Sweet pepper maturity evaluation via multiple viewpoints color analyses

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Abstract

Maturity evaluation is an important feature for selective robotic harvesting. This paper focuses on maturity evaluation derived by a color camera for a sweet pepper robotic harvester. Fruit visibility for sweet peppers is limited to 65% and multiple viewpoints are necessary to detect more than 90% of the fruit. This paper aims to determine the number of viewpoints required to determine the maturity level of a sweet pepper and the best single viewpoint. Different color-based measures to estimate the maturity level of a pepper were evaluated. Two datasets were analyzed: images of 54 yellow bell sweet peppers and 30 red peppers both harvested at the last fruit setting; all images were taken in uniform illumination conditions with white background. Each pepper was photographed from 5-6 viewpoints: one photo of the top of the pepper, one photo of the bottom and 3-4 photos of the pepper sides. Each pepper was manually tagged by a human professional observer as 'mature' or 'immature'. Image processing routines were implemented to extract color level measures which included different hue features. Results indicates high correlation between the sides to the bottom view, the bottom view shows the best 0.86 correlation in the case of yellow peppers while the side view shows the best 0.835 correlation in the case of red peppers (the bottom view yields 0.82 correlation).

Keywords: Agricultural robots, Image processing, Computer vision, Pepper maturity, Robotic harvesting.

1. Introduction

To automate the harvesting process, robots have been actively developed over the last 30 years (Bac et al. 2014). An agricultural robot must deal with an unstructured and dynamic environment (e.g., changing illumination, clouds), and random and difficult locations of the fruit which are highly variable in size, shape and structure and obstructed by foliage (Edan et al. 2000). An important module in a robotic selective harvester is the maturity detection system which is fruit dependent and therefore usually requires individual research and development (Edan 1995). Maturity detection can be a big challenge for fruits like sweet pepper where parts of the fruit are not visible (Bac et al. 2014) or must be examined from different viewpoints (Hemming et al. 2014). Research to date in sweet pepper harvesting focused mostly on the fruit detection without evaluating the fruit maturity level (Bac et al. 2014; Kitamura and Oka 2005; Kitamura et al. 2008).

Maturity at harvest is the most important factor that determines the fruit quality and storage life (Kader 1999). In order to determine the quality and the maturity level of a fruit or vegetable there are four categories of factors: visual parameters (e.g. color, shape, size etc.), firmness, soluble solids content and titratable acidity (Lorente et al. 2012; Mitcham et al., 1996). The visual aspects are commonly used since they can be extracted using machine vision systems by external nondestructive measurements (Brosnan and Sun 2004). Most of the maturity detection research involve color as part of the detection (Bac et al. 2014; Tantrakansakul and Khaorapapong 2014; Wang et al. 2012) since it is an important fruit quality characteristic which represents the degree of maturity, sugar content, acidity and taste (Li et al., 2009). It is also a main factor in customer's selection of sweet peppers (Frank et al. 2001; Brosnan and Sun 2004)).

In order to fulfill the development of a selective harvester fruit maturity must be detected. The focus of this research is to determine the best view point to derive the sweet pepper color level using machine vision.

2. Materials and Methods

2.1. Datasets

Photos of 54 yellow bell sweet peppers (Cultivar: Sensatio, Seed company: Syngenta) and 30 red sweet peppers (Cultivar: DR3914PB Seed company: De Ruiter) were acquired in uniform illumination conditions with white background, after their harvest from a greenhouse in Proefstation Groenteteelt Belgium. Both datasets were acquired at the last fruit setting. The photos were taken using a Panasonic DMC-LX7 CMOS 3648x2736. Each pepper was photographed from 5-6 viewpoints: one image of the top of the pepper, one image of the bottom and 3-4 images of the sides in no particular order. In the first image of each pepper the ripeness classification of the pepper was marked as "YES" (ripe) or "NO" (unripe). Forty eight peppers were classified as ripe and six were classified as unripe. Some of the images included a hand stabilizing the pepper.

2.2. Algorithms

The image processing algorithms were developed in MatLab 2014b using the image processing library. The image processing routines developed included transformation to the HSV color space, segmentation and features extraction procedures. The extracted data features were saved in an Excel file and then and analyzed with the R statistical package.

The top view image was disregarded from the analysis since most of the pepper was concealed by the peduncle. Furthermore, this view is not practical for robotic harvesting implementation. An algorithm was developed to segment the pepper from the rest of the image as precise as possible in order to minimize the bias in the statistics calculations. The features derived from the hue dimension are detailed in the section below. Two estimators were calculated for the estimation of a sweet pepper denoted as a 'whole pepper': the first estimator was based on the mean values of all views and the second estimator was based on the cumulative data, a vector composed of the pixels of all the views.

2.3. Statistical color analysis

Statistical analyses were conducted on the hue color dimension after normalizing the double values to 360 degrees. Two different data distributions were found: normal (unimodal) distribution when one color is dominant in the image (green, yellow or red) and a bimodal distribution when there were two colors (yellow-green or red-green).

The following features were derived for the images with normal color distribution:

- Pixel size of the view
- Mean of Hue.
- Standard Deviation of hue.
- Mean of the top 3 most common hue values.
- Mean of the top 4 most common hue values.
- Mean of the top 5 most common hue values.
- Standard Deviation of the top 3 most common hue values.
- Standard Deviation of the top 4 most common hue values.
- Standard Deviation of the top 5 most common hue values
- Frequency of the top 3 most common hue values.
- Frequency of the top 4 most common hue values.
- Frequency of the top 5 most common hue values.

For bimodal color distribution, the image was automatically divided into the two different color distributions using color thresholding, one marked as the yellow or red colors and the second as green colors, and then the following features were calculated:

- Summation of the yellow/red pixels number divided by the green pixel number.
- Mean of the yellow/red pixels value divided by the mean of the green pixels value.
- Standard deviation of the yellow/red pixels value divided by the standard deviation of the green pixels value.

2.4. Statistical analysis of viewpoints

The correlation between the different views to the whole pepper was based on the hue mean attribute derived from the statistical color analysis. Correlation between views was determined in order to find the correlation between the side views to the bottom view. Analysis of the correlation between each view to the whole pepper was determined in order to find if there is a view that represents the whole better than other views.

Paired t-tests were conducted between each view to the whole pepper value of mean by cumulative data. The hypothesis was tested for an s level of 5% (t critical value is 1.674):

H0: $\mu_{\text{whole pepper}} = \mu_{\text{view}}$

H1: $\mu_{\text{whole pepper}} \neq \mu_{\text{view}}$

All the correlation calculations were calculated using the Pearson correlation method. In addition, as the side views images were randomly taken in no particular order, an estimator of the side value was calculated using the mean of the side views values. Each analysis was also conducted on the sides mean estimator in comparison to the bottom view .

3. Results and Discussion

3.1. Image processing algorithm results

An example of the result of pepper 53 can be seen in Table 1.

3.2. Descriptive statistics of the data

The segmented pepper histogram including the value of the yellow-green threshold was examined. The pepper hue's distribution is similar to the normal distribution in the case of one dominant color and similar to B modal distribution in case of two colors (Figure 1).

Yellow pepper results (Figure 2) indicate that for the 'whole pepper' mean of views estimator, 75% of the hue mean values of the mature peppers vary between 54.3 to 62.7 (mean=58.64; std= 5.64) as compared to the mean hue values of the immature pepper which vary between 64.5 to 68.4 (mean=66.77; std= 3.32). In the case of the cumulative data estimator 75% of the hue mean values of the mature peppers vary from 54.4 to 62.5 (mean=58.65; std= 5.72) and the mean hue values of the immature vary from 64.3 to 69.3 (mean=67.14; std= 3.52). (Figure 1).

Table 1. Example of pepper 53 analysis results (only 3 side views)

Pepper 53	Ripe					
Attribute	**View 1**	**View 2**	**View 3**	**View 4 (bottom)**	**Whole by mean**	**Whole by cumulative data**
Pixel size	1787806	1730438	1682472	2631550		7832266
Hue Mean	57.84	60.36	59.43	63.20	60.21	60.54
Hue standard division	7.49	6.44	7.15	8.23	7.33	7.75
Top 3 most common Hue values mean	53.00	57.00	55.00	70.00	58.75	56.00
Top most common 4 Hue values mean	53.75	57.50	55.50	67.00	58.44	56.50
Top 5 most common Hue values mean	54.00	58.00	56.00	65.60	58.40	56.00
Top 3 Hue values standard division	1.00	1.00	1.00	1.00	1.00	1.00
Top 4 Hue values standard division	1.71	1.29	1.29	6.06	2.59	1.29
Top 5 Hue values standard division	1.58	1.58	1.58	6.11	2.71	1.58
Portion of Top 3 Hue values	0.28	0.46	0.43	0.20	0.34	0.27
Portion of Top 4 Hue values	0.36	0.54	0.53	0.25	0.42	0.33
Portion of Top 5 Hue values	0.44	0.61	0.60	0.29	0.49	0.39
yellow to green size ratio	4.72	4.05	4.47	0.85	3.52	2.37
yellow to green means ratio	0.77	0.80	0.78	0.80	0.79	0.80
yellow to green standard division ratio	0.78	0.80	0.78	0.81	0.79	0.81

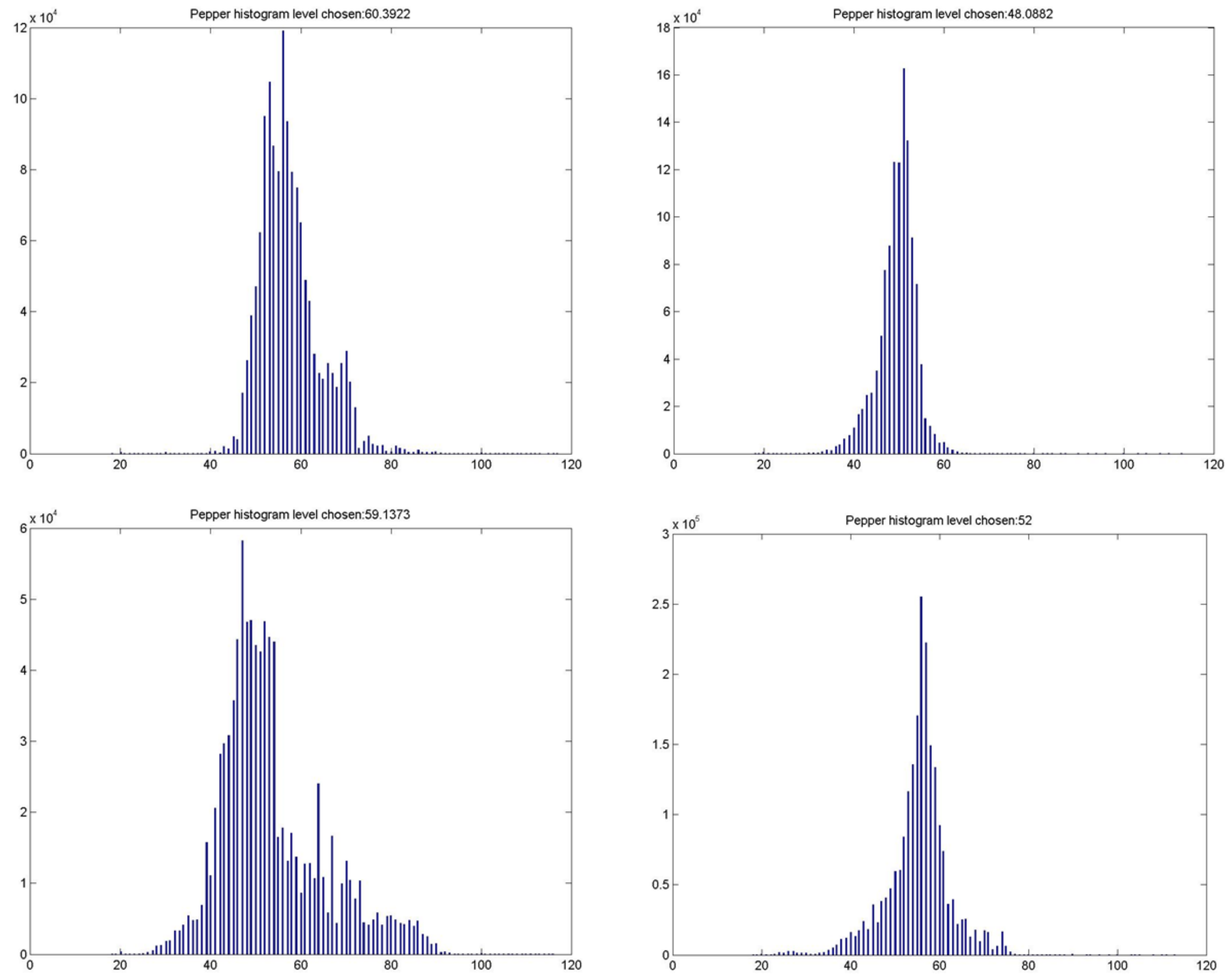

Figure 1. Examples of pepper view hue distributions.

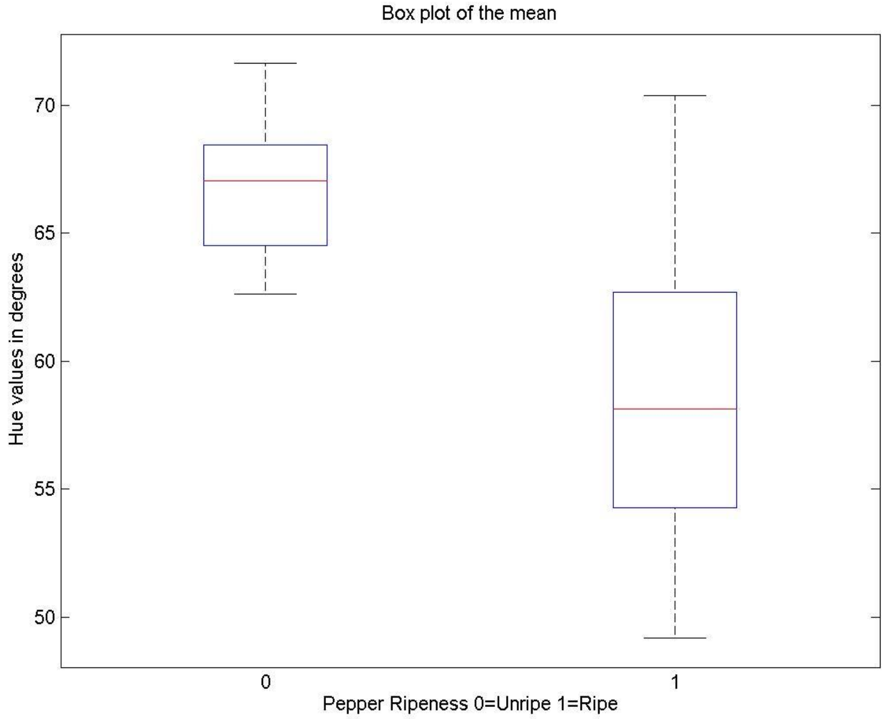

Figure 2. 'Whole' pepper mean of views estimator - hue mean box plot

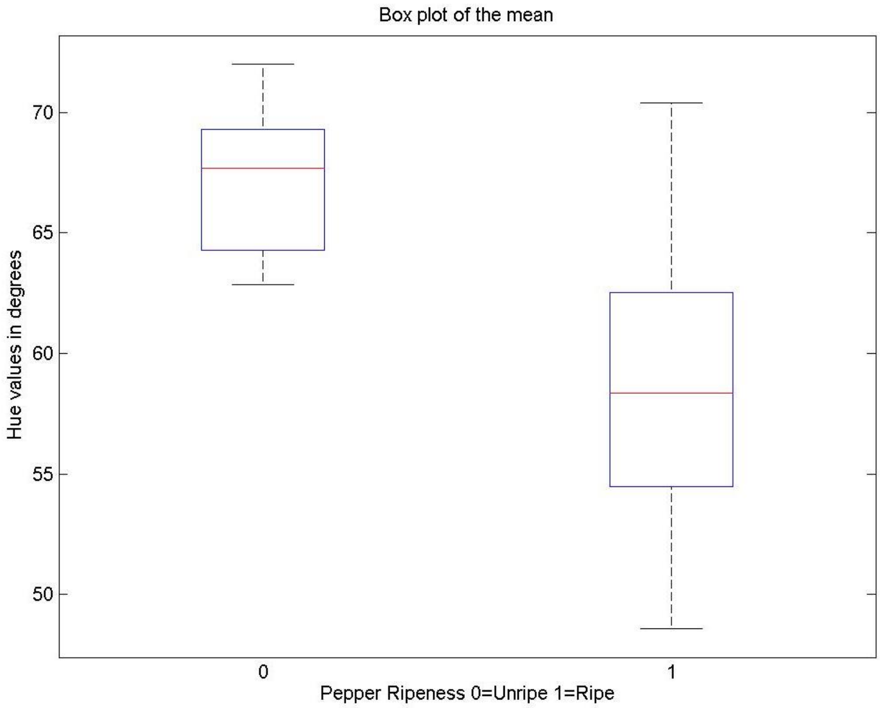

Figure 1: 'Whole' pepper cumulative data estimator - hue mean box plot

Yellow pepper results (Figure 4) indicate that for the 'whole pepper' mean of views estimator, 75% of the hue standard deviation of the mature peppers values vary between 5.8 to 8.5 (mean=7.25; std= 1.84) as compared to the hue standard deviation of the immature pepper which values vary between 9.5 to 10.8 (mean=10.23; std= 0.67). In the case of the cumulative data estimator, 75% of the hue standard deviation values of the mature peppers vary from 7.0 to 11.2 (mean=9.00; std= 2.70) and the mean hue of the immature peppers vary from 13.45 to 14.36 (mean=14.00; std= 1.00) and an exception in one of the mature peppers with a standard deviation of 12.86 (Figure 5).

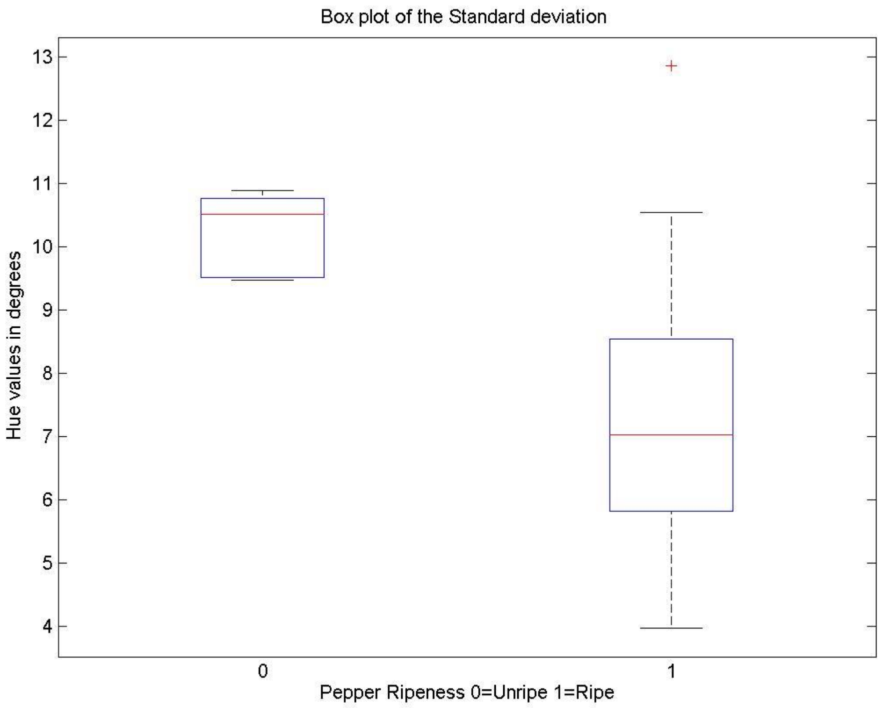

Figure 2: Box plot of the whole pepper by mean - hue standard deviation

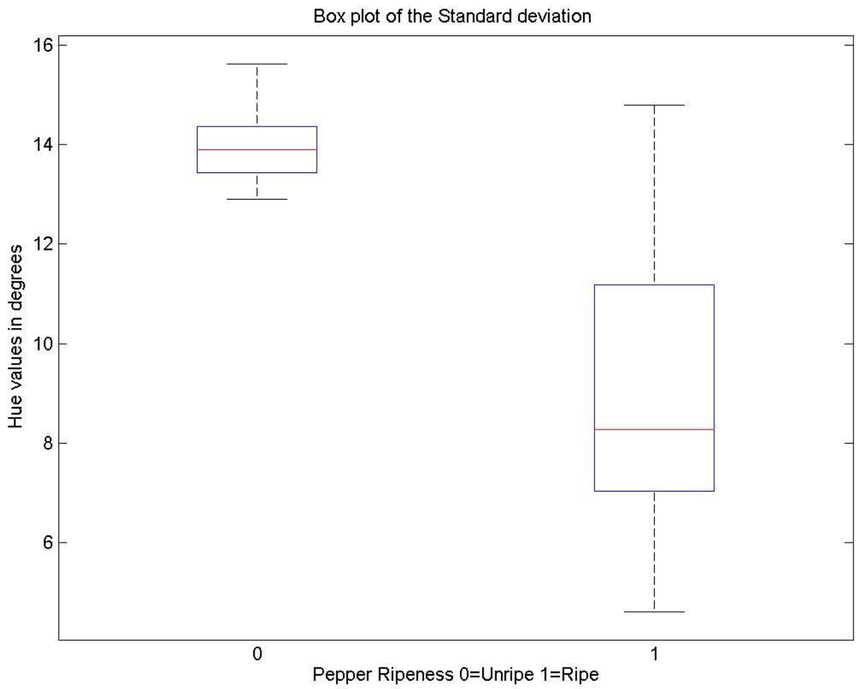

Figure 3: Box plot of the whole pepper by cumulative data – hue standard deviation

3.3. Analysis of views

Results of correlation analysis (Figure 6) between the views of the yellow peppers indicates that the bottom view has a high correlation to the other views. The histogram of each view hue mean (diagonal), the Pearson correlation between all the different combinations of view and the estimator for the side view total value (above the diagonal) and the scatter plot including the fitting reggresion line (below the the diagonal) can be seen in the Figure 5. The correlation between the sides view estimator to the bottom view resulted in 0.68 positive correlation. In the case of red peppers the bottom view has 0.69 positive correlation to the side views.

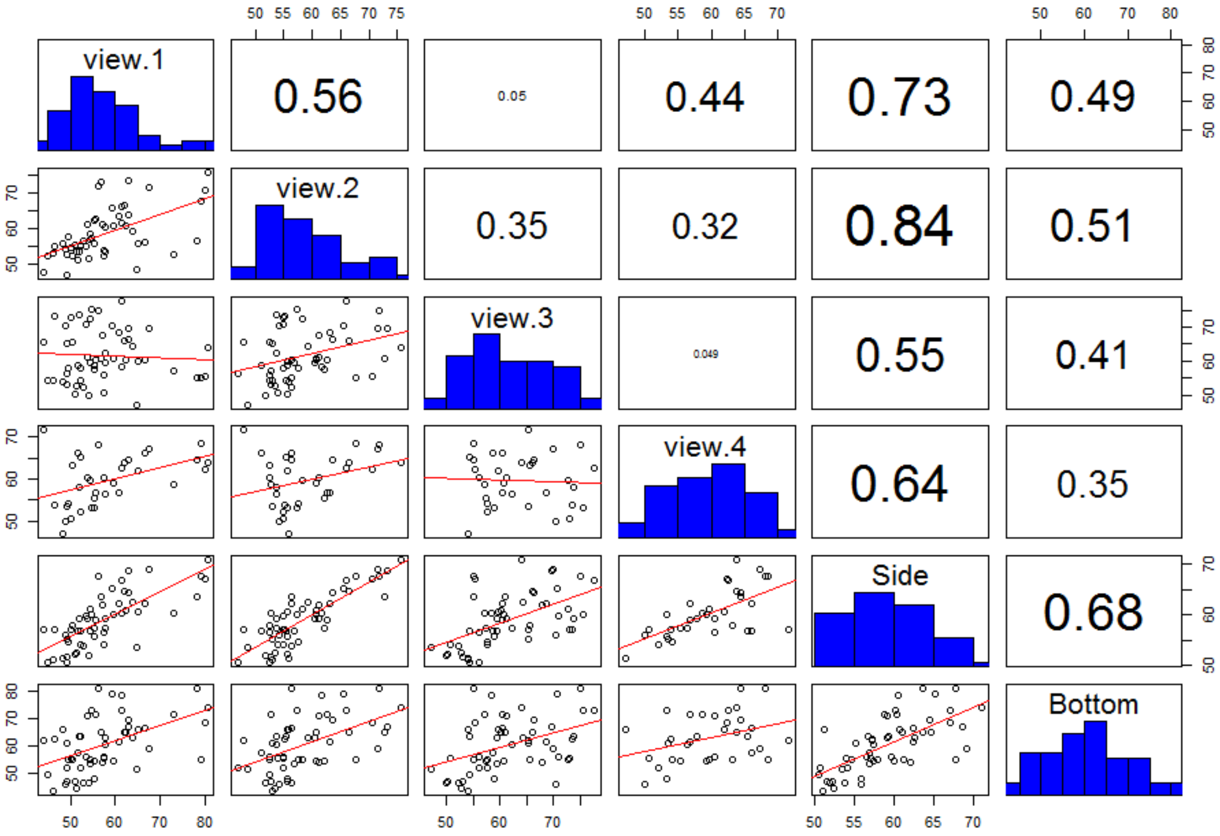

Figure 4: Yellow peppers correlation analysis of views

3.4. Views correlation to the whole pepper

Results (Table 2-3) indicate that the bottom view has 0.86 and 0.82 correlation to the whole pepper for red and yellow peppers respectively. For the yellow peppers the bottom view has the best correlation among all the single views. For the red pepper one of the side views yields highest 0.835 correlation with little difference from the bottom view (0.015 difference). However, the hemoptysis test of the highest 0.835 correlation rejected H0. Therefore, the view with the highest correlation that has an accepted H0 was the bottom view. All the side views correlations vary from 0.526 to 0.835. High correlations of 0.957 and 0.976 are obtained for the average values of all sides which is composed of 3-4 views.

Table 2. Yellow peppers paired samples t-tests results

Comparison to whole	**V1**	**V2**	**V3**	**V4**	**Bottom**	**Sides mean**
Correlation	0.707	0.78	0.526	0.618	0.86	0.957
Observations	54	54	54	34	54	54
P-value	0.029	0.141	0.019	0.183	0.161	0.202
Test results	$\mu_{whole} \neq \mu_{V1}$	$\mu_{whole} = \mu_{V2}$	$\mu_{whole} \neq \mu_{V3}$	$\mu_{whole} = \mu_{V4}$	$\mu_{whole} = \mu_{B}$	$\mu_{whole} = \mu_{S}$

Table 3. Red peppers paired two samples for mean t-tests results

Comparison to whole	V1	V2	V3	V4	Bottom	Sides mean
Correlation	0.674	0.815	0.835	0.731	0.82	0.976
Observations	30	30	30	10	30	30
P-value	0.456	0.388	0.04	0.143	0.263	0.615
Test results	$\mu_{whole} = \mu_{V1}$	$\mu_{whole} = \mu_{V2}$	$\mu_{whole} \neq \mu_{V3}$	$\mu_{whole} = \mu_{V4}$	$\mu_{whole} = \mu_{B}$	$\mu_{whole} = \mu_{S}$

4. Conclusions

The research results shows that there is a significant difference in the color hue mean between mature and immature bell peppers. Hence, this feature can be used to detect maturity. The correlation analysis shows that the bottom viewpoint has a high correlation to the other views as well as to the 'whole pepper' hue level. In the case of yellow sweet peppers, the bottom view was the best correlation (0.86) while for red peppers it was second best with a small difference from the side view (0.82 to the bottom vs. 0.835 to the best side view) correlation. Ongoing research is aimed to validate results on larger samples of peppers with equal distributions between mature and immature fruit. Since the bottom view is not likely to be practical for a robotic harvester, future research is also examining additional viewpoints from different angles.

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