Arduino-based Sound Acquisition System for Coconut Maturity Classification Using Fast Fourier Transform Algorithm

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Abstract*— The farmers and vendors in the Philippines classify coconuts through knocking manually either by bare hands or knife as 'mala-uhog', 'mala-kanin' and 'mala-tenga'. The said technique is well-known but yet carries no scientific proof. Thus, the proponents conducted this study to develop a knocking device that automatically classify coconuts by characterizing its maturity according to meat thickness and peak frequency using Fast Fourier Transform (FFT) algorithm. Sixty coconuts were sampled; each being initially categorized by a 'mangangatok' to the stage it belongs using the conventional method. Each were knocked using a knife at a constant distance and then opened right after for the measurement of its meat thickness using a Vernier Caliper. The recorded sounds were then analyzed using FFT Algorithm in OCTAVE. Statistical analysis show that each of the three stages has high correlation between 0.869 and 0.897 in terms of meat thickness versus peak frequency. Results showed that 'malauhog' coconuts have peak frequency range of about 200 to 400 Hz, 400 to 600 Hz for 'malakanin' and 600 to 800 Hz for 'malatenga'. From these results, a standalone Arduino-based sound acquisition knocking device was developed. The Sound acquisition system is designed to be portable. Its functionality was tested by sampling 119 random coconuts. Results showed that out of 119 there were 10 errors made by the device, exhibiting 91.6% accuracy. The device has capabilities of classifying maturity stages of coconuts which provides efficiency for vendors and compatibility for consumers with no knowledge in the currently known method.

***Keywords*—knocking device, coconut, Fast Fourier algorithm (FFT), mala-uhog, mala-tenga, mala-kanin, peak frequency**

I. INTRODUCTION

The 'mangangatoks' are very important workers of the coconut industry in the Philippines. The skills they possess through traditional knocking of the shell using a knife is very notable and dates back ever since the industry existed. It is a traditional method that is practiced ever since then, but comes with some disadvantages. The said approach is well known yet a tedious and time-consuming process [1]. It is also unsafe since they are using a knife in tapping. Sense of hearing also declines as people age, thus farmer's performance may be affected [2]. Thus, the proponents revolutionized this method by making a self-automated device that is very efficient, safe and portable by using the Fast Fourier Transform Algorithm (FFT).

Coconuts can be categorized into three different stages. These are 'mala-uhog'(mucous-like), 'mala-kanin'(cooked-rice like) and 'malatenga' (leather-like) as shown in Fig. 1.

A coconut with soft and gelatinous meat and about 6-month old is 'mala-uhog'. 'Mala-kanin', on the other hand, is 7-8 month old and has soft meat turned into a firm solid consumption. And 'mala-tenga', 8-9 month old, has thick meat which is no longer suitable for fresh consumption [2].

a. Mala-uhog

b. Mala-kanin

c. Mala-tenga

Fig. 1. Three stages of coconut maturity

Many efforts has been done in characterizing coconuts which includes the dehusking of coconuts before being dropped [3] and by using an acoustic tester [4]. Customizing sound boxes has also been done to knock the coconuts [2]. Likewise, almost all of the sounds recorded in the studies mentioned was processed using the Fast Fourier Algorithm

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(FFT) which visualizes the signal in frequency domain from time domain [5]. It has the best capabilities when compared to other algorithms such as Autocorrelation [6].

Other studies also used methods such as FFT and the like in the characterization of different crops aside from coconuts such as eggs [7], tomatoes [8] and watermelons by acquiring vibrations [9] or by android application [10].

The objectives of this study are as follows: 1) to characterize coconut maturity using its meat thickness and sound processing, 2) to design and develop a coconut knocking device, 3) to design a sound acquisition circuit to be integrated with a coconut knocking device, 4) to identify the best sampling method appropriate for sorting coconut maturity level, 5) to characterize coconuts (frequency) of three maturity level using the developed device and spectral analysis in Arduino and 6) test its functionality.

By conducting this study, the classification of the coconuts will be more trustworthy. It will help farmers to identify coconuts that will be made into several products [11] (e.g. as copra, virgin coconut oil, coconut cream, coconut milk, desiccated coconut, coconut water, nata de coco, etc.) with more efficiency and precision. On the side of the consumers, they would be able to find their preferred quality without the help of anyone.

II. METHODOLOGY

This study is divided into three parts: the coconut meat characterization; the prototype development.

A. Coconut Meat Characterization

Sixty coconuts were sampled; each being initially categorized by a *'mangangatok'* to the stage it belongs using the conventional method. Fig. 2 shows the block diagram of the sampling method done by the proponents. The coconuts were first knocked inside a soundproof box and then opened to measure the meat thickness. The sound produced was then analyzed using a computer through Fast Fourier Algorithm in OCTAVE software.

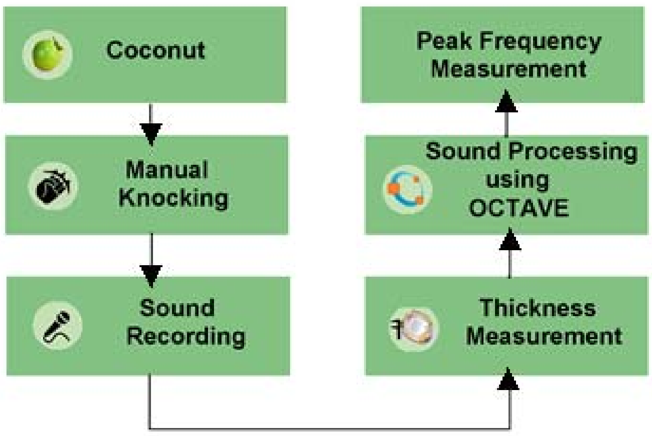

Fig. 2. Sampling Method Block Diagram

1) Manual Knocking

Each coconut was taken into an improvised sound box which has an electret microphone inside connected externally to a computer. The purpose of the box is to isolate each to the outside environment so that the recorded sounds are as quiet as possible. Before knocking the coconuts with a *knife* edge, the distance was considered. The distance was measured from the top of the box to the shell.

2) Thickness Measurement

After acquiring the sounds, the coconuts were opened right after for the measurement of meat thickness using a Vernier caliper.

3) Sound Processing

The recorded sounds were then processed through OCTAVE [12] using the Fast Fourier Algorithm (FFT). The peak frequency of each sample was considered and tabulated. Fig. 3 shows an example spectral graph of the sound files using the algorithm. The first shows the original sound signal in time domain and the second shows the signal in the frequency domain. The graph of the signal in frequency domain was used for finding the value of the highest peak frequency.

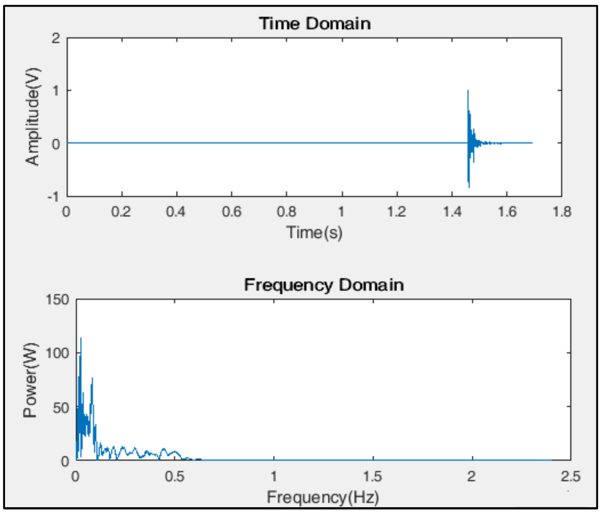

Fig. 3. Spectral Analysis of Recorded Coconut Sounds

Fast Fourier transform is used to transform a signal from time domain to frequency domain. In doing that, certain features such as frequency, amplitude and average power could be computed. Below is the Fast Fourier transform formula used [13]:

$$X_k = \sum_{n=0}^{N-1} x_n e^{-i2\pi kn/N}$$

where,

$$\mathrm{k} = 0,1,2, \dots \dots \dots, \mathrm{N}-1$$

$$\mathrm{N} = \mathrm{FFT\ size}$$

$$X_n = TIme\ Domain\ Samples$$

$$X_k = Frequency\ Domain\ Samples$$

B. Development of the Knocking Device

1) Chassis Design

The authors iterated several chassis designs in the development of the prototype. It took three fabricated devices before the final fabricated design was developed. Figures 4 and

5 show the evolution of device in proposed and actual fabricated design, respectively.

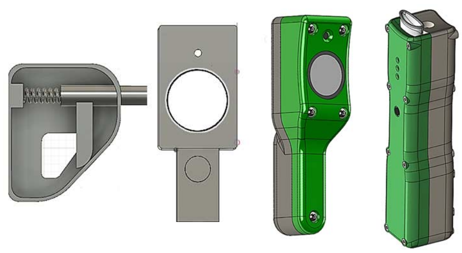

Fig. 4. Design of past 3D model of the knocking device

From the previous designs and actual fabricated devices, there were numerous problems experienced. The problem encountered in the design was the portability of the device. As can be seen in the pictures, the sizes of the devices were reduced so that it would provide the best efficiency for the users. The designs were developed by the proponents further until the size of the device is in its optimal satisfaction.

Fig. 5. Previous fabricated designs

Fig. 6 shows the final and most functional device developed by the proponents. The dimensions of this final version is 170mm in length, 42mm in width and a height of 50mm.

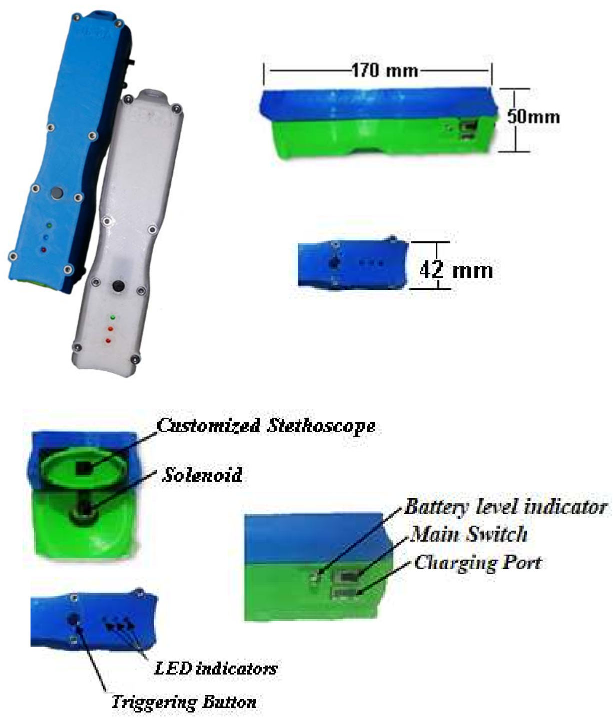

Fig. 6. Final Design of the knocking device with label of parts

2) Development of Internal System

From the initial computer-dependent design, the proponents arrived to using a 32 bit Arduino board microcontroller which is capable of standalone sound processing operation [14]. The board has FFT capable libraries that processes the sound obtained right away with no external resources.

A Bluetooth module was initially used for wireless sound acquisition system. However, this was very slow and inefficient so the proponents replaced it with an electret mic until it became into an I2S mic[15]. In terms of performance, the electret mic and I2S mic was proven to do both job only that the latter is for digital sound processing which is compatible with the current microcontroller used. The mic module was installed inside a custom stethoscope also designed by the proponents. Fig. 7 shows this customized sound gathering mechanism.

To automatically tap the coconut, an electromagnetic solenoid was installed at the tip of the device.

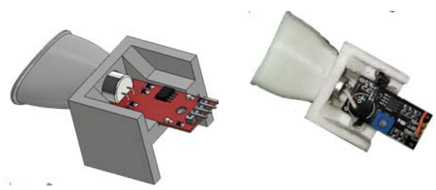

Fig. 7. Customized stethoscope

This is powered by a 11.1 V, 850 mA-H Lipo battery installed at the backside of the device. This battery also powers up the Arduino through a buck converter that steps down the voltage to 4 V that the board needed. This is also rechargeable and with an indicator installed at the side of the device

Lastly, LED indicators were installed to the system that lit up for classification. The microcontroller sends signal to these indicators after processing the sound obtained. The red is for ‘mala-tenga’, the blue is for ‘mala-kanin’ and the green is for ‘mala-uhog’. Fig. 8 shows the system block diagram of the internal system of the device.

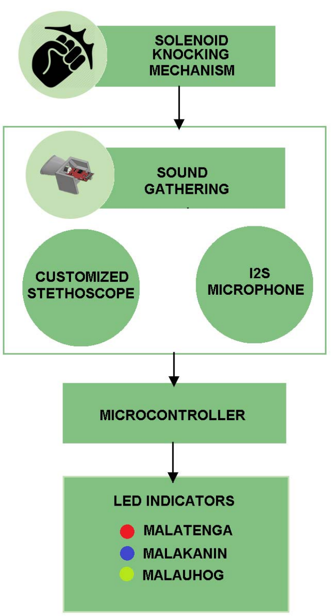

Fig. 8. System Block Diagram

3) Program Development

Fig 9 shows the program flow done using ARDUINO IDE version 1.8.5. The process starts with the push button. If it sends a 'HIGH' signal to a input digital pin, the program executes processing of sound signal heard from the mic. This is then analyzed through Fast Fourier Transform algortihm to measure the peak frequency from the signal. The ArduinoSound library was used since it has FFT as a syntax. The value is then compared to the ranges of each maturity.

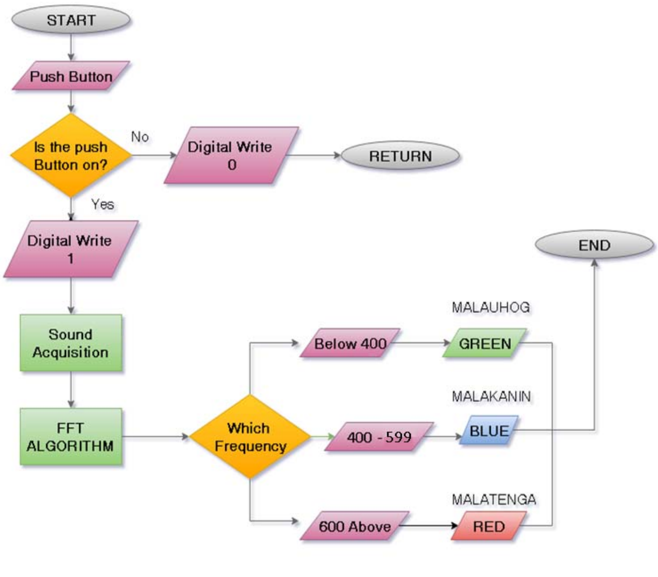

Fig. 9. Program Flow Diagram

4) Functionality

Fig. 10 shows how the device was used in classifying coconuts. The button is pressed when the device is laid flat on the skin of a coconut. This triggers the tip attached at the solenoid to move forward and make contact to the skin. The sound heard by the mic, also attached at the tip, is then processed by the microcontroller and displays the maturity through the color of the LEDs.

5) Testing Procedure

After the fabrication and development of the device, it was tested for 45 random coconuts before deploying and reproducing it to three key areas where vendors, farm owners and consumers could use it. All in all, there were added 72 coconuts in these deployment areas resulting to a total of 119 coconuts tested for functionality.

Fig. 10. Photo of testing the device

III. RESULTS AND DISCUSSION

A. Characterization Result

The meat thickness and peak frequency collected in the experiment done were summarized in Table 1.

TABLE I. SPECIFIC RANGES OF FREQUENCY AND MEAT THICKNESS ACCORDING TO MATURITY

Coconut Classification	**Range**		**r2**
	Frequency (Hz)	***Meat Thickness (mm)***	
Malauhog	200-399	0-2.0	0.86
Malakanin	400-599	2.1-5.5	0.87
Malatenga	600-800	5.6-7.0	0.89

The table above shows the peak frequency of each sounds from each of the maturity differs from one another. It could be observed that the mala-tenga has the highest peak frequency in all of the three stages. This means that the pitch and tone of the sound the coconut produces are the most notable, which can be described as high and piercing. It was also observed that mala-tenga has the thickest meat and lowest water content. On the other hand, the sound produced by mala-uhog has the lowest peak frequency. The tone it produces can be described as surface-like. The meat thickness of it is almost zero and the water content is high in volume. Lastly, the ranges of mala-kanin lies in the middle of the two previous stages. The tone it produces is almost as high as mala-tenga but not as piercing. The meat thickness and water content also lies in the middle.

To further prove the strong relationship of the peak frequency to maturity, the proponents applied a statistical analysis on it by relating it to the meat thickness. It can be seen that all maturity has high correlation of above 87%.

B. Test Result

The results showed that in the 45 coconuts classified, the device made six errors. On the other hand, the *'mangangatok'* has made five mistakes in reference to the meat thickness range obtained by the proponents in the study.

Meanwhile, another 74 fruits were categorized when the device was deployed in a coconut farm. The device made four mistakes. Table II displays the summary of previous and most recent data gathered by using the device with total mistakes. Also, Table III shows the summary of data obtained by the device with number of mistakes in grade difference. Mala-uhog coconut which is categorize as 'mala-kanin' has one grade difference while 'mala-uhog' as 'mala-tenga' has two grade difference. Analyzing these data, the device obtained an accuracy of 91.6%.

Additionally, some coconut vendors as well as buyers used the device. Good feedbacks were received such as the short time it needs to classify the coconuts and the portability of the device. The farmers who used the device said that by using it, they wouldn't waste any fruit by removing it from the tree because they could use the device at the top. New traders as well as inexperienced consumers will greatly benefit from it.

TABLE II. NUMBER OF TESTED COCONUTS

	No. of Coconuts	**No. of Coconuts Classified by the Device**	
		Correctly	**Incorrectly**
Total	119	109	10

TABLE III. SUMMARY OF CLASSIFIED COCONUTS

Coconuts Classification	Using the device		
	Mala-uhog	*Mala-kanin*	*Mala-tenga*
Mala-uhog	31	0	2
Mala-kanin	0	34	6
Mala-tenga	0	2	44

C. Cost Analysis

1) Unit Price

Table IV shows the breakdown of the prices of the parts of one device. The total unit price is 2598 pesos.

TABLE IV. TOTAL COST BREAKDOWN OF ONE UNIT

	Unit Number	Unit Price
Arduino	1	1200
Customized stethoscope	1	17
Upper 3d printed case	1	92
Lower 3d printed case	1	66
I2s mic module	1	328
Solenoid	1	300
Battery	1	380
Resistors	4	5
Tact switch	1	20
LED	4	15
Slide switch	1	5
Balance Charger	1	150
XT30 connector	1	20
TOTAL UNIT PRICE	2598	

2) Return of Investment

The device was deployed in three areas: a coconut farm located at Lebak, Sultan Kudarat and two coconut stands located in San Juan, Manila and Balintawak Market. Based on the data obtained from the farm, in using the device, almost 100 coconuts can be harvested for 1 week of business. The coconuts costs 25 pesos per piece. Adding the labor fee of a 'mangangatok' which is 500 per 100 coconuts, the profit will be only 2000 pesos. On the other hand, the capital cost for the device would only be spent on the first five weeks of hiring 'mangangatok' during harvest as shown on Table V. The formula for the rate of return is shown in (1).

$$ROR = (Current\ Value–Initial\ Value)/Initial\ Value\ x100 \quad (1)$$

Table VI shows the possible ROR value of a business owner in a month with using the device. The value for ROR will be 250000% for 1 week which is a thousand times faster compared to the 300% ROR value if labor fees are paid. This means that the return will almost be like no initial value is taken and the total investment will return immediately. With this, business owners will earn the right amount of profit alongside with the benefits they can receive upon using the device such as efficiency and portability.

The investment for 1 unit can be reduced since the cost of 2598 pesos is for a prototype only. The device can be further improved by using commercially made microcontrollers that only costs below 200 pesos. This will greatly decrease the price value for a unit but has the same capabilities. The price can become 1598 pesos and the ROR will become 43.55% for the first week of investment. This shows that if the device became even cheaper, there will be no loss of money at all and the total ROR for six weeks will become even greater.

TABLE V. POSSIBLE PROFIT TRAJECTORY FOR SIX WEEKS OF USE

Week (5 days)	Number of coconut identified	Price of coconut	With 'Mangangatok'		With the device	
			Labor Fee	*Total Profit*	*Unit Price*	*Total Profit*
1	100	2500	500	2000	2598	-98
2	100	2500	500	2000	-98	2402
3	100	2500	500	2000	0	2500
4	100	2500	500	2000	0	2500
5	100	2500	500	2000	0	2500
6	100	2500	500	2000	0	2500
Total	800	10000	2000	16000	2500	12,304

TABLE VI. POSSIBLE ROR TRAJECTORY FOR SIX WEEKS OF USE

Week (5 days)	With 'Mangangatok'		ROR (%)	With the device		ROR (%)
	Initial Value	*Current Value*		*Initial Value*	*Current Value*	
1	500	2000	300	2598	-98	-1.04
2	500	2000	300	-98	2402	-25.51
3	500	2000	300	0	2500	250e3
4	500	2000	300	0	2500	250e3
5	500	2000	300	0	2500	250e3
6	500	2000	300	0	2500	250e3
Total	2000	8,000	12000	2500	12,304	999e3

Furthermore, the device is not only for the value of ROR but also for the benefits it can provide such as efficiency, less time for harvesting fruits and the portability. Adding this benefits to the rate of return, this could help all kinds of business owners in the country - small or big and local or international.

IV. CONCLUSION

After gathering data for the development of the device, it can be concluded that the meat thickness and peak frequency is direct relationship to each other as evidence by the correlation value of above 85%. Thus, both parameters can be used to characterize the fruit's maturity.

Alongside with this, in terms of the development of the device, it can be concluded that it has the capabilities to identify the maturity of a coconut as evident to the accuracy percentage of 91.6% that was exhibited by the device in all of the deployment areas. Thus, the device can provide optimal efficiency, portability and speed when used by farmers, consumers and vendors in doing their business.

V. RECOMMENDATIONS

For the future of the study, the proponents is recommending devices and components to further lessen the device's cost. For the microcontroller, to lessen its cost up to 75 %, the proponents were recommending the use of different microcontroller of same function but with lesser cost. In terms of fabrication, the proponents were recommending the use of injection molding for the device's body to save up to 70%. Also, in terms of the algorithm used, it is recommended to compare the FFT algorithm to other signal processing algorithm such as zero crossing or using Fuzzy logic.

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