# Weight determination of mango (*Mangifera indica L.*) by frequency analysis

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**Abstract:** The study involved the fabrication and formulation of an alternative system that use natural frequency analysis for weight measurement of mango fruits. The system was mainly composed of an ADXL345 accelerometer, Arduino UNO board, stainless steel cantilever beam, frames and breadboards, and two developed program algorithms. The Frequency Detector (FD) and Frequency and Weight Detector (FWD) algorithms were written using National Instruments LabVIEW 2014. Thirty (30) carabao mango fruits of varying sizes were used during the testing process. The actual weights of the samples were obtained using a digital weighing scale. Size classification of each mango fruits based on actual weight and based on the weights predicted by the system involving natural frequency analysis was performed. The percent error using natural frequency analysis was 2.89%. Moreover, the accuracy of natural frequency analysis in size classification was determined and found that 29 out of the 30 samples were correctly classified. A verification run was performed to check the similarity of the predicted and detected frequencies of the new set of fruit samples. A t-test analysis showed that the predicted and detected frequencies had no significant difference. The average percent error between the predicted and detected frequencies was computed to be 1.10%. The verification run established that the frequency analysis could be used to estimate the weight of mango fruits and classify them in size.

**Keywords:** frequency analysis, weight, natural frequency, program algorithm, t-test

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## 1 Introduction

The mango (*Mangifera indica*) is considered as the third most important fruit crop of the Philippines based on the export volume of 671,861.93 metric tons and valued at 41.81 pesos per kilogram (wholesale) in 2013. The country's carabao mango variety is one of the best varieties in the world. The industry supports 2.5M farmers. Moreover, it promotes opportunities like large domestic market, high demand in international market for fresh, dried, and purees mango, and expanding export markets (DA-HVCDP, 2013). The Department of Agriculture (DA) identified this fruit as one of the priority crops which ensures that necessary support will be provided for the development of the mango industry. Carabao mango is also among the high-value crops to be given priority under the High-Value Crops Development Act of 1995. Mangoes have its own standards where the

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general definitions, the kinds of damage, varieties, minimum requirements, classifications, tolerances, sampling, provisions, and labelling are included.

The study of vibration can be an alternative method to determine the weight of an object. This process may provide a quick and accurate results. In agriculture, the method of determining the weight of fruits is still being done using simple mechanical scales or platform scales. It is done manually which takes more time to finish and requires that the object is in a stationary position. For faster measurement, weight determination using the concept of vibration analysis may reduce some of this time and make the whole process automatic since the concept can be implemented in a conveyor system. It is a potentially faster option since weight measurement is being performed while the product is on the move. Other processes like size classification may also be done since size is usually correlated to weight.

Natural frequency is the frequency that a system follows when it is disturbed or provided with a small oscillation. Every system has a natural frequency and it is directly related with resonance. The natural frequency depends on many factors such as tightness, length, or weight of a string (CPO Science, 2003). Fundamental frequency, on the other hand, is the lowest frequency component of a periodic waveform. Usually, it also has the highest amplitude. As will be explained further in this paper, to determine weights of mango fruits, the natural frequency of the fabricated system is estimated to be the same as the detected fundamental frequency.

Analysis of time-varying signals involves the determination of component frequencies and their amplitudes. Computer programs which implement the Fourier series analysis are now easily available among many software products. With adequate filtering and windowing techniques through simulated software programs, it is possible to eliminate unwanted signals and limit the computational work within a narrow band of frequencies.

In this work, an instrumentation system is assembled to determine the natural frequency of the system composed of the mango fruit and the containers and platform. The resulting signal undergoes spectral analysis to determine the fundamental frequency which is characteristic of the system as directly affected by the weight of the mango fruit.

Thus, this study aimed to formulate a system that determines the weight of mango fruits by natural frequency analysis. Specifically, it intended to:

(1) compare the weight obtained using the alternative system with the weight of mango obtained using a digital weighing scale; (2)determine the accuracy of the alternative weighing system; and (3)use the developed system to perform size classification on the mango samples.

## 2 Materials and methods

The main parts of the hardware components (Figure 1) are the cantilever beam, base frame, breadboard, Arduino board, platform, and ADXL345 accelerometer. The computer used was equipped with Intel® Core™ i5-4210U 2.4 GHz processor with 4096 MB of RAM. It was also installed with AMD Radeon R5 M230 graphics processing unit. The operating system of the computer was a Microsoft® Windows® 10 Pro 64-bit.

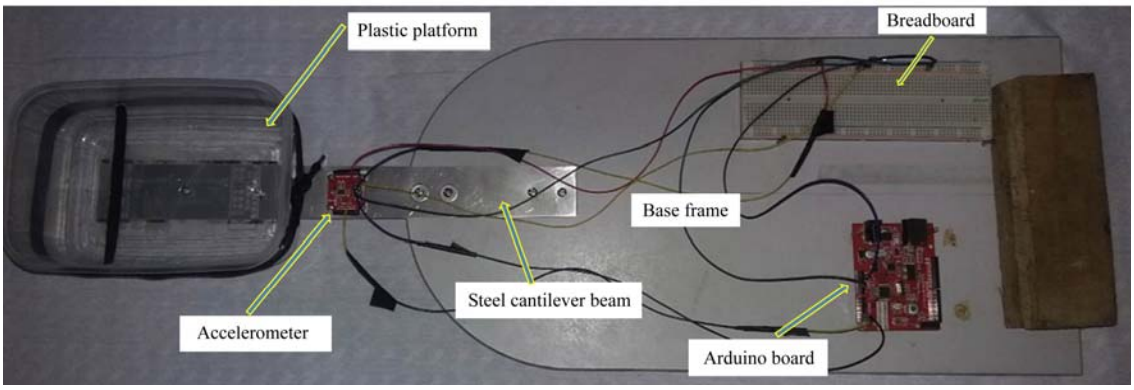


Figure 1 The hardware assembly

The heart of the instrumentation system is the accelerometer which detects displacement in the z-axis. The signals characterized by the regularly timed upward and downward motion are transmitted by the Arduino microcontroller to the computer for spectral analysis.

### 2.1 Calibration of the device

The device was calibrated using 14 different calibration loads. In each test run, the load is placed in the container platform and an excitation was applied at the free end of the cantilever beam. Vibration signals are detected by the accelerometer and are transmitted to the computer through the Arduino microcontroller. The Frequency Detector (FD) program written in LabVIEW 2014 performs the necessary analysis of signals (Seen discussion below). All data were recorded in an Excel file. From the frequency data, calibration curves were generated which would later be used to estimate the weight of the applied load.

### 2.2 Test procedure and verification run

A total of 30 samples of carabao mango fruits procured from the local market were used. The weight of each fruit was determined using a digital weighing scale. The digital weighing scale used was a Shimadzu ELB600 model which has a maximum capacity of 600 g and minimum reading of 0.01 g. The obtained values were the actual weights of each mango and were used as comparison for the weights obtained using frequency analysis.

The weights of the same samples were then determined using the developed alternative system, this time using the Frequency and Weight Detector (FWD) program also written in LabVIEW 2014 (Seen discussion below). The procedure consisted of putting each fruit on the platform, and a manual excitation was applied at the free end of the beam. Three trials were performed for each fruit.

After testing a total of 30 samples, another five mango fruits were used during the verification run. The actual weights of each sample were determined using a digital weighing scale. The obtained actual weights were then substituted to the equation generated from the calibration curve in order to determine the predicted frequency of each sample. The samples were subjected to vibration tests on the fabricated device. The obtained vibration data was used to determine the fundamental frequency. The predicted and measured frequencies were compared.

### 2.3 The frequency and weight determination programs

To determine the frequencies and estimate weights, two program algorithms, the Frequency Detector (FD) and the Frequency and Weight Detector (FWD) were written in LabVIEW 2014 of the National Instruments. LabVIEW is a graphics-based programming language which uses blocks with pre-coded functions and virtual wires to connect one programming block to another. The two programs use LINX, a third-party add-on, to communicate with the ADXL345 accelerometer and the Arduino board. FD program was used during the calibration of the device, while FWD was used during actual testing and verification run.

a) The Frequency Detector (FD)

Figure 2 shows the front panel (interface) and the block diagram (code diagram) of the FD program. The numbers on the front panel and the block diagram correspond to the different algorithms implemented on the program. Label 1 corresponds to the algorithm that establishes the communication between the ADXL345 accelerometer and the Arduino UNO board. In addition, a For-loop was added which corresponds to the number of times the program will run. A constant of 1 was used.

Label 2 corresponds to the acquisition of data from the incoming signal. Another For-Loop was used to take all the data and put them in an array. Only the signal from the z-axis was analyzed because the direction of the vibration of cantilever beam was in the direction of the z-axis. The number of samples to be taken was set at 100. The samples collected were plotted in real-time in the Time Domain Sequence graph.

The algorithm labelled as 3, although it was not used in the study, basically collected the time between detected peaks from the incoming signal. The average time was computed and an average frequency of the vibration was obtained.

The algorithm labelled as 4 includes the filter and frequency analysis algorithm. The incoming raw signal enters the filter algorithm to eliminate unnecessary frequencies and to undergo Fourier analysis. The resulting signal with the highest amplitude and its corresponding fundamental frequency was plotted on the Frequency Domain Sequence graph. The values of the amplitude and the fundamental frequency were shown in the textbox indicator above the graph.

The inclusion of the bandpass filter in the algorithm 4 served to simplify the spectral analysis. Initial test runs have shown that fundamental frequency of the signals was within the 100 Hz and 500 Hz range.

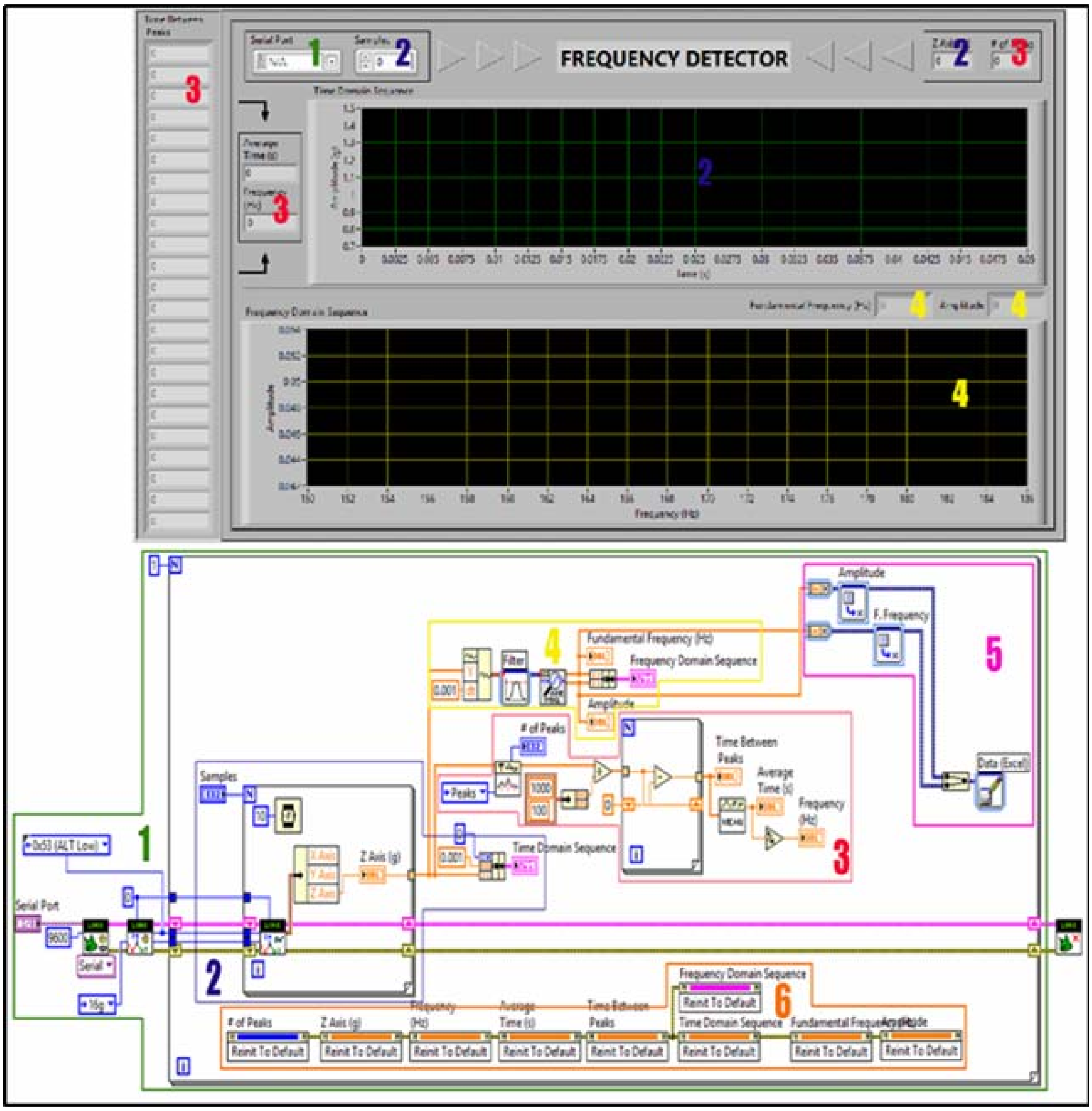


Figure 2 Frequency Detector front panel (top) and block diagram (bottom)

The number 5 algorithm is the write data algorithm. It records the amplitude and the fundamental frequency in a single Excel file named “Data.xlsx”. Lastly, the number 6 algorithm was the reset algorithm. It re-initializes all controls and indicators (except for the serial port and the number of samples) back to its default value before another test run was made.

b) The Frequency and Weight Detector (FWD)

Figure 3 shows the front panel and block diagram of the FWD program. The number 1 and number 2 algorithms were the same as in the FD program. The time between peaks were removed in the FWD program. However, it only displayed how many peaks were detected from the raw signal.

Number 4 algorithm was the same filter and frequency analysis implemented in the previous program. An added feature is the weight calculation algorithm. The established equation from the calibration of the device was included in this algorithm.

The number 5 algorithm was the same writing data algorithm only that the weight was included in the data recorded in a single Excel file named “Weight.xlsx”. Number 6 was the same reset algorithm. Lastly, the number 7 algorithm was the size classification algorithm. The LED light indicators turns on depending where the calculated weight falls in the provided range.

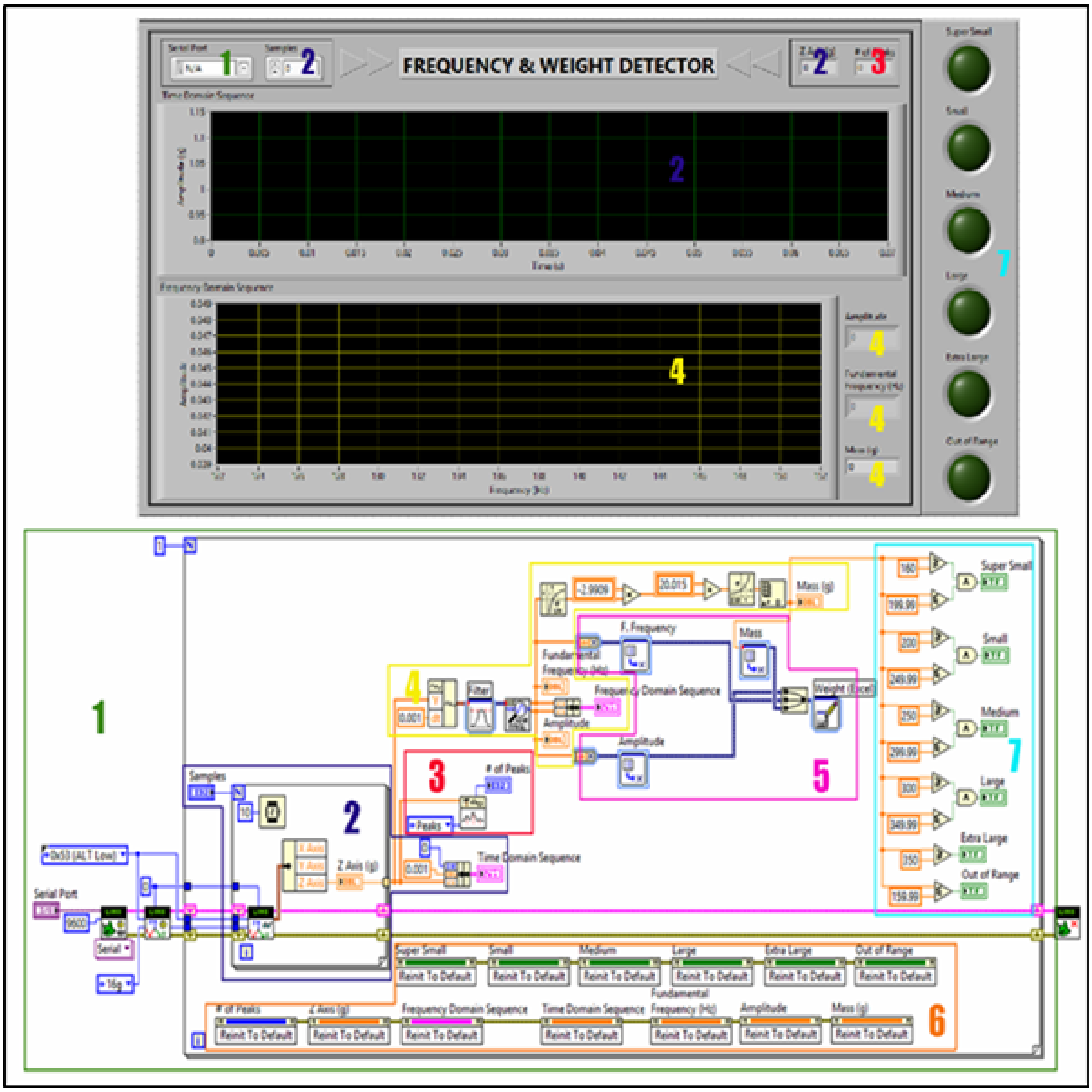


Figure 3 Frequency & Weight Detector front panel (top) and block diagram (bottom)

## 3 Results and discussion

### 3.1 The generated calibration curves

The results of the calibration tests are shown in Table 1 below. The respective natural logarithmic (ln) values of the data were also calculated and included in the table for the purposes of analysis of their relationship. Three plots of the data are shown in Figures 4, 5 and 6.

The curves show that the ln-ln relationship is the most linear among the three relationships. Its $R^2$ value (0.9984) is much higher than the normal-normal and the ln-normal curves. The indicated equation established in the ln-ln relationship was used in the determination of the mango weights.

**Table 1 Load applied, fundamental frequency, ln(load), ln(fundamental frequency)**

| Load (g) | ln (load) | Fundamental frequency (Hz) | ln(Fundamental frequency) |
|---|---|---|---|
| 0 | --- | 328.75 | --- |
| 30 | 3.40 | 255.66 | 5.54 |
| 50 | 3.91 | 215.66 | 5.37 |
| 100 | 4.61 | 175.46 | 5.17 |
| 150 | 5.01 | 152.32 | 5.03 |
| 180 | 5.19 | 143.55 | 4.97 |
| 200 | 5.30 | 139.78 | 4.94 |
| 230 | 5.44 | 130.92 | 4.87 |
| 250 | 5.52 | 127.04 | 4.84 |
| 280 | 5.63 | 122.28 | 4.81 |
| 300 | 5.70 | 119.51 | 4.78 |
| 330 | 5.80 | 114.59 | 4.74 |
| 350 | 5.86 | 112.56 | 4.72 |
| 380 | 5.94 | 109.89 | 4.70 |

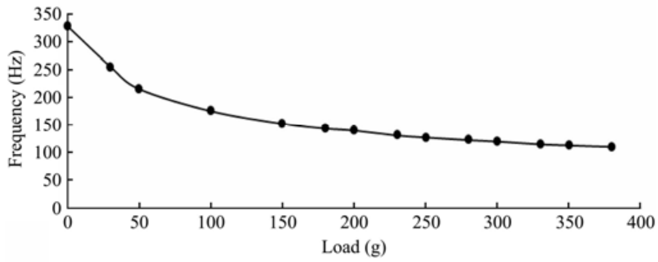


Figure 4 Generated calibration curve; load (normal scale), fundamental frequency (normal scale)

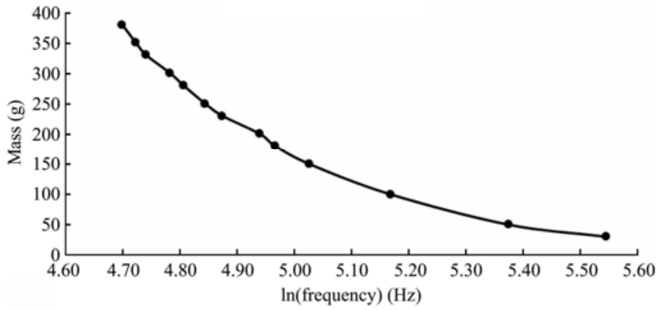


Figure 5 Generated calibration curve; load (normal scale), fundamental frequency (ln scale)

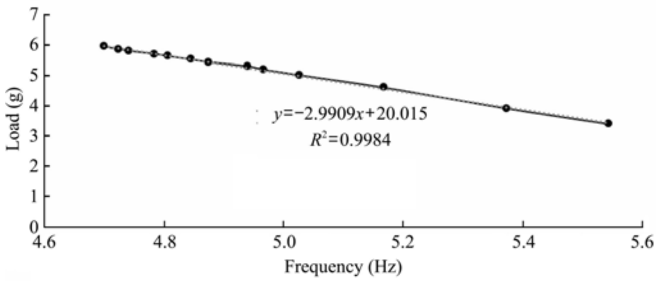


Figure 6 Generated calibration curve; load (ln scale), fundamental frequency (ln scale)

### 3.2 Frequency analysis of mango fruits

The predicted weight of each of the thirty mango samples was determined using frequency analysis implemented in the FWD program created in LabVIEW. Three trials were done in determining the model weight of each sample. The detected fundamental frequencies and average values are shown in Table 2 below.

**Table 2 Detected fundamental frequencies for each trial**

| Sample | Frequency (Hz) Trial 1 | Frequency (Hz) Trial 2 | Frequency (Hz) Trial 3 | Average frequency (Hz) |
|---|---|---|---|---|
| 1 | 135.62 | 133.61 | 132.08 | 133.77 |
| 2 | 131.64 | 133.72 | 131.01 | 132.12 |
| 3 | 140.23 | 139.45 | 138.78 | 139.49 |
| 4 | 134.13 | 128.58 | 129.83 | 130.85 |
| 5 | 137.88 | 135.81 | 136.64 | 136.78 |
| 6 | 134.57 | 132.22 | 132.11 | 132.97 |
| 7 | 140.72 | 135.77 | 138.07 | 138.19 |
| 8 | 133.19 | 131.79 | 130.95 | 131.98 |
| 9 | 133.22 | 134.20 | 133.44 | 133.62 |
| 10 | 137.50 | 136.88 | 137.08 | 137.15 |
| 11 | 141.11 | 145.75 | 138.48 | 141.78 |
| 12 | 136.15 | 136.36 | 135.41 | 135.97 |
| 13 | 129.67 | 129.69 | 130.58 | 129.98 |
| 14 | 131.24 | 131.43 | 130.56 | 131.08 |
| 15 | 135.69 | 136.69 | 133.97 | 135.45 |
| 16 | 120.71 | 121.38 | 121.94 | 121.34 |
| 17 | 127.87 | 130.29 | 129.33 | 129.16 |
| 18 | 116.49 | 115.04 | 113.45 | 114.99 |
| 19 | 126.24 | 127.40 | 126.87 | 126.84 |
| 20 | 121.66 | 125.47 | 121.12 | 122.75 |
| 21 | 123.77 | 126.50 | 125.55 | 125.27 |
| 22 | 127.50 | 130.63 | 129.11 | 129.08 |
| 23 | 131.27 | 130.36 | 129.64 | 130.42 |
| 24 | 128.01 | 126.83 | 125.04 | 126.63 |
| 25 | 127.55 | 128.19 | 130.49 | 128.74 |
| 26 | 118.38 | 119.56 | 122.13 | 120.02 |
| 27 | 130.74 | 129.31 | 127.97 | 129.34 |
| 28 | 125.34 | 124.03 | 126.17 | 125.18 |
| 29 | 122.95 | 122.51 | 120.58 | 122.01 |
| 30 | 133.95 | 133.35 | 133.69 | 133.66 |

Using the above frequencies and based on the ln-ln relationship earlier established (See Figure 6 above), the predicted weights were determined. Table 3 below shows the predicted and the actual weights of the fruits.

A t-test analysis (Table 4) was performed. It was found out that the actual weight and the predicted weight have no significant difference since the critical t-value (2.0025) is greater than the t-value (–0.6466). This is also confirmed by the p-value of 0.5205 or 52.05%. In other words, there is a 52.05% chance that the actual weight and the predicted weight are the same.

In addition, the percent error for each sample was also calculated to check the differences between the two measurements. The highest percent error was 10.17% and the lowest percent error was 0.03%. Furthermore, the average percent error calculated was 2.89%. The maximum margin of error for weighing scales is 10% according to the NIST Handbook 44 (2015). The possible sources of errors were as follows:

(1) The mango counteracts the applied excitation when it is not tightly secured in the platform.

(2) When the applied load was too heavy the beam bent and had to be re-aligned before another test run was made.

(3) The manually applied excitation was not constant for each trial.

**Table 3 Predicted weights and actual weights of the mango fruit samples**

| Sample | Predicted weight (g) | | | Average predicted weight (g) | Actual weight (g) |
|---|---|---|---|---|---|
| | Trial | | | | |
| | 1 | 2 | 3 | | |
| 1 | 206.47 | 215.89 | 223.44 | 215.12 | 204.10 |
| 2 | 225.69 | 215.37 | 228.95 | 223.24 | 213.15 |
| 3 | 186.81 | 189.95 | 192.73 | 189.81 | 190.85 |
| 4 | 213.38 | 242.16 | 235.26 | 229.82 | 208.60 |
| 5 | 196.52 | 205.61 | 201.87 | 201.28 | 201.00 |
| 6 | 211.29 | 222.77 | 223.31 | 219.03 | 211.15 |
| 7 | 184.90 | 205.77 | 195.68 | 195.20 | 192.40 |
| 8 | 217.94 | 224.93 | 229.27 | 223.98 | 216.55 |
| 9 | 217.81 | 213.04 | 216.74 | 215.84 | 215.90 |
| 10 | 198.12 | 200.85 | 199.93 | 199.63 | 195.70 |
| 11 | 183.37 | 166.44 | 193.98 | 180.78 | 188.55 |
| 12 | 204.07 | 203.13 | 207.44 | 204.86 | 196.85 |
| 13 | 236.09 | 235.98 | 231.22 | 234.43 | 219.05 |
| 14 | 227.78 | 226.80 | 231.33 | 228.61 | 215.70 |
| 15 | 206.15 | 201.66 | 214.18 | 207.24 | 204.75 |
| 16 | 292.50 | 287.69 | 283.73 | 287.95 | 271.35 |
| 17 | 246.19 | 232.77 | 237.99 | 238.89 | 236.60 |
| 18 | 325.31 | 337.77 | 352.13 | 338.17 | 313.95 |
| 19 | 255.80 | 248.90 | 252.05 | 252.24 | 253.00 |
| 20 | 285.74 | 260.56 | 289.57 | 278.20 | 277.45 |
| 21 | 271.38 | 254.23 | 260.03 | 261.77 | 260.95 |
| 22 | 248.36 | 230.94 | 239.17 | 239.35 | 238.10 |
| 23 | 227.58 | 232.37 | 236.27 | 232.05 | 229.85 |
| 24 | 245.37 | 252.26 | 263.26 | 253.49 | 251.85 |
| 25 | 248.01 | 244.33 | 231.69 | 241.23 | 238.50 |
| 26 | 310.07 | 301.03 | 282.43 | 297.53 | 285.85 |
| 27 | 230.38 | 238.07 | 245.59 | 237.92 | 234.75 |
| 28 | 261.33 | 269.68 | 256.24 | 262.35 | 259.70 |
| 29 | 276.84 | 279.85 | 293.44 | 283.25 | 271.70 |
| 30 | 214.25 | 217.15 | 215.53 | 215.63 | 222.15 |

**Table 4 t-test analysis between the actual weight and predicted weight**

| | Actual weight (g) | Predicted weight (g) |
|---|---|---|
| Mean | 230.6683 | 236.2960 |
| Variance | 1029.5297 | 1243.0717 |
| Observations | 30 | 30 |
| Hypothesized Mean Difference | 0 | |
| df | 57 | |
| t Stat | -0.6466 | |
| P(T≤t) two-tail | 0.5205 | |
| t Critical two-tail | 2.0025 | |

## Size classification

The Bureau of Agriculture and Fisheries Product Standards (BAFPS) has the following tables for the classification of mango based on weight.

Based the above table, the actual and the predicted weights of the mango samples were classified with the following results.

**Table 5 Size classification of green carabao mango fruits**

| Size | Weight (g) | Number of pieces/carton | | | |
|---|---|---|---|---|---|
| | | 2.5 kg | 5.0 kg | 10.0 kg | 12.0 kg |
| Extra large | >350 | 6 - 7 | 12-14 | 24-28 | 30-32 |
| Large | 300-349 | 8 | 16 | 32 | 41-43 |
| Medium | 250-299 | 10 | 20 | 40 | 41-50 |
| Small | 200-249 | 12 | 24 | 48 | 51-63 |
| Super small | 160-199 | 14-16 | 28-32 | 56-64 | 64-75 |

Note: Source: PNS-BAFPS 13-2004: Mangoes.

**Table 6 Comparison of the actual and predicted size classification of the mango samples**

| Sample | Actual weight (g) | Actual size classification | Predicted weight (g) | Predicted size classification | T/F |
|---|---|---|---|---|---|
| 1 | 204.10 | Small | 215.12 | Small | T |
| 2 | 213.15 | Small | 223.24 | Small | T |
| 3 | 190.85 | Super Small | 189.81 | Super Small | T |
| 4 | 208.60 | Small | 229.82 | Small | T |
| 5 | 201.00 | Small | 201.28 | Small | T |
| 6 | 211.15 | Small | 219.03 | Small | T |
| 7 | 192.40 | Super Small | 195.20 | Super Small | T |
| 8 | 216.55 | Small | 223.98 | Small | T |
| 9 | 215.90 | Small | 215.84 | Small | T |
| 10 | 195.70 | Super Small | 199.63 | Super Small | T |
| 11 | 188.55 | Super Small | 180.78 | Super Small | T |
| 12 | 196.85 | Super Small | 204.86 | Small | F |
| 13 | 219.05 | Small | 234.43 | Small | T |
| 14 | 215.70 | Small | 228.61 | Small | T |
| 15 | 204.75 | Small | 207.24 | Small | T |
| 16 | 271.35 | Medium | 287.95 | Medium | T |
| 17 | 236.60 | Small | 238.89 | Small | T |
| 18 | 313.95 | Large | 338.17 | Large | T |
| 19 | 253.00 | Medium | 252.24 | Medium | T |
| 20 | 277.45 | Medium | 278.20 | Medium | T |
| 21 | 260.95 | Medium | 261.77 | Medium | T |
| 22 | 238.10 | Small | 239.35 | Small | T |
| 23 | 229.85 | Small | 232.05 | Small | T |
| 24 | 251.85 | Medium | 253.49 | Medium | T |
| 25 | 238.50 | Small | 241.23 | Small | T |
| 26 | 285.85 | Medium | 297.53 | Medium | T |
| 27 | 234.75 | Small | 237.92 | Small | T |
| 28 | 259.70 | Medium | 262.35 | Medium | T |
| 29 | 271.70 | Medium | 283.25 | Medium | T |
| 30 | 222.15 | Small | 215.63 | Small | T |
| Accuracy | | | | | 29/30 or 96.67% |

From the table above, the accuracy of using frequency analysis in mango size classification was found out to be 29 out of the 30 samples or 96.67% were correctly classified. Figure 7 shows representative fruit samples for each size category.

(a)

(b)

(c)

(d)

Figure 7 Size classification (a) super small, (b) small, (c) medium, and (d) large

### 3.3 Verification run

The verification run was the reverse of the earlier procedures. The frequency was the unknown parameter and the weight was known. This was done to verify whether the detected frequency is close to the predicted frequency. The predicted frequency was obtained by substituting the actual weight (measured using a digital weighing scale) to the established equation. The detected frequency and the weight were obtained from the created program.

**Table 7 Predicted and detected frequencies obtained during verification run**

| Sample | Predicted | | Detected | |
|---|---|---|---|---|
| | Weight (g) | Frequency (Hz) | Weight (g) | Frequency (Hz) |
| 1 | 272.20 | 123.65 | 278.99 | 122.63 |
| 2 | 350.30 | 113.65 | 380.10 | 110.60 |
| 3 | 244.65 | 128.14 | 246.66 | 127.79 |
| 4 | 277.35 | 122.87 | 269.49 | 124.06 |
| 5 | 374.80 | 111.11 | 383.57 | 110.25 |

It can be observed that the predicted and the detected frequencies were relatively close to one another. A t-test analysis (Table 8) was performed to check the level of significance between them. A p-value >0.05 after t-test means that difference is not significant, while a p-value <0.05 means that the difference is significant (Biddix, 2009). The predicted frequency and the detected frequency have no significant difference since the critical t-value (2.3060) is greater than the t-value (–0.1681) and this is confirmed by the p-value of 0.8707 or 87.07% which is greater than 0.05. In other words, there is an 87.07% chance that the predicted and detected frequency are the same.

**Table 8 t-test analysis between predicted frequency and detected frequency**

| | Predicted frequency (Hz) | Detected frequency (Hz) |
|---|---|---|
| Mean | 119.0674 | 119.8828 |
| Variance | 65.8023 | 51.7978 |
| Observations | 5 | 5 |
| Hypothesized Mean Difference | 0 | |
| df | 8 | |
| t Stat | -0.1681 | |
| P(T≤t) two-tail | 0.8707 | |
| t Critical two-tail | 2.3060 | |

The percent error between the predicted and detected frequencies was 1.10% and is shown in Table 9.

**Table 9 Computed percent error between predicted and detected frequency**

| SAMPLE | PERCENT ERROR |
|---|---|
| | Predicted vs Detected |
| | Frequency (Hz) |
| 1 | 0.82 |
| 2 | 2.69 |
| 3 | 0.27 |
| 4 | 0.97 |
| 5 | 0.77 |
| Average | 1.10 |

## 4 Conclusion

The method of determining the weight of mango is still done using traditional weighing scales which requires the mango to be stationary. Hence, this study may provide an alternative method in determining the weight by correlating it to the natural frequency produced. It may also be implemented in a conveyor system making the process of weight measurement automatic and potentially faster since weight is measured while the mango is on the move.

## 5 Recommendations

The study has been limited by several factors. In order to further improve the performance of the alternative system, the platform to be used must be wider so that it can fit bigger mango and can be easily secured tightly into place. Also, a constant excitation force is recommended during calibration and testing. An automatic device that can provide this force is highly recommended. Load cells with strain gauge may also be used instead of an accelerometer.

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