A Rudimentary Optical System in Detecting Ripeness of Red Watermelon

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Abstract. The purpose of this project is to detect the ripeness and quality of the watermelon particularly for red watermelon. The ripeness of the watermelon will be evaluated by using near-infrared spectroscopy sensor (NRIS). The color wavelength will classify the ripeness of the watermelon. An infrared light will be used to get the appropriate wavelength from the watermelon either from the rind or inner of it and the signal received will be analyzed. An appropriate algorithm is used to extract the information of the inner of the watermelon. A microcontroller namely Programmable Interface Controller (PIC) will be used to execute the algorithm and the result will be displayed on Liquid Crystal Display (LCD). Based on the result obtain from the device, the data is computed by using Statistical Package for the Social Sciences (SPSS). This approach is vital to verify the relationship between unripe and ripeness of red watermelon. The objective of this project is to produce an efficient system to detect the ripeness of the watermelon.

1. Introduction

Normally, determination process of fruit and vegetables quality is believed to be very crucial for both producers and processors[1]. In this work, a research has been conducted to detect the watermelon ripeness via optical system. Apparently, previous research has stated that it is very difficult to judge the ripeness of the watermelon just by examining the outward characteristics of the fruit such as the size or its external color in which different limitations are considered except with aid of experience person [2]. Hence, it is a necessity for the farmers to constantly maintain the good quality of watermelon and deliver a good supply of watermelon to the market due to the great demand on this fruit[2]. In modern agriculture, the need to maintain the quality of fruit is very important in order to improve the industry. Current and brand new technologies are being developed and projected to fully utilized the Near Infrared spectroscopy (NIR) which can offer better and non-destructive methods for measuring the quality of fresh fruit and vegetable[3].Thus, the techniques of measuring fruit and vegetables by using nondestructive methods are highly desirable[4]. As a result, researchers have actively been focused on developing non-destructive techniques in order to measure fruit quality attributes[5]. According to Nilsson(2005), NIR is becoming a routine used in agriculture , pharmaceuticals, combustion products, astronomy, food stuffs and in research[6]. In particular, fruits are categorized and sorted according to their attributes such as size, colour, and surface defects but other attributes such as firmness and total soluble solids content are also important internal quality of...
fruit products[5]. Various methods for measuring fruit quality non-destructively are being evaluated by using different technologies which include surface reflectance, diffuse reflectance, transmittance, interactance (body transmittance), fluorescence, and delayed emission from acoustical, ultrasonic, vibrational, and deformation properties[3]. Amongst these techniques, practically, the principle operation of NIR uses surface reflectance and diffuse reflectance in order to measure the ripeness of a watermelon. According to a journal published by Dull, infrared spectrometry is currently a technique that is widely used by researchers to analyze food and agricultural products, with most of the applications are using the near infrared (NIR) region which is between 700 to 2500nm [7]. The NIR region was exploited due in part to the availability of strong radiation sources and detectors with high sensitivity. Thus, NIR has been used in the non-destructive quality evaluation of a different types of fresh fruit and vegetables [7]. The main objective of this study is to discover the most appropriate algorithms to detect information of the inner content of the red watermelon. In this work, NIR technique based on surface reflectance is used to determine the watermelon ripeness based on the calculation from the surface of the watermelon. All the acquired data was analyzed by using statistical method in order to grade and evaluate the ripeness of watermelon.

2. Principle of NRIS

The electromagnetic (EM) fields that exist in a transmission medium are being gathered to create an electromagnetic spectrum[9]. The electromagnetic spectrum includes all type of electromagnetic radiation in which can be divided into the following band such as cosmic rays, gamma rays, x-rays, ultraviolet, visible light, infrared, and radio wave as shown in Figure 1.

![NIR in the Electromagnetic Spectrum](image)

**Figure 1.** The electromagnetic spectrum and NIR representation[9].

In Figure 1, NIR range is between 750-2500nm. When the light from the source such as light emitting diode (LED) is emitted, a small region or part of the light will be reflected by the surface and also after it absorbs the colour of the object. This phenomenon is called a regular reflectance [10]. The remaining radiation is transmitted through the surface of the other part of the watermelon where the transmitted radiation can be transformed into other forms of energy such as heat as illustrated in Figure 2.
3. Methodology

3.1. Introduction
This section will briefly explain the samples collection process and the hardware development for designing the watermelon ripeness detector. The hardware development phase will discuss in brief the measurement setup for NIR sensor and will be followed by some explanations on the components used.

3.1.1. Samples Collection
There are about 30 red watermelon samples were evaluated from Hypermarket and Night Market in Shah Alam Selangor. A total of 10 samples from each shop were chosen in which 10 samples from Giant supermarket, and 20 other were from 2 shops at Pasar Malam Seksyen 7 Shah Alam. A total of 30 unripe watermelon were evaluated in which from Giant supermarket and Pasar Malam Seksyen 7 Shah Alam.

3.1.2. Hardware Development
The circuit development is started by creating a schematic design by using Proteus software. All of the components were undergoing troubleshooting process to ensure the circuit is working. The programming of the PIC will be the starting of the simulation of the project. Figure 3 shows the flow chart of the hardware development.

3.1.3. Measurement Setup
There are several methods to obtain the measurement of near infrared spectra as shown in Figure 4. In reflectance mode (a), the light source or infrared light emitting diode (IRLED) and detector or phototransistor are fixed under a specific angle for example 45° in order to avoid specular reflection. In transmittance mode (b), the IRLED is pointed at the opposite of the phototransistor so that the light is able to pass through the fruit and then is detected by the phototransistor. While in interactance mode (c), the IRLED and phototransistor are placed parallel to each other in such a way that light cannot
directly enter the phototransistor due to a barrier is placed between them which physically prevented
the light from reaching the detector. Both reflectance and transmittance technique may also be applied
in order to collect light and increase the signal to noise ratio[11].

Figure 4. Setup for the acquisition of (a) reflectance, (b) transmittance, and (c) interactance spectra,
with (i) the light source, (ii) fruit, (iii) detector, (iv) light barrier, and (v) support. In interactance
mode, light due to specular reflection is physically blocked from entering the detector.[10]

The principle of the reflectance technique used in this project is indicated as in Figure 5 where the
incident radiation of the IRLED is projected to the sample and the radiation will pass through the rind
of the watermelon and detect the red part of the inside of the watermelon. The radiation is then
reflected and then detected by a phototransistor to measure its voltage[11].

Figure 5. The principle of reflectance beam diffuses into a sample

For the measurement setup, it is known that the penetration of NIR radiation into fruit tissues
decreases exponentially with the depth found a penetration depth of up to 4mm in the 700-900 nm
range between 2 and 3mm in the 900-1900 nm range[11]. Based on the Figure 6, the angle of
reflectance used was 45° so that the IR phototransistor is able to receive the infrared radiation that was
reflected from the red sample of the watermelon. The range between the sensor and the surface of the
watermelon was kept at 2.5cm in order for it to fully utilized the reflectance technique so that the
phototransistor able to receive large amount of infrared radiation[11].
When a sample is illuminated by the beam light, the reflected radiation is measured by the phototransistor. The intensity of the radiation will be measured by the receiver in the units of voltage. However, the reflectance value may be varied depends on the condition of the watermelon whether it is ripe, unripe or overripe.

3.1.4. Measurement Point

The detector used in this project is a phototransistor. The collector emitter voltage, $V_{CEO}$, is measured either on a transistor curve tracer or statically using the circuit shown in Figure 7 where voltmeter is placed between the collector and emitter[12].

Figure 7. Measurement point of $V_{CEO}$[12]

3.1.5. Near Infrared Sensor

The emitter used in this project is Honeywell SE5455-003 SE series gallium Arsenide (GaAs) Infrared emitting diode. The SE3455/5455 series consists of a GaAs infrared emitting diode mounted in a To-46 metal can package. The SE5455 series has glass lensed cans providing narrow beam angle between 20°-90°. It has the wavelength of 935nm which in the range of near infrared radiation. It is also ideal for high pulsed current applications. Figure 8 shows the structure of SE5455 GaAs Infrared emitting diode[13].
The phototransistor used in this project is from SD3443/5443 series which consists of NPN silicon mounted in a TO-46 metal can package. The SD3443 has flat window cans providing a wide acceptance angle, while the SD5443 has glass lensed cans providing a narrow acceptance angle. It is also compatible and spectrally matched to SE5455 GaAs Infrared Emitting Diode. Figure 9 shows the structure of phototransistor used[14].

3.1.6. Microcontroller PIC16F877A
This project is using microcontroller of PIC16f87XA family which has 40 pins and can be executed by using C programming language. The sensor which is the SE5443 phototransistor is connected to RA0 which is the Analog-Digital converter inside of the PIC[15] via its analog output from the emitter. The value obtained is in bit value and an algorithm is used inside the programming to display the actual voltage. From the output, the voltage of ripeness of red watermelon can be seen. Figure 10 shows the features of PIC16F877A. Figure 11 shows the PIC microcontroller kit used to program the PIC chip.
3.1.7. Liquid Crystal Display (LCD) 16x2

Liquid Crystal Display (LCD) screen is a flat panel display that uses the light modulating properties of liquid crystals. There are several types of LCD display such as 16x2 and 16x4. This project is using LCD 16x2 which is a very basic module and very commonly used in various projects and devices. Since the output of this project is only voltage, this LCD 16x2 is very suitable to be used to display watermelon ripeness. Figure 12 shows the features of LCD 16x2[16].

![Figure 12. 16x2 Liquid Crystal Display (LCD)](source)

3.1.8. Project Algorithm

Based on Figure 13, Light Emitting Diode (LED) is being projected to the rind from outer and also from the inner. From the outer and inner layer, the value of light intensity is converted into voltage in order to get the value of α and β.

![Figure 13. Presentation of how incident light is being reflected by the inner, rind & outer.](source)
Based on the fundamental of light properties on surface material[17], the following equations are extracted.

\[ i_o = \alpha + \delta_{ro} \]  
(1)

\[ i_i = \beta + \delta_{ri} \]  
(2)

Where

\[ i_o = i_i \] = incident light due to LED
\[ \alpha \] = diffuse reflectance light due to \( i_o \)
\[ \delta_{ro} \] = diffuse transmitted light due to \( i_o \)
\[ \beta \] = diffuse reflectance light due to \( i_i \)
\[ \delta_{ri} \] = diffuse transmitted light due to \( i_i \)

Since \( i_o = i_i \), equation (1) and (2) can be generalized as

\[ \beta + \delta_{ri} = \alpha + \delta_{ro} \]  
(3)

\[ \therefore \beta = \alpha + \delta_{ro} - \delta_{ri} \]  
(4)

Then, the measurement of any diffuse reflectance light at the inner section of watermelon, for any given sample of \( n=1, 2, 3, \ldots \ldots N \) can be summarized as

\[ \therefore \beta_{act}(n) = \alpha_{act}(n) + \delta_{ro}(n) - \delta_{ri}(n) \]  
(5)

Equation (5) is validated by making comparison with the measurements of diffused reflectance gathered from raw data of 200 ripe and 200 unripe watermelons. Figure 14 shows the correlation between these parameters. It is shown that the correlation is 100% (Pearson’s factor, \( r =1 \))[18].

![Figure 14. Correlation bet. diffused reflectance measurements at the inner section of watermelon](image)

Since the motive of this project is to determine ripe and unripe of red watermelon, it is viable to produce an estimation of reflectance measurement (\( \beta_{est} \)) of the inner section based on the available
measured raw data parameters such as $\alpha$, $\delta_{ro}$ and $\delta_{ro}$. The equation can be formulated by firstly, finding the average diffuse transmitted light from the measured raw data as shown below.

$$\delta_{ri}^{avg} = \frac{\sum_{n=1}^{N} \delta_{ri}(n)}{N}$$  \hspace{1cm} (6)

$$\delta_{ro}^{avg} = \frac{\sum_{n=1}^{N} \delta_{ro}(n)}{N}$$  \hspace{1cm} (7)

Finally, the estimation of reflectance measurement of the inner section of watermelon can be derived as in equation (8). It is also known as $HF$ formula representing the contributed mathematical ideas from Hadzli (Researcher) – Faiz/ Fathullah (Investigator).

$$\therefore \beta_{HF}^{est} (n) = \alpha_{act} (n) + \delta_{ro}^{avg} - \delta_{ri}^{avg}$$  \hspace{1cm} (8)

Equation (8) is also validated by making comparison between the measurements of diffused reflectance gathered from raw data of 200 ripe and 200 unripe watermelons. Figure 15 shows the correlation between these parameters. This time, the correlation is about 79% (Pearson’s factor, $r$ =0.789)[18]. The result is considered to be reliable and can be used for further statistical inference analysis in comparing ripe and unripe of red watermelon.

![Figure 15. Correlation bet. estimated diffused reflectance and actual measurements at the inner section of watermelon](image)

3.1.9. Validation Formula For Watermelon Ripeness Detector

In order to validate the samples of data collected from the red watermelon, equation (9), (10), and (11) are extracted from Table 1 in order to determine the sensitivity, specificity and accuracy of the device respectively[19].

|            | Ripe | Unripe |
|------------|------|--------|
| Display “Ripe” | TP   | FP     |
| Display “Unripe” | FN   | TN     |

Table 1. Validation of Watermelon Ripeness Detector
Sensitivity = \frac{TP}{TP + FN} \times 100\% \quad (9)

Specificity = \frac{TN}{TN + FP} \times 100\% \quad (10)

Accuracy = \frac{TP + TN}{TP + TN + FN + FP} \times 100\% \quad (11)

4. Result and Discussions

4.1. Test of Normality

The data collected were transferred to SPSS statistical software in order to identify whether the voltage readings for the raw data could be categorized as parametric samples or not. Based on Table 2, it shows the result of Kolmogorov-Smirnov (one of Normality test result) to test its normality. It can be observed that all of the samples have p-value less than 0.05 which indicate that the distributions of data are not normal. Hence, the suitable test for this population data is by using non-parametric test.

| Tests of Normality |
|---------------------|
|                      |
| Kolmogorov-Smirnov² |
| Statistic | df | Sig |
| Beta actual | ripe | 0.07 | 200 | 0.128 |
|             | unripe | 0.09 | 200 | 0.003 |
| Beta estimate | ripe | 0.10 | 200 | 0.000 |
|             | unripe | 0.14 | 200 | 0.000 |

a. Lielihood Significance Correction

4.2. Non-Parametric Test

A non-parametric test was done to ensure that the data can be validated. Table 3 shows the hypothesis between 2 groups of samples which include actual ripe and unripe data and estimate ripe and unripe data. Independent sample test of median, Mann-Whitney U and Kruskal-Wallis Test were conducted to validate the distribution of data. Based on Table III, there is overwhelming evidence that the two group of ripe and unripe are significantly different.
Table 3. Comparison Between Ripe and Unripe of Beta Actual and Beta Estimate

| Null Hypotheses                                                                 | Test                  | Sig.     | Decision                  |
|---------------------------------------------------------------------------------|-----------------------|----------|---------------------------|
| 1. The medians of ripe are the same across categories of group.                  | Independent-Samples Median Test | .000     | Reject the null hypothesis |
| 2. The distribution of ripe is the same across categories of group.             | Independent-Samples Mann-Whitney U Test | .000     | Reject the null hypothesis |
| 3. The distribution of ripe is the same across categories of group.             | Independent-Samples Kruskal-Wallis Test | .000     | Reject the null hypothesis |
| 4. The medians of unripe are the same across categories of group.               | Independent-Samples Median Test | .000     | Reject the null hypothesis |
| 5. The distribution of unripe is the same across categories of group.           | Independent-Samples Mann-Whitney U Test | .000     | Reject the null hypothesis |
| 6. The distribution of unripe is the same across categories of group.           | Independent-Samples Kruskal-Wallis Test | .000     | Reject the null hypothesis |

Asymptotic significances are displayed. The significance level is .05.

4.3. Error Bar and Box Plot

Comparison between ripe and unripe value of actual and estimated value has been done as shown in error bar in Figure 16 whereas Figure 17 shows the box plot of the sample taken between actual and predicted ripe watermelon. It shows that there is difference as can be seen visually between the value of ripe and unripe of red watermelon for both figures.

![Figure 16. Error bar of ripe and unripe watermelon (actual versus estimate)](image-url)
Based on the boxplot, the range of voltage for ripe and unripe can be estimated as shown in Table 4.

**Table 4.** Estimate range of voltage of ripe and unripe for watermelon

|          | Min(V) | Max(V) |
|----------|--------|--------|
| Ripe     | 3.30   | 3.56   |
| Unripe   | 3.57   | 3.71   |

4.4. Validation of Watermelon Ripeness Detector

Table 5 shows the resultant of using the watermelon ripeness detector to test its accuracy. In this work, there were a total 60 red watermelons which include 30 ripe and 30 unripe watermelons tested by using the device. From Table 5, its sensitivity and specificity of Watermelon Ripeness Detector are 80% and 73.3% respectively. The accuracy of the device, thus can be specified where only 76.7% of the tested watermelon gave accurate result.

**Table 5.** Validation of Watermelon Ripeness Detector

| Result from LCD | Ripe | Unripe | Total |
|-----------------|------|--------|-------|
| Display “Ripe”  | 24   | 8      | 30    |
| Display “Unripe”| 6    | 22     | 30    |
| Total           | 30   | 30     | 60    |

Sensitivity of Watermelon Ripeness Detector:

$$\frac{24}{30} \times 100 = 80\%$$

Specificity of Watermelon Ripeness Detector:
\[
\frac{22}{30} \times 100 = 73.3\%
\]

Accuracy of Watermelon Ripeness Detector:

\[
\frac{24 + 22}{60} \times 100 = 76.7\%
\]

5. Conclusion and Discussion
The outcome of the project has shown that the developed device which is Watermelon Ripeness Detector (WRD) that uses near infrared sensor is successfully able to measure the ripeness of the watermelon with the accuracy of 76.7% which is enough to justify the device effectiveness. As a conclusion, this project still need to be observed and adjustment to the device is very important in order to achieve a better validation about the ripeness of watermelon. This project could act as a stepping stone in order to develop a better watermelon ripeness detector in order to maintain the quality of fruits in market.

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