Philippine e-Journal for Applied Research and Development 6(2016), 44-56 ISSN 2449-3694 (Online)
http://pejard.slu.edu.ph/vol.6/2016.05.26.pdf

Development of an Android-Based Maturity Detector Mobile Application for Watermelons [*Citrullus Lanatus* (Thunb.) Matsum. & Nakai] using Acoustic Impulse Response

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Received, 16 February 2016; Accepted, 24 May 2016; Published, 26 May 2016

Abstract

Impulse signals from thumping of watermelon samples were correlated with fruit sweetness as measured by a refractometer in order to develop a classification model that was later on applied to an Android-based mobile application for measuring watermelon maturity. Correlation coefficients were -0.721, -0.554 and -0.331 when the samples were thumped at the top, center and bottom respectively. As to sample size, correlation coefficients of -0.522, -0.525 and -0.250 were observed for small, medium and large watermelon samples, respectively. The Android-based mobile application had an average accuracy of 85.90% considering all watermelon sizes, showing 92.79% accuracy when samples were thumped at the equator, and 92.89% accuracy when used on large watermelons. The study suggested that as the sweetness of the watermelon increased, the frequency decreased, hence a mature watermelon produced lower frequency. Furthermore, the android-based maturity detector mobile application proved to be most accurate when used on large watermelons thumped at the equator.

Keywords: impulse, frequency response, sweetness, maturity detection, classification model

Introduction

Unlike other fruits whose maturity level can be determined by inspecting their external features like color and softness, Citrullus lanatus (commonly known as watermelon) does not exhibit much change in its external color or texture as it matures, hence the difficulty of assessing the fruit's ripeness. To determine the watermelon's maturity, either destructive or non-destructive methods are used. The destructive method entails opening up the fruit to check the color of its flesh as indicator of ripeness. Several studies proposed non-destructive methods, like those using frequency response through Laser Doppler Vibrometry (Abbaszadeh, Rajabipour, Ying, Delshad, Mahjoob, & Ahmade, 2015); acoustic technology (Ay, 1996); impulse response (Farabee, 1991); waveform analysis through Fast Fourier Transform (Kouno, Mizuno, & Maida, 1993), rind color analysis through RGB image (Nasaruddin, Baki, & Tahir, 2011); acoustic impulse (Stone, Armstrong, Zhang, Brusewitz, & Chen, 1996); and, visible and near-infrared (VIS-NIR) spectroscopy and X-ray image (Qi, Song, Jiang, Chen, Li, & Han, 2014). However, most of these studies made use of large or expensive equipment for assessing the maturity of watermelons. The continuing challenge is to come up with equally reliable but affordable and convenient devices that can be used not just by growers and vendors but especially by consumers themselves.

Android apps in mobile devices have recently been introduced for watermelon maturity detection. Google Play offers watermelon maturity detector apps such as the Watermelon Prober by Izn1007, Watermelon Picker by Acashic Intellectual Capital Pty Limited, and PickAMelon by Mobile Edge Development. A study by Zeng, Huang, Arisona, & McLoughlin (2014) used the Support Vector Machine (SVM) model in developing a crowdsourcing application for Android, which allows users to identify watermelon ripeness in real time. However, the apps display only an evaluation result of whether the watermelon was ripe or unripe.

This study aimed to present maturity detection in an app, not just to show an evaluation result of ripeness as described in the paper of Zeng et al. (2014). Moreover, it also presents the sweetness index of the fruit along with the ripeness evaluation. Through this, a user can evaluate how ripe and sweet the watermelon is. The Cherry Mobile Flare S3 octacore mobile phone was used in the study to make sure that the app works in a not-so-high-end mobile phone, taking into consideration the average consumers who cannot afford high-end mobile phones. Furthermore, the app created has a noise detection feature that allows the signal to be evaluated more accurately, such that the noise is filtered out from the signal of the thumping to determine the signal frequency without the noise being added to it.

The objectives of this study were to (1) determine the correlation between sweetness and frequency response of the watermelon; (2) create a classification model to describe the correlation of the two parameters; (3) implement the classification model in an android phone application; and (4) evaluate the accuracy of the application when used on a watermelon sample.

Materials and Methods

Classification of Watermelon Sizes

Initial sampling was done using 60 green, spherical shaped watermelons of different sizes. Both the vertical and horizontal diameters of each sample were measured. The vertical diameter was measured from the watermelon's apical top to its apical bottom whereas the horizontal diameter was measured around the equator perpendicular to the top and bottom. After the vertical and horizontal diameters as well as the corresponding weight of each watermelon sample were taken, the fruit was categorized as small, medium or large. The sample size consisted of 20 watermelons per size, with the average sizes listed in Table 1.

Table 1. Average diameter and weight of watermelon samples.

SIZE	AVERAGE VERTICAL DIAMETER (cm)	AVERAGE HORIZONTAL DIAMETER (cm)	AVERAGE WEIGHT (kg)
Small	200.32	191.33	3.83
Medium	227.35	216.5	5.21
Large	256.3	235.95	7.00

Gathering of Acoustic Data Samples

Each watermelon sample was made to stand up on its bottom atop a wooden board with a curved support to hold the watermelon in place. A rubber ball was used to thump the watermelon at the right side while the sound was recorded at the opposite side of the thumping point using Recforge II Lite, a free mobile app recorder installed in an octacore Cherry Mobile Flare S3 mobile phone.

All samples were thumped at three points, namely, (1) a part equidistant from the apical top of the sample and the equator; (2) at the center or equator of the sample; (3) the part equidistant from the apical bottom of the sample and the equator. Thumping at each point was done three times so as to produce three acoustic impulses per sound clip.

The watermelon was then cut horizontally into disks with a thickness of approximately one inch each according to the thumping point location to produce three disks for sweetness test. After the peeling and rind were removed, the watermelon samples were homogenized using a blender. The homogenized sample was subjected to sweetness test using a refractometer. The %Brix reading was noted hereafter.

Data Analysis

Each sound clip was edited using Audacity, a free computer software, where the sample was cleaned using the noise removal function of the app. Each acoustic impulse with a length of 0.15 seconds was clipped from the recorded sound clip. Included in the sound clip is also a 0.01 second of silence at the beginning of each sound clip, which can be considered as noise data. The frequency response of the signal and noise were generated and the noise was removed. The resulting acoustic response was saved as a wav file, the format necessary for the analysis software requirement.

Data Analysis and Display (DADisp) software, an engineering workbench for data analysis, was used for initial data analysis to determine where most of the signal and noise were located in the sound clip. The display that appeared on the screen of the DADisp analysis is subdivided into 6 windows as shown in Figure 1. The first window displays the input wav format signal as 6615 sample points; the second window shows the normalized signal, i.e., the signal divided by the maximum value; window three displays the frequency domain of the signal using a 4096-point Fast Fourier Transform algorithm; windows four and five show the peak values of the frequency domain and the main peak frequencies, respectively. The values of these peak frequencies are tabulated in window 6.

Three random sound clips from each size were subjected to the initial data analysis. The peak values of the said sound clip samples as well as their indices were obtained. After this, a code that could analyze all the data was created in Matlab. For consistency, results of both analysis methods used the same number of FFT points and sampling rate.

Data generated from the frequency response analysis was correlated with the sweetness test data to arrive at a classification model that would represent the relationship of the frequency response to the sweetness of the watermelon. The trend line that resulted was used as a basis for the software implementation of the mobile app.

Software Implementation

The Android Studio v.1.3.1 (IDE) software was used to create the algorithm needed for maturity detection. Three stages were considered in the maturity detection process. The first stage entailed determining the frequency response of the signal through Fast Fourier Transform. The second stage consisted of a filter algorithm that was used to filter out noise. Lastly, the

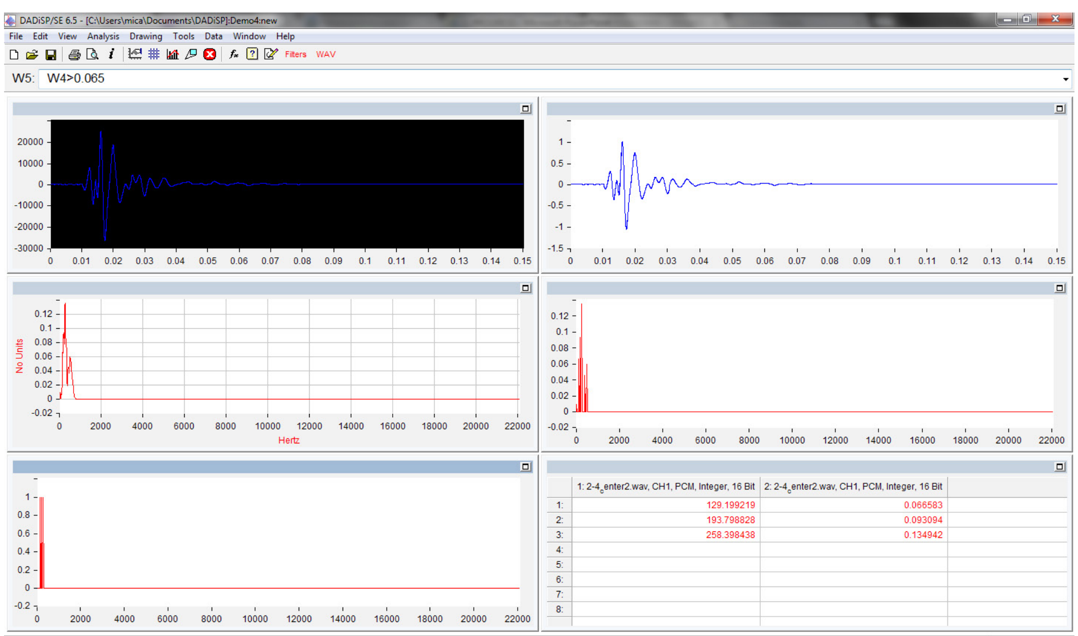

Figure 1. DADisp worksheet.

third stage was the frequency evaluation stage where the classification model derived was used to evaluate the maturity of the watermelon. The code created was implemented on an Android mobile phone. The results displayed by the app include the %Brix sweetness measurement of the watermelon and the corresponding comment: "ripe" or "unripe."

Testing and Evaluation

Twenty watermelon samples were evaluated using both the android app and the refractometer. This sample size is based on the American Society of Agricultural Engineers standard (ASAE S368.4) stating that a minimum of 20 samples is required to arrive at an acceptable level of confidence insofar as significant differences are concerned. As the results of the study showed that the frequency and sweetness indicators of maturity did not necessarily depend on the size, 20 random-sized watermelons were used. The watermelon was again subjected to thumping to validate the app created. The three thumping points in the initial procedure were once more considered as sampling points for the testing. The reading displayed in the maturity detector app was compared to the refractometer reading for each point in the sampling.

Results

Frequency Response

Each sound sample contained nine impulse signals, with three from each thumping point as seen in Figure 2. The first three impulses in the sample were produced by the top thumping point, followed by the three sound impulses from the center thumping point, while the last three were taken from the bottom thumping point. A 0.15-second length of each sound impulse, as in Figure 3, was considered one sample, saved as a

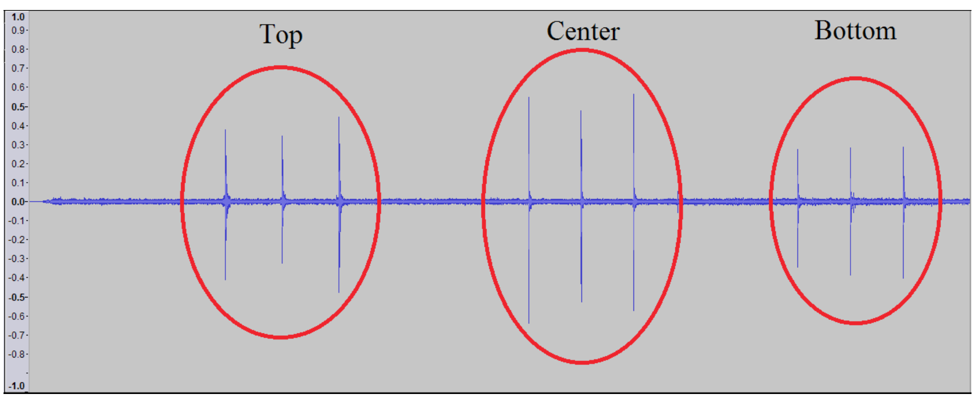

Figure 2. Sound sample.

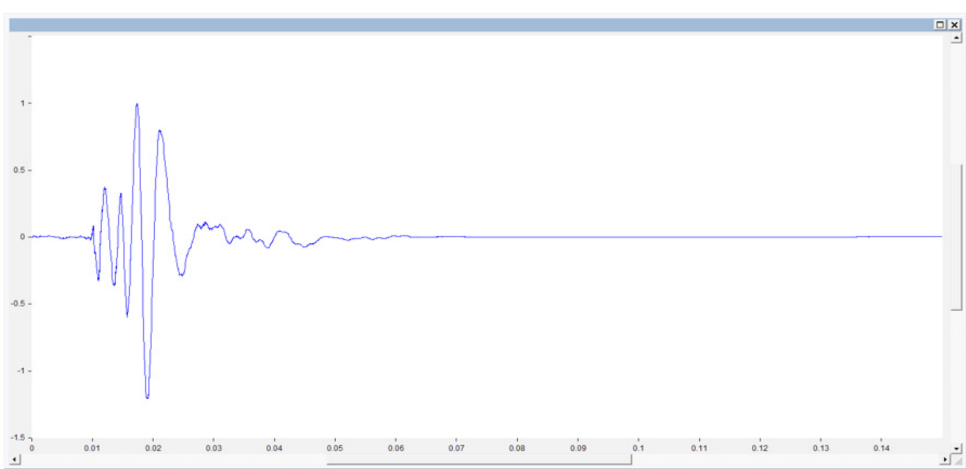

Figure 3. Time Domain of sound impulse at 0.15 second clip.

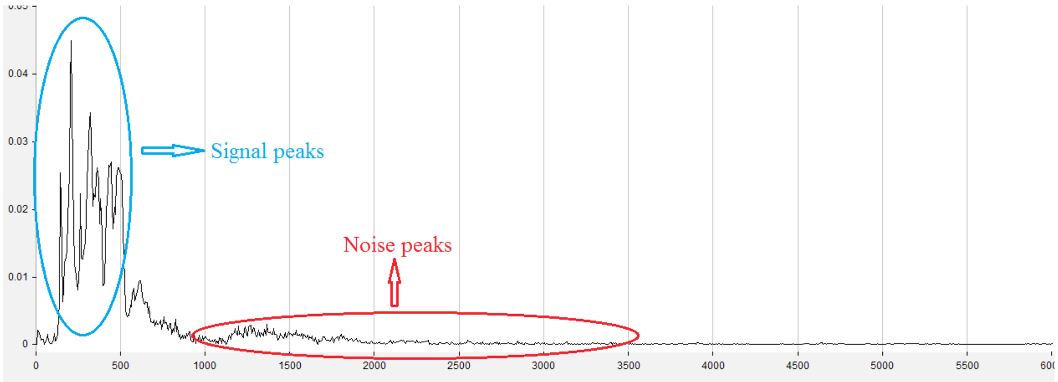

Figure 4. DADiSP analysis of 0.15 second sound clip.

wav file after initial editing for noise removal in Audacity.

Analysis of the sound sample in DADisp ensured that the peak signal frequencies were distinguished from the noise frequencies as seen in Figure 4. High peak frequencies represented the signal whereas low peak frequencies represented the noise. Results from the analysis showed that peak signal frequencies were about 500 Hz and below. Peak noise frequencies with low amplitudes were found to be around 1000 Hz and above.

With the initial analysis results, a code was created in Matlab to analyze all sound clips automatically. Sound clips were renamed in consecutive order from large to small samples starting from the bottom to the top thumping point. Each 0.15-second signal sample wav file was read using the "wavread function" and stored in an array with default data type double. This array was then normalized, dividing it by the maximum value so as to limit the values of the array between -1 and 1. A Butterworth filter was used to eliminate unwanted signals at its stopband. The order of the filter used was 10, indicating the desired attenuation response of eliminating frequencies above 1000 Hz and maintaining frequencies below 500 Hz. After the signals were filtered, these were transformed to the frequency domain using the FFT function. The index of the maximum value in the array was then determined to get the peak frequency using equation 1.

$$frequency = index \times \frac{sampling\ frequency}{array\ length}$$

(Equation 1)

Results were saved in an Excel file, as tabulated in Table 2. As seen in the table, 180 frequencies are generated from the 60 watermelon samples at all three thumping points. Results show a minimum frequency of 80.75 Hz and a maximum of 236.87 Hz.

Sweetness Measurement

The homogenized sample from each thumping point was measured using a refractometer and the results are presented in Table 3. From the results obtained, it was noted that the minimum sweetness index was measured at 5.7 %Brix and the maximum sweetness index was 10.07 %Brix.

Table 2. Frequency data of watermelon samples at all thumping points.

SAMPLE		FREQUENCY (Hz)			SAMPLE		FREQUENCY (Hz)		
		SMALL	MEDIUM	LARGE			SMALL	MEDIUM	LARGE
1	Bottom	161.5	145.35	116.64	11	Bottom	166.88	163.29	165.09
	Center	96.9	122.02	125.61		Center	122.02	156.12	118.43
	Top	138.17	154.32	96.9		Top	161.5	145.35	118.43
2	Bottom	159.7	96.9	150.73	12	Bottom	91.52	188.42	209.95
	Center	163.29	91.52	127.4		Center	129.2	113.05	86.13
	Top	183.03	172.27	91.52		Top	104.08	209.95	118.43
3	Bottom	113.05	190.21	80.75	13	Bottom	96.9	127.4	111.25
	Center	107.67	86.13	114.84		Center	102.28	91.52	134.58
	Top	118.43	145.35	152.53		Top	96.9	107.67	129.2
4	Bottom	220.72	95.1	217.13	14	Bottom	156.12	209.95	150.73
	Center	123.82	98.69	114.84		Center	123.82	113.05	129.2
	Top	166.88	209.95	148.94		Top	209.95	129.2	96.9
5	Bottom	209.95	118.43	107.67	15	Bottom	236.87	150.73	200.98
	Center	209.95	139.97	139.97		Center	139.97	91.52	145.35
	Top	118.43	107.67	107.67		Top	134.58	156.12	113.05
6	Bottom	107.67	147.14	161.5	16	Bottom	211.74	204.57	129.2
	Center	139.97	96.9	134.58		Center	215.33	123.82	129.2
	Top	148.94	91.52	107.67		Top	215.33	145.35	96.9
7	Bottom	226.1	161.5	213.54	17	Bottom	215.33	136.38	150.73
	Center	226.1	134.58	109.46		Center	215.33	91.52	139.97
	Top	226.1	136.38	147.14		Top	209.95	123.82	107.67
8	Bottom	123.82	113.05	105.87	18	Bottom	163.29	113.05	199.18
	Center	91.52	120.23	96.9		Center	156.12	107.67	150.73
	Top	98.69	113.05	123.82		Top	145.35	118.43	113.05
9	Bottom	152.53	132.79	154.32	19	Bottom	209.95	229.69	102.28
	Center	129.2	156.12	129.2		Center	113.05	118.43	134.58
	Top	102.28	134.58	132.79		Top	145.35	113.05	143.55
10	Bottom	226.1	193.8	127.4	20	Bottom	236.87	209.95	129.2
	Center	91.52	96.9	123.82		Center	139.97	113.05	129.2
	Top	226.1	127.4	113.05		Top	134.58	145.35	96.9

Table 3. Sweetness measurements of watermelon samples at all thumping points.

SAMPLE		SWEETNESS (%Brix)			SAMPLE		SWEETNESS (%Brix)		
		SMALL	MEDIUM	LARGE			SMALL	MEDIUM	LARGE
1	Bottom	7.37	7.87	8.6	11	Bottom	7.37	7.93	8.4
	Center	9.1	9.23	9.97		Center	9.17	8.9	9.23
	Top	8.53	9.5	9.2		Top	8.77	7.93	8.97
2	Bottom	7.37	9.9	9.7	12	Bottom	7.83	8.1	8.63
	Center	8.4	9.43	9.37		Center	8.5	8	9.9
	Top	6.8	7.27	9.6		Top	7.73	6.5	8.9
3	Bottom	8	9.43	9.77	13	Bottom	7.77	8.5	8.4
	Center	8.67	10.07	9.57		Center	9.3	9.27	9.13
	Top	7.7	9.2	9.07		Top	7.87	8.03	7.7
4	Bottom	6.6	8.97	8.8	14	Bottom	7.87	7.77	8.5
	Center	8.03	8.8	9.4		Center	8.23	9.3	9.77
	Top	6.37	6.4	9.4		Top	6.2	8.2	8.87
5	Bottom	7.17	9.27	8.6	15	Bottom	8.63	7.37	8.03
	Center	7.93	9.4	9.1		Center	8.93	8.63	9.1
	Top	8.5	8.77	9.43		Top	6.97	7.33	8.53
6	Bottom	8	9.33	8.23	16	Bottom	6.9	8.5	8.57
	Center	8.4	10	8.57		Center	7.83	9	8.67
	Top	8.27	9.83	8.8		Top	5.7	8.3	9
7	Bottom	6.77	8.83	8.57	17	Bottom	7.4	8.03	8.03
	Center	7.63	9.07	8.63		Center	7.8	9.53	9.2
	Top	6.1	7.84	8.37		Top	6.27	8.33	8.87
8	Bottom	7.67	8.93	9.13	18	Bottom	7.87	8.83	8.9
	Center	8.7	9.4	9.17		Center	9.03	8.97	9.77
	Top	8.27	8.22	9.23		Top	7.8	7.5	8.73
9	Bottom	8.27	8.27	8.17	19	Bottom	8.13	8.3	8.3
	Center	9.43	9.53	8.5		Center	8.63	9.3	9.07
	Top	9.9	8.83	8.37		Top	7	8.2	8.37
10	Bottom	8.33	8.77	8.5	20	Bottom	8.6	7.97	8.4
	Center	9.27	9.47	8.97		Center	8.8	8.47	8.93
	Top	7.57	8.5	8.6		Top	8.07	7.27	8.33

Correlation Analysis

The data obtained from Tables 2 and 3 were used to determine the relationship between the frequency response of the watermelon and its sweetness. Using the values of the maximum peak frequency and the sweetness measurement in %Brix, a correlation analysis was created. Correlation analyses were based on both the thumping points and the sizes of the samples.

Table 4 describes the result of the correlation analysis based on the thumping points. A negative correlation was observed between the main peak frequency and sweetness. This implies an inverse relationship between the main peak frequency and sweetness index. Hence, the greater the sweetness index, the lower the frequency is. All correlation coefficients were found to be statistically significant with P-values less than 0.05 level of significance at all thumping points. The correlation coefficient further shows that among the three thumping points, the strongest correlation existed when the watermelon was thumped on top, with a value of -0.72122. A moderate correlation coefficient of -0.55396 was evident when the watermelon was thumped at the center and a weaker correlation of -0.33139 was noted when the watermelon was thumped at the bottom. This may imply that the frequency and sweetness as indicators of the watermelon's maturity is most evident when thumping it at the upper half portion rather than the bottom of the watermelon. This could explain why it was observed that vendors thumped the upper half of the watermelon when the samples were bought.

Table 4. Correlation between frequency and sweetness based on thumping points.

THUMPING POINT	CORRELATION, R	P-VALUE
Top	-0.72122	8.04565E-11
Center	-0.55396	4.39935E-06
Bottom	-0.33139	0.00969554

The analysis based on the size of the samples is summarized in Table 5. The main peak frequency and sweetness follows a negative correlation, once more indicating an inverse relationship between the main peak frequency and the sweetness. Correlation coefficients of -0.52233 and -0.52548 may be interpreted as moderate correlation, meaning that the frequency and sweetness relationship may not necessarily be strong when the size is used as a basis. This was more evident when the frequency-sweetness correlation was evaluated on large watermelons. A weak correlation between the two parameters, with a value of -0.25056, indicates that the frequency and sweetness relationship is not necessarily based on the size. This could imply that the frequency and sweetness indicators of maturity test would not differ much on any watermelon size.

Table 5. Correlation between frequency and sweetness based on size of watermelon sample.

SIZE	CORRELATION, R	P-VALUE
Small	-0.52233	1.86333E-05
Medium	-0.52548	1.62454E-05
Large	-0.25056	0.053406713

Figure 5 shows the trendline produced by the regression/relationship of the main peak frequency data and sweetness as described by equation 2. As seen in the figure, an indirect proportion of sweetness and frequency is evident.

$$\%Brix = -0.0113 * frequency + 10.08$$

(Equation 2)

The average sweetness index resulting from Ay's study (1996) was used as a basis to determine the borderline value for the maturity detection used in the app created. Going back to the values in the study, the mature watermelon's average sweetness index was 10.66 %Brix and the non-mature watermelon's average sweetness index was 6.84. The borderline value between the mature and non-mature was determined by taking the average of the two values, resulting to a borderline value of 8.75. Any value less than 8.75 was deemed as not mature and values greater or equal to 8.75 was considered mature.

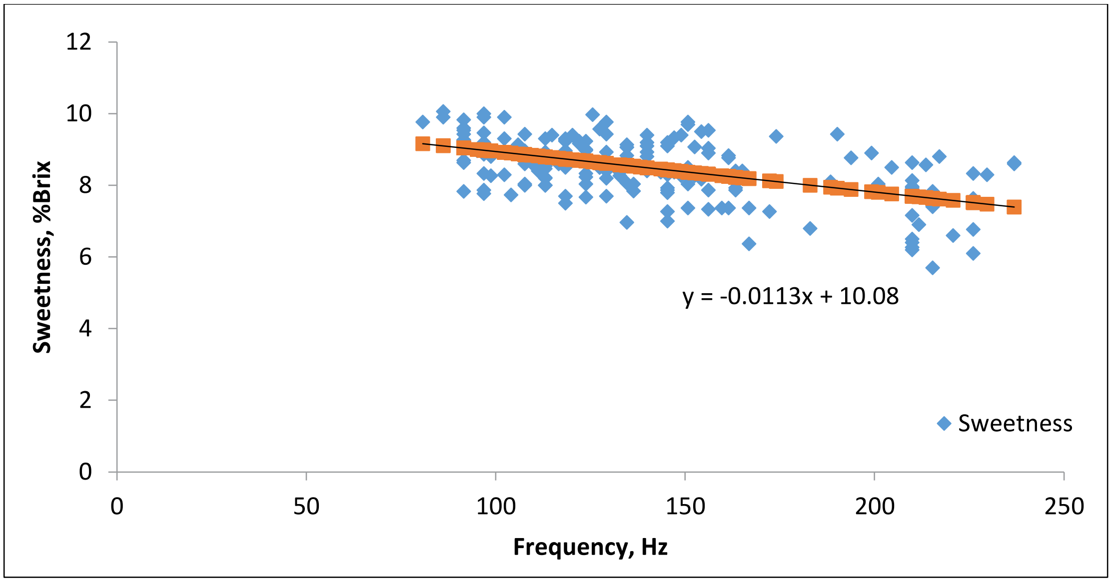

Figure 5. Relationship between frequency and sweetness for all samples.

Software Implementation

Reading and processing of the sound signal of the application was accomplished through AudioRecord objects. A sampling rate of 44100 Hz was used on a mono channel, as guaranteed to work on all devices by developer.android.com, the official website of Android developers. Past studies also confirmed the said configurations. De Moes and Valipoor (2012) noted the use the 44100 Hz sampling rate on a mono channel to initialize AudioRecord objects in their study. The same configuration settings were used to initialize AudioRecord objects in Bianchi's study (2014) where real-time audio was processed on Android systems. A sampling rate of 44100 Hz was used on a mono channel in 16-bit PCM encoding.

The right type of pulse-code modulation required was determined by trying the three available encoding choices i.e. 8-bit, 16-bit, and float in the initialization process. Both the 8-bit and float produced an error saying that the AudioRecord object was not properly initialized. Only the 16-bit encoding was able to initialize the AudioRecord object. Therefore, initialization of the AudioRecord objects used a 44100 Hz sampling rate on a mono-channel using a 16-bit PCM encoding. Furthermore, the JTransforms library, an open source, pure java FFT library, was used to transform the signal from the time domain to its frequency domain equivalent. The process was divided into two parts, noise analysis and signal analysis.

The app operation is described in the flowchart in Figure 6. Upon pressing the start button, the application will record the noise and start noise analysis to identify the maximum noise frequency. This frequency is used as a cut-off frequency for the signal analysis to determine the maximum frequency of the signal. After the noise cut-off frequency had been identified, the user must thump the watermelon for the application to detect a signal. After this, the stop button is pressed to end the process. The signal is then analyzed in the same manner as the noise was analyzed. The noise is also filtered to determine the maximum frequency of the desired signal. The resulting frequency is used in the classification model (equation 2) to determine the equivalent sweetness index. The application then shows the sweetness equivalent in % Brix and a remark showing the maturity evaluation, i.e. whether the sample is ripe or unripe.

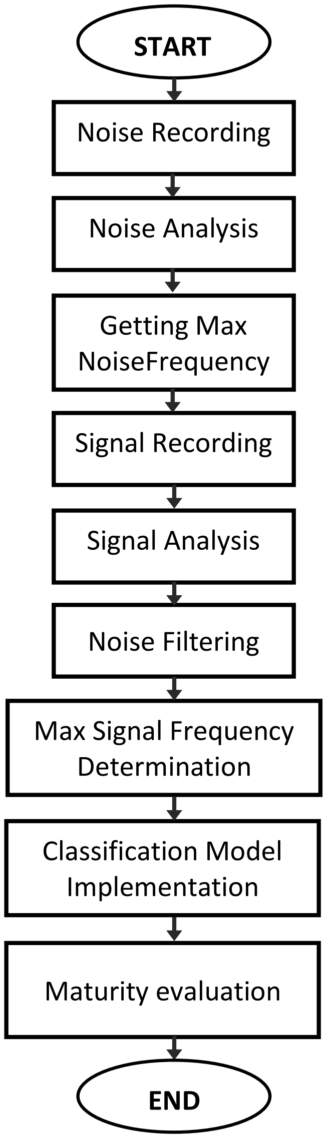

Figure 6. WatermelonChecker app process flowchart.

Sample measurements are shown in Figure 7. Figure 7a shows a measurement of a ripe watermelon while figure 7b shows the measurement of an unripe watermelon.

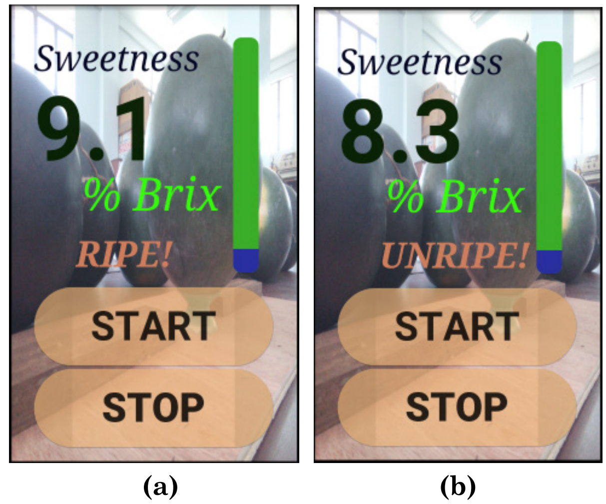

Figure 7. WatermelonChecker app measurements.
(a) ripe watermelon (b) unripe watermelons.

Accuracy of the Developed App

The app installed in the mobile phone was tested on twenty watermelon samples of random sizes. The same samples were evaluated for sweetness test using the refractometer. The readings from the app were compared to those of the refractometer and are summarized in Table 6. Accuracy of the app reading with respect to the refractometer reading for each sample and thumping point is included in the table for comparison. The label 'WC' in the table stands for 'WatermelonChecker' while 'REF' stands for refractometer. The results from Table 6 show an average accuracy of 85.9%. The standard deviation resulting from the data in Table 6 is 14.24%, implying that the there is a wide range of values derived from the accuracy results. Thus, to interpret the data in a more efficient way, the data gathered from the testing and evaluation is further analyzed by looking into the accuracy results per thumping point and per size.

Table 6. Comparison of sweetness measurement readings of the WatermelonChecker app and the refractometer.

SAMPLE		SWEETNESS (%Brix)		ACCURACY (%)	SAMPLE		SWEETNESS (%Brix)		ACCURACY (%)
		WC	REF				WC	REF	
1	Top	8.13	8.3	97.91	11	Top	7.57	5.4	59.81
	Center	7.88	8.9	88.54		Center	8.22	7.7	93.25
	Bottom	7.51	7.7	97.49		Bottom	7.54	5.2	55.06
2	Top	8.13	8.3	97.95	12	Top	7.53	6.2	78.49
	Center	8.25	9.1	90.7		Center	7.94	8.3	95.66
	Bottom	8.13	8.6	94.53		Bottom	6.6	6.7	98.51
3	Top	8.29	8.9	93.11	13	Top	7.72	6.5	81.23
	Center	7.94	9.3	85.38		Center	7.85	8	98.13
	Bottom	7.82	8.7	89.89		Bottom	5.69	7.4	76.89
4	Top	7.6	7.2	94.49	14	Top	8.4	6.4	68.75
	Center	8.38	8.2	97.85		Center	7.81	7.5	95.82
	Bottom	7.66	8.4	91.19		Bottom	7.69	6.3	77.99
5	Top	8.32	6.4	70	15	Top	6.56	5.6	82.8
	Center	8.38	8.2	97.85		Center	6.91	6	84.89
	Bottom	6.41	7.2	88.98		Bottom	6.13	6.2	98.82
6	Top	8.37	8.2	97.97	16	Top	7.03	5.8	78.74
	Center	8.26	9.1	90.73		Center	7.6	7.7	98.7
	Bottom	7.63	8.9	85.69		Bottom	6.38	6	93.67
7	Top	7.44	7.4	99.5	17	Top	7.66	6.6	83.94
	Center	8.18	8.7	94.06		Center	8.29	8.2	98.94
	Bottom	6.59	6.8	96.96		Bottom	7.59	8.2	92.56
8	Top	7.89	7.7	97.58	18	Top	7.78	6.2	74.46
	Center	7.29	8.6	84.73		Center	8.18	7.4	89.41
	Bottom	8.03	6.7	80.15		Bottom	6.47	6.5	99.54
9	Top	8.12	5	37.53	19	Top	7.47	4.8	44.31
	Center	8.31	8.1	97.37		Center	8.19	7.1	84.65
	Bottom	7.07	5.8	78.16		Bottom	6.6	5.8	86.21
10	Top	7.13	5.4	67.96	20	Top	7.29	5.1	57.12
	Center	7.19	7.5	95.91		Center	7.28	7.8	93.33
	Bottom	6.66	6.2	92.58		Bottom	6.73	4.8	59.79
								MAXIMUM	**99.54**
								MINIMUM	**37.53**
								AVERAGE	**85.90**
								STANDARD DEVIATION	**14.24**

Table 7 demonstrates the accuracy results per thumping point and per size. Greatest accuracy is evident when thumping at the center or the equator of the watermelon, with 92.79% accuracy. Least accuracy is found when thumping at the top, having a 78.18% accuracy. As to size of the watermelon sample, accuracy is greatest when the app is used on large watermelons, having a 92.89% accuracy. Small watermelon samples have the least accuracy, with a value of 82.35%. Lower accuracy results, especially on small watermelons and on top thumping points may be attributed to the fact that the range of the sweetness measurement used in the app developed was based on Ay's 6.84 – 10.66 %Brix and the actual data gathered from the testing showed a range of 4.8 – 9.3 %Brix.

Table 7. WatermelonChecker app sweetness accuracy at each point and size.

PARAMETER		ACCURACY
Thumping point	Top	78.18
	Center	92.79
	Bottom	86.73
Size	Small	82.35
	Medium	86.02
	Large	92.89

Discussion

The method for maturity detection presented in this study entailed thumping of different sizes of watermelon and processing the recorded acoustic data to determine the frequency response of the samples. Sweetness test using a refractometer was obtained after homogenizing watermelon sample disks produced at three thumping points: top, center and bottom portions of the watermelon. The resulting trend line was used as a basis for creating the WatermelonChecker app.

Results showed a negative correlation between the peak frequency and sweetness, based on size and on thumping point, showing that the frequency decreased as the sugar content increased. A stronger correlation was obtained when the frequency and sweetness correlation was based on thumping points than on size, with correlation coefficients of -0.72122, -0.55396 and -0.33139 for the top, center and bottom thumping points respectively and correlation coefficients of -0.52233, -0.52548 and -0.25056 for small, medium and large watermelons respectively. A moderate to weak frequency-sweetness correlation obtained when size was used as a basis implied that the frequency and sweetness parameters do not necessarily depend on the size. Moreover, based on the thumping point, the correlation coefficients showed that a stronger correlation existed between the frequency and sweetness when the watermelon was thumped at the upper half portions, with increasing correlation from center to top. This implied that the frequency and sweetness parameters are best observed when thumping at the upper half of the fruit.

The study included only green spherical-shaped watermelons evaluated on three thumping points that are used as a basis for determining the sweetness and frequency correlation on the top, center and bottom portions of the watermelon. Thumping points were assigned relative to the size of the watermelons, thus the samples are homogenized to assume a constant sweetness index per thumping point. Conversely, since the study aims to correlate sweetness and peak frequency, correlation among other parameters such as sweetness, size, color, texture, shelf life and the like are not included in the study and are thereby part of its limitations. Moreover, the mobile phone used in the study is assumed to have no malfunctions in its recording device, microphone, and other components/properties relevant to the phone app's performance; it is also assumed to be properly calibrated. Noise detection feature also assumes that the noise frequencies are higher than the signal frequencies, i.e., greater than 500 Hz.

Conclusion

The WatermelonChecker app developed was based on a classification model created from the correlation of frequency and sweetness. The noise detection feature created allowed the reading of the peak frequency of thumping sound to be more accurate. The app was found to have greatest accuracy when used to evaluate large watermelons and least accuracy when used on small watermelons. As to the thumping point, greatest accuracy results when thumping the watermelon at the center and least accuracy when thumping it at the top.

Based on the data presented in this study, it is thereby concluded that the WatermelonChecker app could be used to evaluate the maturity of green spherical watermelons, preferably large ones and thumped at the center or equator. Moreover, as a moderate to weak correlation existed between sweetness and frequency when the size was used as a basis, the size is not necessarily an indicator of sweetness and frequency. Hence, any size could have the same result when the thumping procedure was done on it. Finally, with the thumping point as basis, correlation coefficients tend to decrease from the top to the bottom of the watermelon. This means that the thumping point has a great effect on the maturity evaluation through sweetness and frequency parameters.

Further studies could include analysis on noise that has the same frequency as the signal produced by thumping the watermelon. Correlation analysis among other parameters such as color, texture, size, thumping points and shelf life could also be done to further evaluate the maturity of the fruit.

Acknowledgments

The authors acknowledge the financial support of the Institute of Agricultural Engineering, College of Engineering and Agro-Industrial Technology of the University of the Philippines Los Baños. Moreover, our gratitude goes to the faculty and staff of the Electrical Engineering Department and the Instrumentation Section for the use of facilities and assistance during the data-gathering process. We also thank Melvin C. Ilang-ilang and Angelo C. Ani for their help during the revision of the manuscript.

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