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Mangosteen Flesh Condition Detector Based on Microwave Non-destructive Technique Using Spiral Resonator Sensor's

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***Abstract*—The mangosteen fruit has a characteristic thick skin, so it is difficult to know the condition of the flesh. Farmer can only know damage to the fruit flesh after the fruit skin had opened. Detection of the quality of the mangosteen flesh can be detected using a sensor capable of penetrating the thickness of the mangosteen rind. Flesh quality detection is carried out based on the S_{21} value (attenuation of mangosteen flesh value) using a portable device equipped with a sensor and capable of emitting microwaves. The S_{21} value of the fruit's flesh was measured using a spiral resonator that functioned as a sensor. The prototype device consists of an oscillator circuit, a power splitter, and a phase detector with 2507 MHz. Fruit flesh had divided into two conditions: damaged for fruit flesh with yellow sap or Translucent Flesh Disorder (TFD), and suitable condition for clean fruit flesh. The results showed that the fruit flesh had an average S_{21} value of 7.041 dB for damaged flesh and 6.007 dB for good flesh condition. The difference in the value of S_{21} had used as a reference for detecting the shape of the fruit flesh, with the detection threshold calculated by the Support Vector Machine (SVM), resulting in a threshold value of 6.712 dB.**

Keywords: ***portable sensor, mangosteen,*** S_{21}***, spiral resonator, support vector machine***

***Abstrak*—Buah manggis memiliki karakteristik kulit buah yang tebal sehingga sulit untuk mengetahui kondisi daging buahnya. Kerusakan pada daging buah baru dapat diketahui setelah kulit buah dibuka. Deteksi kualitas daging buah manggis dapat dilakukan menggunakan sensor yang mampu menembus ketebalan kulit buah manggis. Deteksi kualitas daging buah dilakukan berdasarkan nilai S_{21} (nilai redaman dari buah manggis) menggunakan alat portabel yang dilengkapi sensor dan mampu memancarkan gelombang mikro. Nilai S_{21} dari daging buah diukur menggunakan *spiral resonator* yang difungsikan sebagai sensor. Prototipe alat terdiri dari kombinasi rangkaian osilator, *power splitter*, dan *phase detector*, dengan frekuensi 2507 MHz. Kondisi daging buah terbagi menjadi dua yaitu: kondisi rusak untuk daging buah dengan getah kuning ataupun *Translucent Flesh Disorder* (TFD), dan kondisi baik untuk daging buah bersih. Hasil penelitian menunjukkan bahwa daging buah memiliki rata-rata nilai S_{21} sebesar 7,041 dB untuk kondisi daging buah rusak dan 6,007 dB untuk kondisi daging buah baik. Perbedaan nilai S_{21} ini dijadikan acuan deteksi kondisi daging buah, dengan ambang batas deteksi dihitung dengan *Support Vector Machine* (SVM), menghasilkan nilai ambang batas pada 6,712 dB.**

Kata kunci: ***sensor portabel, buah manggis,*** S_{21}***, spiral resonator, support vector machine***

I. Introduction

Mangosteen (Graciani mangostana Linn) is a member of the Guttiferae family. The mangosteen fruit is known as the "Queen of the Tropical Fruit" because it has a sweet, sour, and astringent taste rarely found in other tropical fruits. Mangosteen fruit exports play a significant role in increasing the country's foreign exchange and farmer's income[1].

Mangosteen is a staple horticulture crop in Indonesia. Mangosteen fruit produced by Indonesia in 2020 reached 322.41 thousand tons. Some of the mangosteen fruit is exported to several countries in Asia with an export value of US$ 81.15 million. Countries that export destinations for mangosteen include Hong Kong, China, and Malaysia [2].

Mangosteen fruit exports must be of the highest quality. A mangosteen fruit's flesh is one indicator of its quality. Due to the thick skin of the mangosteen fruit, determining the condition of the flesh is difficult. Damage to the mangosteen flesh can alter the flavor of the mangosteen fruit. This condition is due to internal and environmental causes [3]. Internal problems with mangosteen production include the presence of yellow gummy latex in the pulp

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[4], [5] and the semi-transparent condition of the pulp (Translucent Flesh Disorder/TFD) [6], [7]. The outside appearance of the mangosteen fruit does not reveal the problem with the flesh. The condition of the mangosteen flesh can be known after the mangosteen rind has opened. Early detection of horticulture items in need of repair helps enhance quality and protects farmers from crop failure [8].

Two distinct methods are frequently employed to determine the state of fruit [9]color and soluble solids content (SSC). The first technique is to obtain the food's physicochemical characteristics, such as pH and total dissolved solids. This technique provides detailed information about the fruit content, but it takes a relatively long time and is destructive. Second, the nondestructive method uses microwave sensors, image processing, acoustics, and x-rays [10]–[12]. A microwave-based system operates because the transmitter generates microwaves and transmits them to objects via a resonator that acts as a sensor. This technique uses dielectric values such as microwave attenuation to determine the characteristics of the fruit.

Numerous studies have also been undertaken to utilize microwaves to test the quality of fruits and vegetables. [13]–[15]measurements at different temperatures (24, 30, 40 and 50 °C. Nondestructive characterization of the condition of the mango flesh, based on the dielectric value of the fruit, has been carried out previously [16] hardness, weight loss, total soluble content (TSC. The dielectric constant is determined using a double-ring resonator sensor coupled to a Vector Network Analyzer (VNA). Additionally, the measurement data is analyzed on a computer to acquire the fruit's attributes.

Other research utilizing a coupled-dipole resonator to detect the water content of rice has been conducted. The sensor can determine the values of the parameters S_{11} and S_{21} in a rice sample. The sensor was constructed and tested at a frequency of 2.45 GHz. Additionally, microwave sensors can detect chemicals present in food [17], [18].

Based on the explanation above, the author made a prototype of a portable tool to detect the condition of the mangosteen fruit based on S_{21} using a spiral resonator by utilizing microwaves. The benefit of this tool is that it is nondestructive, meaning that it does not cause damage to the object. This method can be detected directly at room temperature and does not require additional instruments. The mangosteen fruit used as the test material was the Lombok mangosteen fruit with several conditions of fruit flesh. The value of S_{21} had used to detect the quality of the mangosteen flesh.

II. Method

This research consisted of several stages: selecting the mangosteen fruit, designing, and manufacturing sensors, measuring the value of S_{21} using sensors and observing the actual condition of the mangosteen flesh. The mangosteen fruit sample used had an unknown pulp condition. The S_{21}value was determined on the surface of the mangosteen rind concurrently with the observation of the mangosteen flesh's quality. The next stage is to find a correlation between the measurement results and the results of visual assessments.

A. Scattering Parameter

Scattering or *S*-parameters define the relationship between the inputs and outputs of ports (or terminals) in an electrical system as shown in Figure 1. For example, if we have two ports (intelligently designated Port 1 and Port 2), S_{21} denotes power transmission from Port 2 to Port 1. S21 represents the transmission of power from Port 1 to Port 2. The S_{21} value correlates to the mangosteen flesh's attenuation value when determining the mangosteen's properties. Scattering parameters can be used at any frequency but are most commonly used in RF and microwave applications. The *S* parameter specifies how an electrical network behaves electrically and linearly. Voltage Standing Wave Ratio (VSWR), gain, return loss, transmission coefficient, and reflection coefficient are expressed using the S parameter. For additional information, please see the following discussion with the two-port network.

In Figure 1, a_1 is the voltage amplitude of the wave going to the port, while b_1 is the voltage amplitude of the tide leaving the transmission system of 2 or more ports. When the characteristic impedance (Z_0) is equal to 50 Ohms, and if the termination is 50 Ohms at port 2, a_2 is reduced to zero, yielding the equations for S_{11} and S_{21}. This principle can be applied in the opposite direction as well. By setting a1 to zero, we obtain the equations for S_{22} and S_{12}, as shown in equations below:

$$S(1,1) = \frac{b_1}{a_1} | a_2 = 0 \tag{1}$$

$$S(2,1) = \frac{b_2}{a_1} | a_2 = 0 \tag{2}$$

$$S(1,2) = \frac{b_1}{a_2} | a_1 = 0 \tag{3}$$

$$S(2,2) = \frac{b_2}{a_2} | a_1 = 0 \tag{4}$$

where *S* is the scattering matrix of a two-port network that can be described as

$$b_1 = S_{11}.a_1 + S_{12}.a_2 \tag{5}$$

$$b_2 = S_{21}.a_1 + S_{22}.a_2 \tag{6}$$

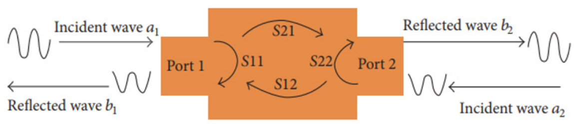


Figure 1. Scattering mechanism parameters

B. Research Materials

As for the materials used to manufacture sensors are Printed-Circuit Board (PCB) double layer and Surface Mount Assembly (SMA) connectors. Another material used is the mangosteen fruit from Lombok Island, West Nusa Tenggara Province. Mangosteen fruit is prepared in as much as 3 kg (29 pieces).

Measurements were made on four sides of the surface of each fruit, resulting in a total of 116 measurement data. The sides of the mangosteen fruit surface are then marked using a specific number code. The spiral sensor measures the S_{21} value of each mangosteen fruit first; then, the mangosteen rind has opened to observe the condition of the flesh based on the previous measurement point.

C. Manufacture of Spiral Resonator

The spiral resonator sensor design uses blood sugar sensor calculations [8]. Simulating the design findings is used to evaluate sensor performance. Then do the manufacture of sensors using a double layer PCB, as shown in Figure 2.

Performance analysis of the spiral resonator design used is known based on the total inductance (LSP) and capacitance (CSP) values [9]. The parameters needed are the spiral diameter value (l=20.08mm), the spiral trace width (w=2.08mm), the distance between the spiral circles (s=2.08mm), and the number of loops in the spiral (N=2).

The average total length (l_{avg}), and the total inductance (L_{SP}) respectively can be calculated by [19]

$$l_{avg} = \frac{1}{N}\sum_{n=1}^{N} l_n = \frac{4lN - \left[2N(1+N)-3\right](s+w)}{N} \tag{7}$$

$$L_{SP} = \frac{\mu_0}{2\pi} l_{avg}\left[\frac{1}{2} + \ln\left(\frac{l_{avg}}{2w}\right)\right] \tag{8}$$

where μ_0 is the magnetic permeability of free space, $\mu_0=4\pi\times10^{-7}\text{H}\cdot\text{m}^{-1}$. The capacitance value per unit length (C_l) can be expressed as [19]

$$C_l = \varepsilon_0 \frac{K\left(\sqrt{1-k^2}\right)}{K(k)} \tag{9}$$

where ε_0 is vacuum permittivity, $\varepsilon_0=8.854\times10^{-12}\text{F}\cdot\text{m}^{-1}$ and

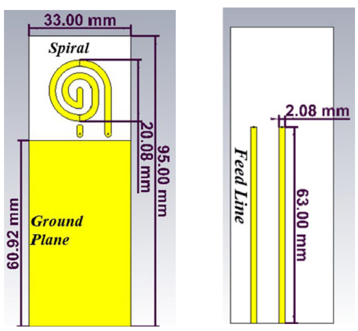


Figure 2. Spiral resonator design (a) front view; (b) rear view

k is the first complete elliptic integral calculated by [19] the metamaterial has greater attention for antenna designing. Simulation results show the improvement of mutual coupling loss and return loss by adding spiral resonator structure to the antenna substrate.

$$k = \frac{s/2}{w + s/2} \tag{10}$$

Then the total capacitance (C_{SP}) can be calculated by [19]

$$C_{SP} = C_l \frac{l}{4(w+s)} \frac{N^2}{N^2+1} \sum_{n=1}^{N-1}\left[l - \left(n + \frac{1}{2}\right)(\text{w}+\text{s})\right] \tag{11}$$

The resonant frequency of the spiral resonator (f_R) can be estimated by [19]

$$f_R = \frac{1}{2\pi\sqrt{L_{SP}C_{SP}}} \tag{12}$$

Then the spiral resonator was tested to see the frequency value with the most significant difference between the $S21$ values for mangosteen flesh in prime condition and damaged. Tests were conducted at a frequency of 100 MHz to 3 GHz (2900 MHz bandwidth) using a VNA.

D. Prototype Design

The Arduino Uno R3 serves as the detector's primary control device. Arduino provides power to the oscillator. Next, the oscillator generates a signal and sends it to the power splitter. The power splitter sends its output to the spiral resonator and the phase detector. Then the resonator sends its output signal to the phase detector. The phase detector detects the difference in magnitude and phase that comes later as attenuation (S_{21}). The S_{21} value measured by the phase detector is then sent from the VMAG port on the phase detector to port A4 on the Arduino in the form of voltage, as expressed in Figure 3.

Arduino then compares the damping value it receives to the damping value specified by its value range. This result reflects whether the flesh of the mangosteen fruit is damaged or not. The findings of this detection then serve as the basis for the Arduino software to determine the state of the fruit flesh. Additionally, the LCDs show the sorting results.

E. Measurement of Mangosteen Fruit

Figure 4 shows the measurement block used to measure the S_{21} value of the mangosteen fruit using the Spiral

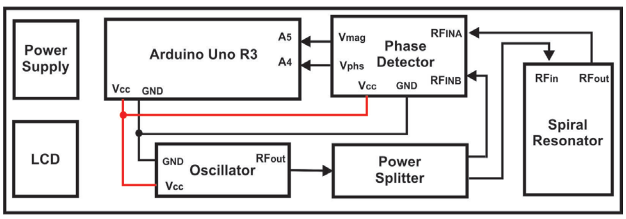


Figure 3. Prototype design

Figure 4. Measurement block of S_{21} values

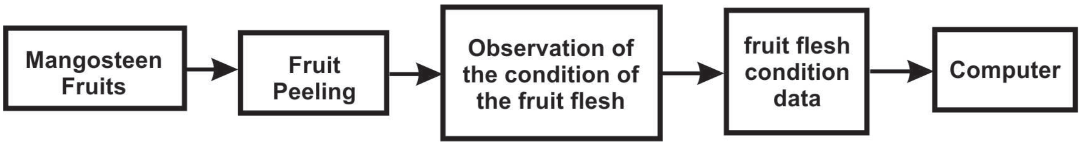


Figure 5. Block diagram of observing the condition of fruit flesh

Resonator sensor. The sensor installed on the prototype serves to measure the value of S_{21} according to its working frequency. Then the computer saves the measurement data result.

Figure 5 shows the measurement blocks used to treat the condition of the mangosteen flesh. The process of determining the mangosteen fruit's quality consists of several stages. First of all, the magnitude and phase of the mangosteen are measured. Second, the mangosteen fruit is then peeled off and observed for the condition of the flesh using the sense of sight. The results of these observations are divided into two categories, as shown in Figure 6. These observations yielded two types: good condition for clean fruit flesh and damaged condition for fruit flesh contaminated with yellow sap or TFD. The computer records the result of the fruit flesh.

The data from the measurements and observations are then correlated to find a relationship. Based on the measurement data obtained, look for the threshold value of S_{21} for the condition of good and damaged meat using the linear Support Vector Machine (SVM) method.

III. Result and Discussion

The results and discussion include the results of making and testing a spiral resonator, the results of making a prototype tool, the results of measuring and processing data on the value of S_{21} and the condition of the fruit flesh, and the results of detection trials with the prototype.

A. Spiral Resonator Sensor

Figure 7 shows a spiral resonator sensor used to detect the quality of the mangosteen fruit. It can be seen in the figure that the sensor has two ports consisting of one input port (*Tx*) and one output port (*Rx*) using the SMA port. The mangosteen fruit's attenuation value (S_{21}) was determined and compared to the visual state of the mangosteen flesh.

(a) (b) (c)

Figure 6. The appearance of mangosteen flesh condition; (a) Good condition; (b) Bad condition (yellow sap); (c) Translucent Flesh Disorder (TFD)

Figure 7. Spiral resonator sensor

The measurement data is processed on a computer and classified as fresh sap and damaged mangosteen fruits.

Figure 8 depicts the total measurement findings for the S_{21} value at frequencies ranging from 100 to 3000 MHz. The measurements were taken on ten mangosteens or forty sides, 27 of which were in good condition and 13 damaged. This graph represents the average result of mangosteen fruit measurement. The blue line represents the S_{21} value for mangosteen in good condition, whereas the red line represents mangosteen in poor condition. The observed value of S_{21} over the frequency range 1800-2600 MHz demonstrates a reasonably considerable difference between good and bad conditions, particularly around 2500 MHz.

The graph in Figure 9 shows the S_{21} trend value of the spiral resonator for the frequency 2478-2536 MHz. The frequency of 2507 MHz shows the difference in the value of S_{21} between mangosteen with good and bad conditions with the most considerable difference in weight. The value of S_{21} for mangosteen with good conditions measured has

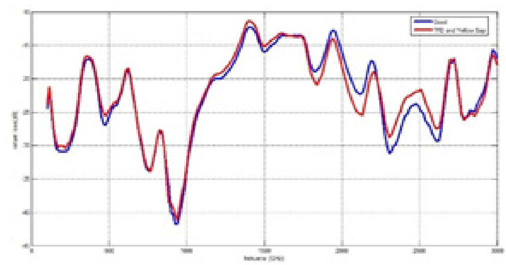


Figure 8. S_{21} value measurement results

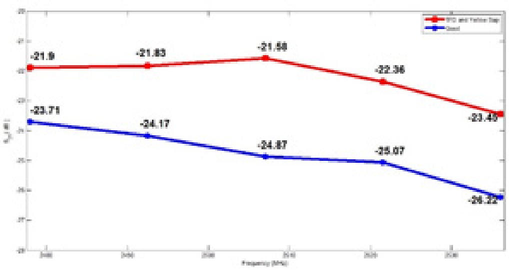
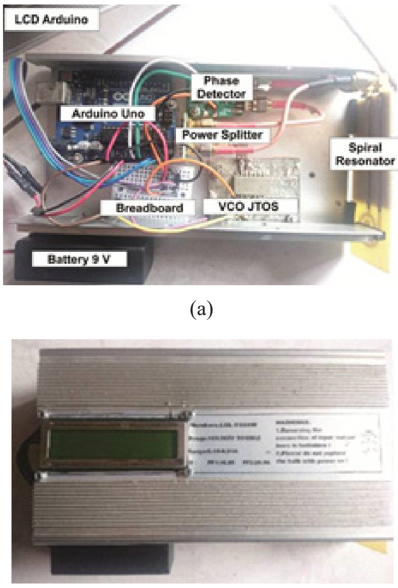


Figure 9. S_{21} trend values



(a)

(b)

Figure 10. Prototype results (a) inside view; (b) outer view

a value of -24.87 dB, and for bad conditions of -21.58 dB, it has a difference of 3.29 dB. Based on the test results, this detector works at 2507 MHz.

B. *Prototype Results*

Figure 10 shows the detector's output. Figure 10(a). illustrates the tool's interior view, whereas Figure 10(b) demonstrates the tool's outside perspective.

C. *Measurement Results of Mangosteen Fruit*

Figure 11 illustrates how the mangosteen fruit's quality is determined. The mangosteen fruit is attached to the sensor so that the S_{21} value can appear on the LCD screen. Twenty-nine mangosteen fruit samples were used in the initialization step. Measurement's position is decided by viewing the little crown at the bottom part of the mangosteen fruit, which shows the number of fleshes and their respective position. Next, the fruit is divided into four territories, with the outer peel of each part then used as the measurement position.

Table 1 contains the findings of the initial measurement of mangosteen's attenuation value using a spiral sensor operating at a frequency of 2507 MHz. The data in Table 1

Table 1. The Initial measurement of mangosteen's attenuation value

No.	Attenuation (dB)	Condition
1	3,928	clean fruit flesh
2	4,516	clean fruit flesh
3	4,690	clean fruit flesh
4	4,828	clean fruit flesh
5	4,922	clean fruit flesh
6	5,180	clean fruit flesh
.	…	…
.	…	…
.	…	…
111	7,672	TFD and Yellow Sap Fruits
112	7,744	TFD and Yellow Sap Fruits
113	7,746	TFD and Yellow Sap Fruits
114	7,810	TFD and Yellow Sap Fruits
115	7,918	TFD and Yellow Sap Fruits
116	7,986	TFD and Yellow Sap Fruits

Table 2. Measurement results of mangosteen fruit

Parameter	TFD and Yellow Sap	clean fruit flesh
total data	35 data	81 data
Minimum value	5,962 dB	3,928 dB
Maximum value	7,986 dB	7,068 dB
Value range	2,024 dB	3,14 dB
Average	7,041 dB	6,007 dB
Standard deviation	0,545	0,573

are then descriptively processed, and the results are shown in Table 2.

According to Table 1, data from mangosteen fruits with healthy flesh has 81 points, whereas those with damaged flesh contain 35. The mangosteen fruit sample used to train the SVM was chosen at random.

SVM was then used to assess the mangosteen measurement data to determine the threshold value. This procedure establishes the threshold, but no testing for mangosteen is conducted. Two mangosteens or eight sides were used for validation. Table 3 and Table 4 provide the validation findings, which show a success rate of 100 %. The SVM training resulted in a detection threshold value of 6.712 dB as a decision boundary with an accuracy rate

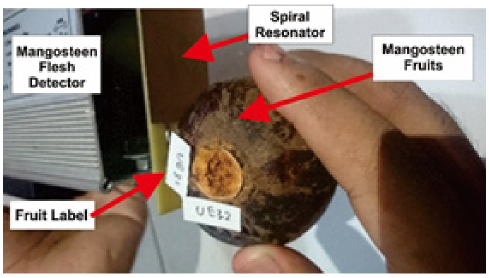


Figure 11. The process of measuring the S_{21} value of the Mangosteen fruit

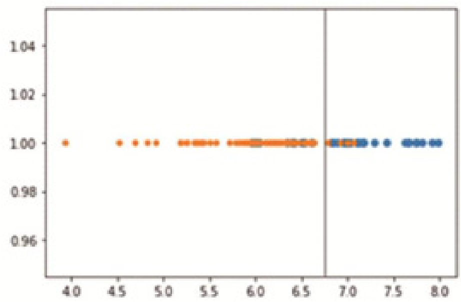


Figure 12. SVM train results

Table 3. Results of clean fruit flesh

Code	Fruit flesh	Display	Decision results
A2.1		 Magnitude: 5,82 clean fruit flesh	clean fruit flesh
A2.2		 Mag: 5,93 clean fruit flesh	
A2.3		 Mag: 5,89 clean fruit flesh	
A2.4		 Mag: 5,97 clean fruit flesh	

Table 4. Results of TFD and yellow sap fruits

Code	Fruit flesh	Results	Decision results
A3.1		 Mag: 5,92 clean fruit flesh	TFD and Yellow Sap Fruits
A3.2		 Magnitude: 6,83 TFD and Yellow Sap	
A3.3		 Magnitude: 7,02 TFD and Yellow Sap	
A3.4		 Magnitude: 5,83 clean fruit flesh	

of 87.9%, as illustrated in Figure 12.

The Arduino program will detect values less than 6.712 dB having good meat conditions and values greater than 6.712 dB having damaged meat conditions.

D. The results of The Detection of Mangosteen Fruit

The results of the detection of mangosteen for clean fruit flesh, also TFD, and Yellow Sap Fruits show in Tables 3 and 4, respectively.

The entire mangosteen fruit was detected using four detections on each side. If the prototype tool declares the four sides of the mangosteen fruit to be in good condition, as the fruit with code A2 in Table 3 does, the mangosteen fruit's flesh is in good condition. However, if one side of the mangosteen is damaged, the system declares the fruit in a damaged condition (TFD and Yellow Sap Fruits), like the fruit with code A3 in Table 4. On the LCD screen display, the mangosteen with yellow sap or translucent flesh is labelled "Kondisi Rusak," while mangosteen fruit in good condition is marked with "Kondisi Baik."

IV. Conclusion

Combining an oscillator, power splitter, and phase detector can work well as an alternative to VNA. The prototype was able to measure the value of microwave attenuation to determine the condition of the mangosteen flesh. The Spiral Resonator sensor used can read the S_{21} value of the mangosteen fruit with an average attenuation value for damaged meat conditions of 7.041 dB, and for good meat conditions of 6.007, with a detection threshold of 6.712 dB.

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