Non Destructive Classification Watermelon Ripeness Using Fuzzy Logic

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Abstract—**A n*on destructive classification watermelon ripeness using acoustic wave and fuzzy logic is designed in this paper. The watermelon weight and propagation frequency of acoustic wave inside watermelon are defined as the input variables. Percentage of watermelon ripeness is defined as the output variable. Acoustic waves were measured by knocking and tapping with and without test base and the output sound is detected by using microphone. The fuzzy rules are designed based on interviewing human experts. Some samples are tested using this system confirmed that, fuzzy logic is able to determine watermelon ripeness. From the findings, it shows that the best model produced an accuracy of 91.38%.***

Keywords— **Watermelon Ripeness, Acoustic Wave, Fuzzy Logic**

I. INTRODUCTION

Watermelons have its own market to commercialize [1]. Seeing it as the most popular and have its own bright future to sell at any country, watermelon is also been grown in Malaysia [2]. The main concerns of the food industry are the systematic determination of fruit ripeness under harvest and post-harvests condition, because variability in ripeness is perceived by consumers as lack of quality [3].

Watermelon are being planted either through hybrid seeds or open pollinated or pure seeds. Nursery is required to ensure high germination and seedling establishment. However, direct planting can also be done using higher rate of seeds [4]. Conventionally, maturity of watermelon is decided by counting the numbers of days after planted. Depending on its varieties, usually for seedless watermelon, harvesting would take after 65 - 70 days where mostly all the watermelons are matured [5].

The main purpose of this project was to develop a non-destructive procedure for detecting watermelon ripeness. Acoustic method is chosen because it is best method to determine ripeness [6] and with the aid of fuzzy logic, the decision of ripeness can be determined quickly. These methods are covered when designing an intelligent decision model for watermelon ripeness.

II. METHODOLOGY

A. Instrumental Measurements

There are 36 samples of watermelons have been chosen. Nine samples are used to verify which methods give lowest error before collecting data for fuzzy; 22 samples are used during collecting data; and five samples are used for fuzzy testing after completed collecting data. These watermelons are chosen in range of 65% to 95% of ripeness by experienced seller. Fig. 1 shows two samples of watermelons.

Acoustic wave are recorded by a dynamic free-field 25mm microphone type SBCMD095 from Philips, of a frequency range from 100 to 10 kHz and a sensitivity of -80dB. Another microphone is also used as external system connected to a computer via sound card of a personal computer board. This type of dynamic microphone modeled ANC-750 is a product by Andrea Electronics. It had response bandwidth between 50 Hz to 20 kHz. Tektronix TDS 2024B is the model used for oscilloscope while OscilloMeter 6.05 by Rotor Research System is the software which also used as oscilloscope in the computer. Both equipments provide an easy output to be used with Microsoft Excel.

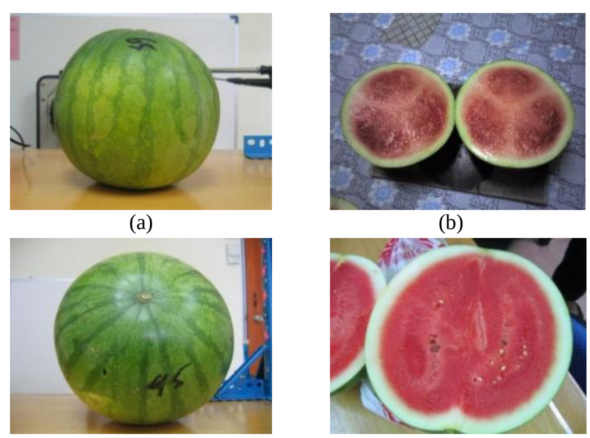

Fig. 1. Samples of watermelon with the aid of experienced watermelon seller;
(a) Outer view of 65% ripeness (b) Inside view of 65% of ripeness
(c) Outer view of 95% ripeness (d) Inside view of 95% of ripeness.

A pen type humidity and temperature sensor which is called as Thermo-Hygro is used to check the environment of testing area. Product of RS Components type 212-540 is capable to show the range of 25% to 95% of humidity and 0°C to 50°C with accuracy of ±5% humidity and ±1°C. A weighing machine used to take the weight of watermelon, type CAS SW-1 has range of 200g to 20kg. This type of digital scale has accuracy of ±10g.

Sugar contents are very important to show whether it is true or not the percentage of watermelon that are chosen by seller is in proper range. The instrument that used is refractometer type PAL-1 from ATAGO. It has range of 0% to 53% Brix. Brix is the measurement of the dissolved sugar-to-water mass ratio of a liquid. A 10% Brix solution means 10 grams of sugar per 100 grams of solution [7]. This version of refractometer has accuracy of ± 0.2% Brix.

Acoustic wave are a weak wave caused by small pressure change in a material [8, 9]. In this paper, this wave is produced by hitting the watermelon. For example, tapping can cause an impact or changes of pressure. Vibrational behaviour of fruits has been used as an indicator of maturity and postharvest ripeness based on the elastic properties of the biological tissue [10, 11]. Therefore, acoustic response of each watermelon was measured by using two methods. For the first method, it divided by two techniques which it is by knocking (*Fig. 2(a)*) and tapping (*Fig. 2(b)*) the sample.

For second method is by using test base (*Fig. 2(c)*). Acoustic wave was measured by hitting the fruit with impactor and the output sound is detected by using microphone at the other side. The impactor is made of a metal ball which has 93 g of weight. It is tied at pendulum and was dropped onto the watermelon surface from a height of 250 mm. The microphone was located at the distance of 5 mm from the fruit (*Fig. 2(d)*). The 43 mm diameter of cardboard is used to isolate the microphone area.

Each watermelon is acoustically recorded in two positions. The target impact is at the equator and rotated in 90°. Six measurements are totally taken in each fruit by formed three times of repetition in each position. Position means the different areas of fruit where the colliding is occur and repetitions refer to the repeated data is taken without changing or touching the position of fruit.

The density was not taken because it is measured by taking the mass and volume of each fruit by using Archimedes principle which involved immersion in water [12]. The size and shape of watermelon needs a large container for the density measurement in laboratory.

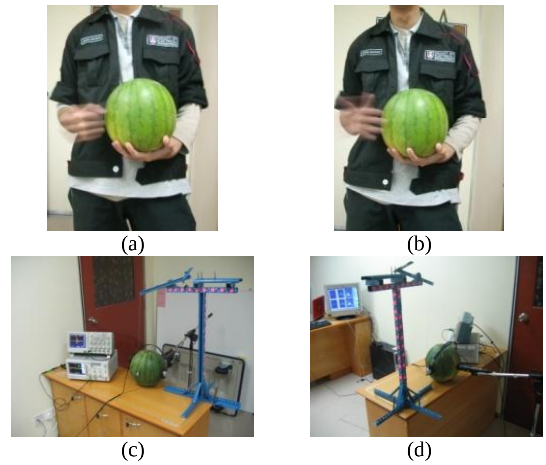

Fig. 2. Upper figure is the first method, while lower figure is second method;
(a) First technique is by knocking the sample (b) Second technique is by tapping the sample
(c) Test base is used to generate acoustic wave (e) Another perspective view of test base

The overall process of taking samples can be described in Fig. 3.

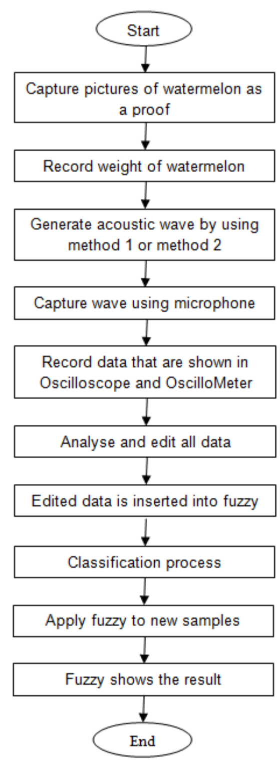

Fig. 3. Flow chart of the process to determine watermelon ripeness

B. Experiments

Three experiments are carried out: tapping, knocking and testing base; applying fuzzy logic controller; and destructive method analysis.

i. *Experiments for Tapping, Knocking and Testing Base*

The first nine samples used in this study were taken from ordinary markets and defined as sample #1 until #9. Weights for these samples are between 1.69 kg and 5.97 kg. These samples are used to determine which methods can give lowest error. For tapping and knocking method, these techniques provide sound as it mimics the human experts' behavior whereas for method that are using testing base is applied as explained in instrumental measurements. Total readings taken for each method is 30.

By referring to [13, 14, 15], range of frequencies that are produced by acoustic wave was between 85 Hz and 200 Hz. This range is defined as frequency in range (FIR). Therefore, other than that range is considered as the data that cannot be used. It was defined as frequency out of range (FOR). This range can be as a guideline for comparing the error. The percent error can be expressed as follows:

$$\frac{\textit{(Observed Value – True Value)}}{\textit{True Value}} \times 100 = \textit{Percent Error}. \quad (1)$$

It should be noted here that these samples are categorized as controlled data as the wave were recorded under controlled environment.

ii. *Designing Fuzzy Logic Controller*

Fuzzy logic was initiated in the 1960s by Lofti Zadeh, Professor of Systems Theory [16, 17] which is also a graduate student at Columbia University [18]. It is exemplified by the use of linguistic variables to represent part of the range of an ordinary crisp variable. It allows a better modeling and control of real world nonlinear and complex problems more effectively. In this paper, fuzzy logic is run by using MATLAB 7.0 and all the data is taken from a method that has lowest error.

A basic of Fuzzy Logic Controllers contains of four basic components which it is fuzzification unit; rule and data base; decision making; and defuzzification unit. Fig. 4 shows general procedure to design fuzzy logic controller (FLC).

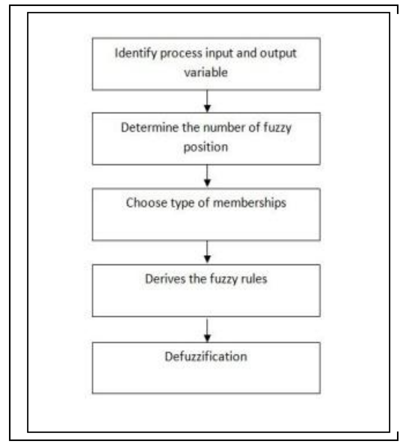

Fig. 4: Procedure to design FLC

<u>Input and Output Variable</u>

The input and the output are:

Input - Weight (*Fig. 5(a)*) and propagation frequency of acoustic wave inside watermelon (*Fig. 5(b)*).

Output - Percentage of watermelon ripeness (*Fig. 5(c)*).

<u>Linguistic Variables</u>

For input of weight (*Fig. 5(a)*), it consists of three levels of linguistic variables which it is small (small), medium (medium) and big (big) whereas propagation of waves (*Fig. 5(b)*)are composed of seven levels of linguistic variables; unripe-medium (UM), unripe-big (UB), ripe-small (RS), ripe-medium (RM), ripe-big (RB), overripe-medium (OM) and overripe-big (OB). The output (*Fig. 5(c)*) shows unripe (unripe), ripe (ripe) and overripe (overripe) as it were three levels of linguistic variables.

<u>Membership Functions</u>

Membership function use probability concept where '1' means the probability is true and '0' means not true. In this paper, triangular and trapezium shape of membership functions are chosen. Membership with shape of triangular has three points of reference controlled by three parameters while trapezium has four.

Fig. 5 presents the membership function for weight at top, wave propagation at center and ripeness determination at bottom. Membership types and range for the linguistic variables are presented in Table I, II and III.

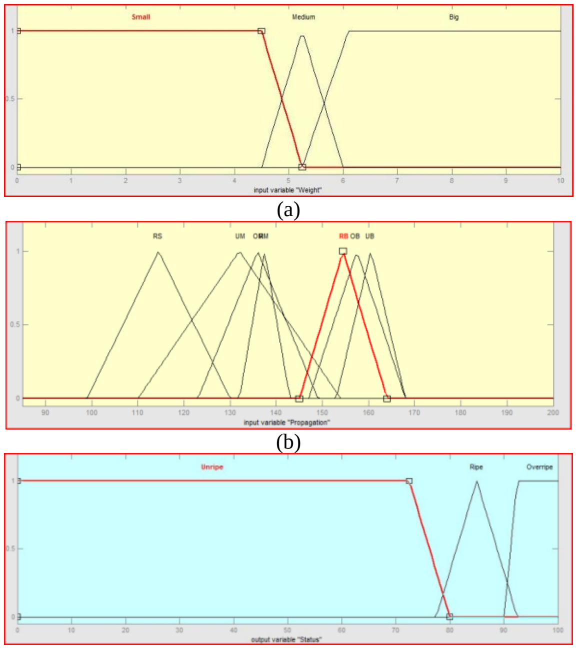

Fig. 5. Memberships of Inputs and Output
(a) Membership for weight (b) Membership for wave propagation
(c) Membership for watermelon status

TABLE I
TYPE OF MEMBERSHIP FUNCTION AND RANGE FOR WEIGHT

Term	Type	Range	In fuzzy notation
Small	Trapezium	0.00-5.25	μ=[0,0,4.5,5.25]
Medium	Triangular	4.50-6.00	μ=[4.5,5.25,6.0]
Big	Trapezium	5.25-10.0	μ=[5.25,6.1,10,10]

By referring to *Fig. 5(a)*, each line represent small, medium and big coordinate with Table I. From that figure, base variable for weight was set from 0 to 10 in unit kilogram.

TABLE II
TYPE OF MEMBERSHIP FUNCTION AND RANGE FOR WAVE PROPAGATION

Term	Type	Range	In fuzzy notation
UM	Triangular	110-154	μ=[110,132.0,154]
UB	Triangular	153-168	μ=[153,160.5,168]
RS	Triangular	099-130	μ=[099,114.5,130]
RM	Triangular	132-143	μ=[132,137.5,143]
RB	Triangular	145-164	μ=[145,154.5,164]
OM	Triangular	123-149	μ=[123,136.0,149]
OB	Triangular	147-168	μ=[147,157.5,168]

For wave propagation, base variable was set from 80 to 200 in unit Hertz (*Fig. 5(b)*) with fuzzy notation (coordinate) shown in Table II.

TABLE III
TYPE OF MEMBERSHIP FUNCTION AND RANGE FOR RIPENESS

Term	Type	Range	In fuzzy notation
Unripe	Trapezium	00-80	μ=[0,0,72.5,80]
Ripe	Triangular	77.5-92.5	μ=[77.5,85,92.5]
Overripe	Trapezium	90-100	μ=[90,92.5,100,100]

Lastly, for ripeness determination, 0% to 100% of watermelon ripeness as been shown in *Fig. 5(c)* is used as range for base variable.

<u>Fuzzy Rules</u>

Rule Editor is used to inspect the rules being used by a fuzzy inference system. To use this editor to create rules, all of the input and output variables must be defined first. In this paper, there are 21 rules created. These rules will be as the guidance for fuzzy to decide. Table IV shows fuzzy rules that are used in MATLAB 7.0.

TABLE IV
FUZZY RULES

If	And	Then
Weight is Medium	Propagation is UM	Status is Unripe
Weight is Small	Propagation is UM	Status is Unripe
Weight is Big	Propagation is UM	Status is Unripe
Weight is Medium	Propagation is UB	Status is Unripe
Weight is Small	Propagation is UB	Status is Unripe
Weight is Big	Propagation is UB	Status is Unripe
Weight is Medium	Propagation is RS	Status is Ripe
Weight is Small	Propagation is RS	Status is Ripe
Weight is Big	Propagation is RS	Status is Ripe
Weight is Medium	Propagation is RM	Status is Ripe
Weight is Small	Propagation is RM	Status is Ripe
Weight is Big	Propagation is RM	Status is Ripe
Weight is Medium	Propagation is RB	Status is Ripe
Weight is Small	Propagation is RB	Status is Ripe
Weight is Big	Propagation is RB	Status is Ripe
Weight is Medium	Propagation is OM	Status is Overripe
Weight is Small	Propagation is OM	Status is Overripe
Weight is Big	Propagation is OM	Status is Overripe
Weight is Medium	Propagation is OB	Status is Overripe
Weight is Small	Propagation is OB	Status is Overripe
Weight is Big	Propagation is OB	Status is Overripe

<u>Defuzzification</u>

The percentage of maturity has to be translated into a real value. This step is called defuzzification. The relation between linguistic values and corresponding real values is always given by the membership function definitions. *Fig. 5(c)* plots the membership functions for the linguistic variable "*Status*".

Experiment for Applying Fuzzy Logic Controller

There are five samples that are used to check the accuracy of fuzzy logic. Two samples are taken just after buying and defined as seedless A and seedless B has weight of 6.008 kg and 6.255 kg respectively. Another two samples that have been left for three weeks are considered as overripe. These samples are defined as seedless C and seedless D. Seedless C has weight of 5.428 kg whereas seedless D has weight of 6.834. Seedless E with weight of 6.008 kg is preferred because it has internal problem. This is been mentioned by human expert.

Three reading are taken for each sample and average of these readings will be taken for each sample. For non-destructive method, each sample is going to has same procedure like doing the experiment. Data that has to be taken is weight and acoustic propagation frequency. After taking all the necessary readings, these samples will cut down so that data for sugar content of each watermelon can be taken.

iii. *Destructive Method Analysis*

For destructive method analysis, a test was designed to study the relationship between percentages of watermelon with sugar contents. Refractometer is used to measure sugar contents in watermelon and range of ripeness is between 65% and 95%.

Table V shows results that are taken during experiment session. These readings involved 22 samples with ranging of 65% to 95%. There are multiples readings for each maturity. All readings are in units of Brix percent (Brix %) and sugar content is increasing similar to the maturity.

TABLE V
SUGAR CONTENT IN WATERMELON

Sample	Brix %
	Readings
65%	04.60 – 05.00
70%	04.90 – 05.60
75%	05.50 – 06.40
80%	06.40 – 08.20
85%	08.90 – 10.60
90%	10.00 – 10.90
95%	10.60 – 11.20

III. RESULTS

A. Experiments for Tapping, Knocking and Testing Base

These tests are performed to collect frequencies of acoustic wave that have been produced. In order to records the necessary range of frequencies, all the possibilities had taken. By referring to Table VI, tapping and knocking method produced error at every single reading for each sample but there are no errors at all when applying experiment using testing base. For tapping method, minimum and maximum error that has been recorded is 26.67% and 83.33% respectively. 83.33% shows that it has very high probability to fail when deciding the ripeness. This symptom also occurs in knocking method where the maximum error is 100%; the result are totally cannot be used in fuzzy logic. Since there is no problems occur during applying an experiment using testing base, this method is chosen as the method for fuzzy to collect data from other 22 new samples. The accuracy for using this method is 100%.

B. Experiment for Applying Fuzzy Logic Controller

Comparison between Human Expert and Fuzzy Logic

Comparison between seller and fuzzy is showed at Table VII. The percentage error for each samples are calculated using (1). For seedless A, the percentage error is small which it has average of 2.04%. The difference between human expert and fuzzy is in one to two percent only. Seedless B has fixed value and has 1.04% of error with difference of one percent of maturity when compared.

Looking at samples that are considered as overripe, the percentage error is quite high. Based on human expert, any watermelon can hold on up to one month. Like sample seedless C and seedless D, the maturity for both fruit is increasing. So, the percentage error should be increasing because of the maturity of fruit is increasing. In 21 days, seedless C and seedless D are increase its maturity for about 7% and percent error produced in this test is 8.24% and 8.62% respectively. Sugar content for seedless C and D still can provide sweetness but its texture is start to weak (flaccid) and water soaked.

Lastly, for sample that is started to rotten, seedless E has a highest percentage of error which it is 9.16%. After being cut, at certain content of this fruit has white foaming. It can be conclude that its texture can affect propagation waves. From this comparison, the accuracy can be made is 91.38%.

Comparison between Human Expert and Sugar Content

By referring to Table V, the comparison between human expert and sugar content can be showed in Table VII by finding the average of percentage of 22 test samples comparing with the result come out from five test samples. From column sugar content (Brix %) is the result that acquired from the specified sample. For example, seedless A produced 6.5 Brix % of sugar content. The comparison is taken by taking 6.5 Brix % and percentage that already showed in Table V. Notice that the sugar content for Seedless A belongs to category of 80%. This comparison makes the percentage error is 0.00%.

TABLE VI
EXPERIMENTS FOR TAPPING, KNOCKING AND TESTING BASE

Sample	Total Readings	Tapping Method			Knocking Method			Testing Base		
		In Range Frequency (FIR)	Out of Range Frequency (FOR)	Error	In Range Frequency (FIR)	Out of Range Frequency (FOR)	Error	In Range Frequency (FIR)	Out of Range Frequency (FOR)	Error
#1	30	6	24	80.00%	0	30	100.00%	30	0	00.00%
#2	30	10	20	66.67%	17	13	43.33%	30	0	00.00%
#3	30	12	18	60.00%	18	12	40.00%	30	0	00.00%
#4	30	13	17	56.67%	12	18	60.00%	30	0	00.00%
#5	30	8	22	73.33%	13	17	56.67%	30	0	00.00%
#6	30	22	8	26.67%	11	19	63.33%	30	0	00.00%
#7	30	18	12	40.00%	21	9	30.00%	30	0	00.00%
#8	30	14	16	53.33%	16	14	46.67%	30	0	00.00%
#9	30	5	25	83.33%	9	21	70.00%	30	0	00.00%

TABLE VII
COMPARISON BETWEEN HUMAN EXPERT AND FUZZY LOGIC

Sample	Keeping Day(s)	Non-Destructive Method				Error
		Weight (kg)	Wave (Average)	Seller	Fuzzy (Average)	
Seedless A	1	6.008	149.4722	80%	81.67%	2.04%
Seedless B	1	6.255	143.7792	90%	91.00%	1.09%
Seedless C	21	5.428	138.1994	85%	92.00%	8.24%
Seedless D	21	6.834	153.8398	85%	92.33%	8.62%
Seedless E	1	6.008	154.4973	80%	87.33%	9.16%

TABLE VIII
COMPARISON BETWEEN HUMAN EXPERT AND SUGAR CONTENT

Sample	Keeping Day(s)	Non-Destructive Method		Destructive Method		Error
		Weight (kg)	Seller	Sugar Content (Brix %)	Percentage (Average)	
Seedless A	1	6.008	80%	6.5	80%	0.00%
Seedless B	1	6.255	90%	10.8	90%	0.00%
Seedless C	21	5.428	85%	10.7	92.5%	8.82%
Seedless D	21	6.834	85%	7.2	80%	5.88%
Seedless E	1	6.008	80%	9.5	85%	5.88%

TABLE IX
COMPARISON BETWEEN FUZZY LOGIC AND SUGAR CONTENT

Sample	Keeping Day(s)	Non-Destructive Method		Destructive Method		Error
		Weight (kg)	Fuzzy (Average)	Sugar Content (Brix %)	Percentage (Average)	
Seedless A	1	6.008	81.67%	6.5	80%	2.50%
Seedless B	1	6.255	91.00%	10.8	90%	1.25%
Seedless C	21	5.428	92.00%	10.7	92.5%	8.24%
Seedless D	21	6.834	92.33%	7.2	80%	8.24%
Seedless E	1	6.008	87.33%	9.5	85%	16.25%

The conclusion can be made is Table V is the outcome of 22 samples based on human expert. So, there is no error occur when comparing Seedless A with Table V. This findings make the references from human experts are totally can be used as indication for creating fuzzy logic controller to determine ripeness.

For Seedless B, the error percentage is also taken by comparing the percentage referred to Table V and with percentage that given by seller. The error produced is zero because sugar content in Seedless B is in category ripeness of 90% which actually has the same case as Seedless A. Percentage of sugar in Seedless C is between range of 90% and 95%. By taking the average of 90% and 95% it gives the answer of 92.5% and when comparing with seller, the error percentage is 8.82%. While Seedless D and E are in category 80% and 85% respectively, gives the same result for percentage error of 5.88%. The conclusions can be made are there is a large error produced when comparing sugar content with seller because the condition of watermelon (such as overripe and internal problem) can affect the decision made by human expert (because of watermelon is matured with respect to time and internal problem can cause changing of internal texture of watermelon that can affect propagation wave).

Comparison between Fuzzy Logic and Sugar Content

This test also uses Table V to compare the sugar content with fuzzy logic. It has same calculation as applied in previous test. By referring to Table IX, Seedless A has same case as previous test where the range cannot be compared.

By referring to Table IX, Seedless A and Seedless B have minor percentage error which it is 2.04% and 1.09% respectively. As been discussed in previous test, Table V is depends on human expert. The conclusion can be made is fuzzy logic actually is non-subjective decider. Therefore, the percent of maturity resulting from fuzzy gives the nearest value compared with previous test. For Seedless C, even though it has been leave for about three weeks, fuzzy logic can determine the maturity with 0.54% of percentage error. Same case for Seedless D, but the error percentage gives the highest which it is 13.35%. Based on [10], sugar content does not increase once it removed from the vein and this case has proven by looking at result Seedless D. For Seedless E, fuzzy logic can still give the percentage of maturity and it has lower error with 2.67% compared to Seedless E in previous test.

IV. CONCLUSION

Acoustic method was chosen because of its low-cost test [6] and was suitable method to determine watermelon ripeness but it is not appropriate for an ordinary person to decide the result of that sound produced. Anyone who interested to learn about watermelon maturity need more trainings to familiar with sound that produced by watermelon. The training durations were as short as five years to be completed as being told by human expert because watermelon has many different weight, shape and behaviors. It can be conclude that, fuzzy logic is one of the best tools to determine watermelon ripeness as been proven in results of these experiments.

V. FUTURE RECOMMENDATION

Fuzzy logic is a decision tools that based on samples data [11]. In order to make it more accurate, more samples are needed. For example, weight; the samples for every class has different length of wave propagation even though it has same percent of maturity. For future recommendation, more exercises are needed in different classes and categories. Classes are referring to weight of watermelon and categories are referring to percents of watermelon maturity. These combinations can give more data to be included in fuzzy because like human, to minimize error he or she must take five years of training but with aid of experimental instruments, there is no need for researcher to take five years instead of watermelon samples only.

After defining the meaning of maturity, a test based on spectrometer must be conducted in order to get the most accurate value for percentage of watermelon ripeness. This is because sugar content does not affect the maturity but the texture of inner surface of watermelon gives the most confirmed results. Another propagation wave test must also consider with the purpose of getting the propagation wavelength inside watermelon.

A little bit sacrifice has to do in order to get something better in future. Therefore, with more samples and data, a device for determine watermelon ripeness can be produced.

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