381	0.473	0.368

Table 2. Average values of  $r, g$  chromaticity coordinates for red and green for ripe apples

Variety	Data	Whole apple		Blush of apple	
		$r$	$g$	$r$	$g$
<i>Gala</i>	15.10.03	0.601	0.196	0.609	0.182
<i>Fiesta</i>	6.11.03	0.547	0.269	0.571	0.212
<i>Sampion</i>	15.10.03	0.573	0.253	0.570	0.241
<i>Jonagold</i>	18.12.03	0.600	0.202	0.603	0.190
<i>Ligol</i>	15.01.04	0.535	0.271	0.595	0.204
<i>Golden Delicious</i>	15.01.04	0.440	0.406	0.452	0.398

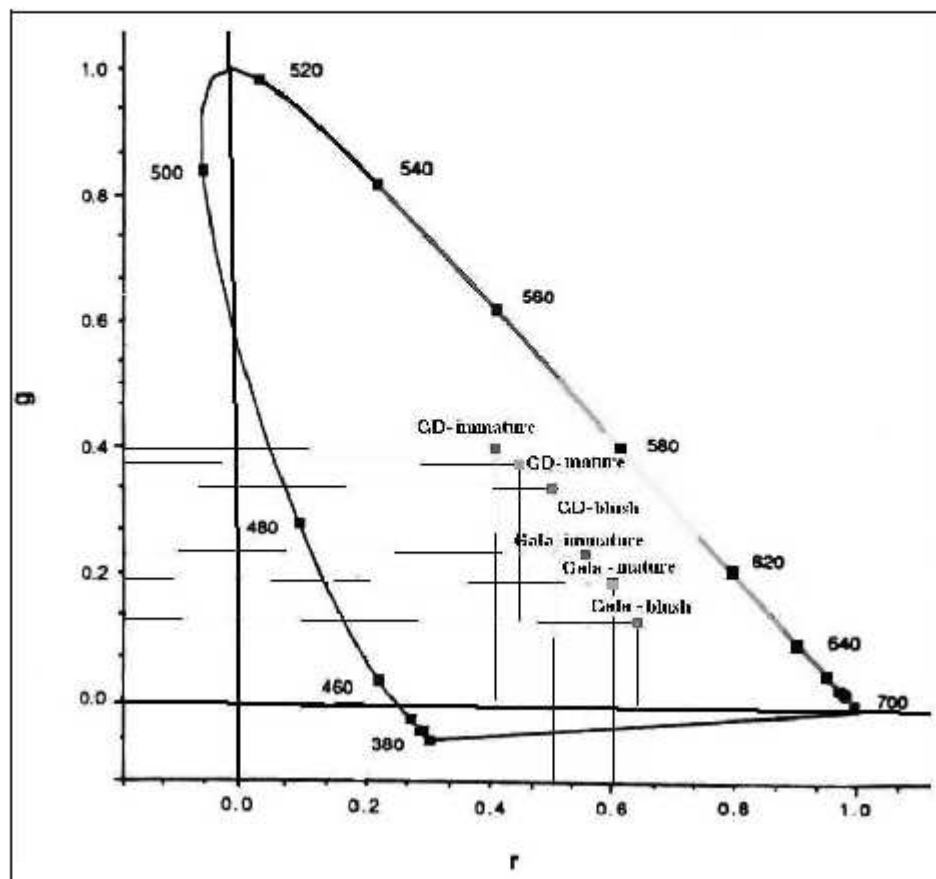


Fig. 11. Chromaticity diagram of  $g$  and  $r$  for apples of Gala and Golden Delicious (GD) on the border spectral colours

## CONCLUSIONS

1. Machine Vision inspection of apples is a feasible approach to evaluating colour and stage of development. In this study, the two systems used to evaluate colour were *RGB* and *HIS*.
2. Results show that histograms of chrominance are a unique characteristic for each variety.
3. Chrominance permits a determination of stage of harvest characteristic of each variety. After reaching maturity, fruit exhibit a different distribution of chrominance. The range of variability of chrominance values for immature apples averaged twice as high than that for mature apples, except for Jonagold and Golden Delicious.
4. The chrominance value maybe a measure of the degree of fruit maturity during harvest period. Chromaticity attributes  $r$  and  $g$  maybe used for the assessment of harvest time and maturity of apples

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ZASTOSOWANIE SYSTEMU WIZYJNEGO DO BADANIA WYBARWIEŃ  
JABŁEK.

**Streszczenie.** Celem pracy jest zastosowanie systemu do oceny dojrzałości jabłek za pomocą komputerowego systemu analizy obrazu. W badaniu użyto dwóch systemów do oceny kolorystyki jabłek: *RGB* oraz *HIS*. Wyniki pokazują, iż histogramy chrominancji są charakterystyczne dla poszczególnych odmian owoców. Po osiągnięciu dojrzałości owoce wyróżniają się różnym rozkładem wartości chrominancji. Badania wykazały, że zasięg zmienności wartości chrominancji dla niedojrzałych jabłek osiągnął przeciętnie dwa razy wyższy poziom w porównaniu do jabłek dojrzałych, za wyjątkiem odmian Jonagold i Golden Delicious. Wartość chrominancji może być miarą stopnia dojrzałości owoców podczas zbiorów. Parametry chrominancji, *r* i *g*, mogą być użyte, do wyznaczenia okresu zbioru i dojrzałości konsumpcyjnej jabłek.

**Słowa kluczowe:** jabłko, kolorystyka, przetwarzanie obrazu

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