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INITIAL STUDY ON THE IMPLEMENTATION OF REFLECTION METHOD IN ULTRASONIC TOMOGRAPHY

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Abstract. The main purpose of this project is to design an ultrasonic scanner system which implements the reflection method through a medical ultrasound probe. Due to the high-cost and complex configuration of some of the well-known names in medical devices; such as Philips, and Brauns, the ultrasonic scanner system in this project is aimed to be cost effective and simple. Basically, the ultrasonic scanner system consists of two parts; the transmitter and the receiver. In this project, a PIC microcontroller was used in the transmitter circuit in order to produce a 2 MHz signal to excite the 2.25 MHz ultrasonic transmitter that exists in the medical ultrasound probe that had been selected, whereas the output or the reflected signal was obtain by tapping at the receiver of the medical ultrasound probe and was observed by using a digital oscilloscope. The ultrasonic scanner system was later tested by scanning a papaya. This project was verified by obtaining the reflected signals that resulted from the papaya scanning tests.

Keywords: Ultrasonic tomography; reflective; medical imaging; ultrasound probe; experimental approach

Abstrak. Matlamat utama projek ini adalah untuk mereka bentuk suatu sistem pengimbas ultrasonik dengan menggunakan kaedah pantulan yang dijana dan diterima oleh alatan ultrasonik yang lazim digunakan di dalam bidang perubatan. Disebabkan oleh kos yang tinggi dan konfigurasi yang rumit bagi sesetengah alat-alat perubatan yang berjenama seperti Philips dan Brauns, sistem pengimbas ultrasonik yang direkabentuk dalam projek ini adalah berhasrat untuk mengurangkan kos dan juga memudahkan konfigurasi. Pada asasnya, sistem pengimbas ultrasonik terdiri daripada dua bahagian; pemancar dan penerima. Dalam projek ini, satu mikropengawal pengimbas ultrasonik perubatan yang telah dipilih. Isyarat pantulan yang dikesan penerima pengimbas ultrasonik perubatan diperhatikan dengan menggunakan osiloskop digital. Sistem pengimbas yang direka kemudian diuji dengan mengimbas sebuah betik.

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Kata kunci: Tomography ultrasonik; pantulan; gambaran perubatan; pengimbas ultrasonik; pendekatan secara eksperimen

1.0 INTRODUCTION

The main purpose of this project is to design a simple and cost-effective ultrasound system. In this project, a medical, high frequency ultrasound probe is being experimented via Reflective Ultrasonic Tomography technique in order to obtain a 2-D cross sectional image of an object. The Reflective Ultrasonic Tomography technique was chosen over the Transmission Ultrasonic Tomography technique because the system that is designed in this project is a prototype of the existing ultrasound system for fetus scanning.

Basically the Ultrasonic Tomography system consists of four modules; PIC microcontroller circuit, amplifier circuit, transmitter excitation circuit, and the receiver circuit [1]. The completed prototype is later verified by obtaining the reflected wave of a papaya.

2.0 ULTRASONIC TOMOGRAPHY

The word tomography is actually a Greek word that is defined as a two-dimensional cross-sectional image of a three dimensional object [2]. In other words, tomography can be said as a process of obtaining a slice image of an object in concerned. This tomography imaging technique can be done by using various types of energy; such as ultrasounds, electrons, alpha particles, lasers, and radars [3]. In this project, only the ultrasound energy is selected and taken into account.

As mentioned before, ultrasound is a high frequency sound wave that is higher than the range detectable by human ears. Ultrasound can be heard by animals and it is usually used as a method of detecting the distance of an object or just simply a method of communication as used by bats and dolphins. This unique animal behavior is later adopted into a tomography process that resulted to a method that offers an insight of the content of an object, non-invasively. As for an example, the ultrasound scan system which is widely used for fetus scanning uses the ultrasonic tomography method to produce an image of the fetus in a mother's womb. This practically uses an ultrasound wave between 1 MHz and 5 MHz and this range of ultrasonic wave is basically used for medical purposes [4].

There are two types of ultrasonic tomography techniques that are normally used for imaging; transmission and reflection method [5]. The transmission mode is usually used for determining variations in material density where the data acquired only concern the amplitude and/or the time of flight, and the construction of the image is based on the assumption of straight-line propagation [6]. In transmission mode, the transmitter and the receiver is usually placed at one end to another which the sound wave will be transmitted through the medium and the data required is collected at the opposite end of the transmitter (the transmitter and receiver is placed facing each other with the media in between them) [7]. Whereas for the reflection mode, it is usually used for locating discontinuities and non-homogeneities, their position, shape and size. The data required for the reflection mode is acquired from the same side as the incident sound wave. This can be done by using the same transducer to transmit and receive the returning echoes. The size and location of the detected discontinuity or material interface can be estimated from the amplitude and the time of flight of the reflected sound wave [5]. This can be represented in mathematical form as:

$$d = \frac{tc}{2} \tag{1}$$

where t is the time of flight of the reflected sound wave at the distance d from the transducer, and c is the ultrasound velocity in the media. This technique is chosen over the transmission mode technique due to the similarity to the functions in the existing ultrasound system.

3.0 HARDWARE IMPLEMENTATION

3.1 Sensor Selection

The appropriate sensors were investigated and selected. For this project, a medical ultrasonic transducer probe with the frequency of 2.25 MHz was used. The transducer probe was received without any documentation attached. Therefore, the transducer probe was experimented to determined the transmitter's and the receiver's port. The transducer probe that was selected and purchased is as depict in Figure 1.

Figure 1 Pulson medical ultrasound transducer probe

After some troubleshooting, it is determined that the white wire is for the receiver's port whereas the black wire is for the transmitter's port.

3.1.1 PIC Microcontroller

The PIC microcontroller is used to generate an electrical signal or pulse in order to excite the transmitter in the transducer probe. Generally, an ultrasound wave is produced as a result of a vibrating piezoelectric crystal. When the piezoelectric crystal is induced with an electrical pulse, it will vibrate and thus producing an ultrasound wave. This is also true vice versa. The piezoelectric crystal will vibrate when it receives or detect an incoming ultrasound wave and this vibration will be interpreted into electrical signals. The strength of the ultrasound wave that hits the piezoelectric crystal is proportional to the voltage produced across the piezoelectric crystal. In this project, an ultrasound medical probe which encompasses a single piezoelectric crystal, is used to produce (transmit) and receive ultrasound wave, alternately.

In the transducer, there are two modes of operation; continuous mode and pulse-echo mode. The continuous mode is the uninterrupted generation of ultrasound. This mode requires two piezoelectric crystals where one is for transmitting ultrasonic wave and the other is for receiving the reflected waves. Both the transmitting and the receiving crystals are mounted in the same housing.

The pulse-echo mode is more commonly used because it only requires one piezoelectric crystal to operate. It consists of short excitation pulses at regular intervals. The crystal will act as a receiver crystal and wait for any returning echoes during the time between the pulses.

The timing for a typical pulsing scheme is as shown in Figure 2. The ratio of the duration of the ultrasonic pulse or also known as the duty cycle for the pulse-echo mode is set to 0.1% to provide ample time for the crystal to detect any returning echoes.

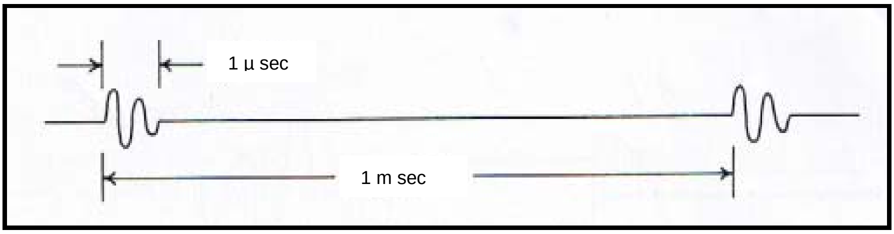


Figure 2 Pulse-echo mode pulsing scheme

The two modes of operation are as illustrated in Figure 3.

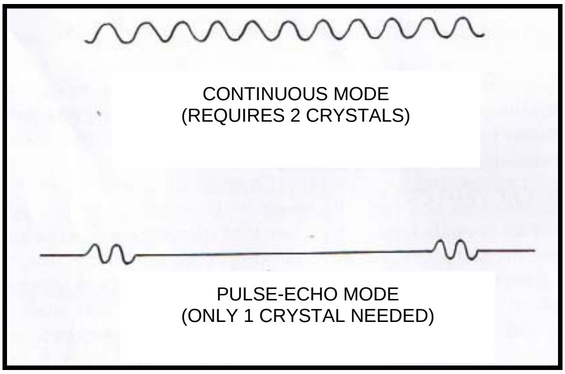


Figure 3 Continuous mode and pulse-echo mode

3.1.2 Detection of the Returning Echoes

Upon receiving the returning echoes, the electrical signal from the ultrasonic transducer probe needs to be pre-processed before it can be sent to the computer to generate an image. This electrical signal needs to undergo a sequence of signal modification in the signal conditioning circuit module. Basically a signal conditioning circuit incorporates five stages of signal modifications. In the first stage, the electrical signal received will be buffered to sustain the original signal. Next, the signal will be amplified to a level large enough to be quantized. This is due to the amount of current needed for a signal to be interpreted as a logic level by the PIC microcontroller. This is followed by the rectification stage where the electrical signal will transformed to only positive amplitudes. In the envelope detection stage, the maximum peaks will be detected and form an envelope. This envelope signal will then go through a final amplification which is then producing a signal called a video signal where this signal is then passed to the PIC controller. The sequence of the stages in the signal conditioning circuit is shown in Figure 4. Due to time constraint and lack of instruments, the receiver circuit only consists of an amplifier of a gain of 600 as shown in Figure 5. The received ultrasound wave is then monitored by using a digital oscilloscope.

The overall system as depict in Figure 6, is verified through obtaining the reflected signal of a papaya after being scanned using the prototype ultrasound scanner.

The reflected signal is observed by using a digital oscilloscope. The resulted waveforms will be briefly analyzed in the next section.

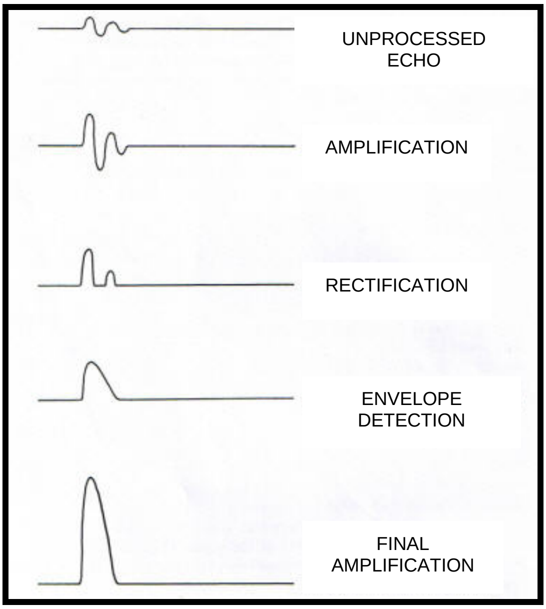


Figure 4 Signal conditioning circuit processes

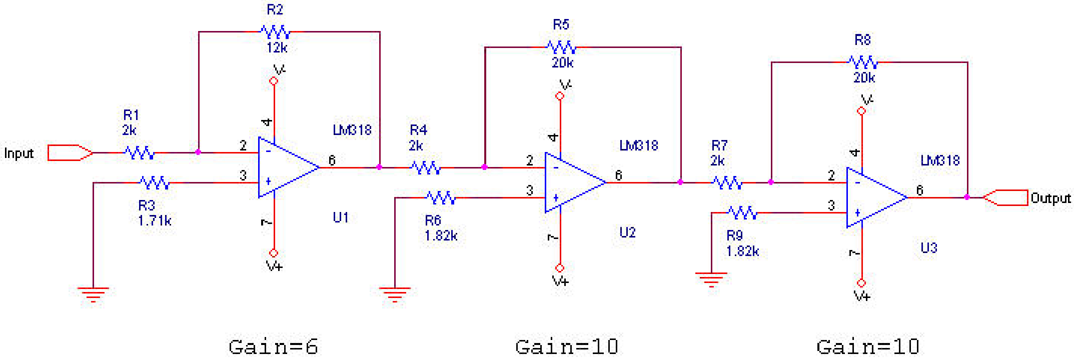


Figure 5 Amplifier circuit

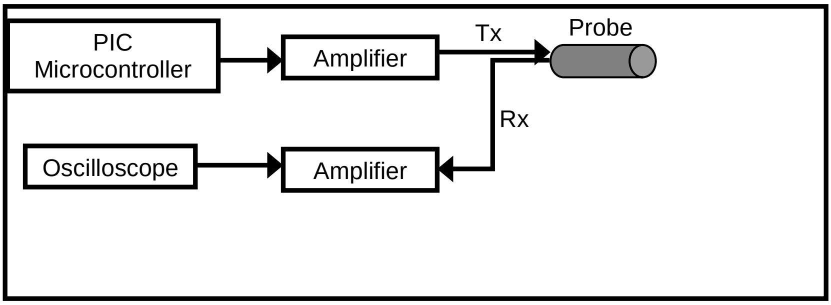


Figure 6 The overall prototype of the ultrasound system

4.0 RESULTS AND ANALYSIS

4.1 Excitation Pulses

As mentioned before, the PIC 18F2550 microcontroller was selected to produce an excitation pulse for the transmitter in the transducer probe. Figure 7 shows the resultant pulse generated from the PIC microcontroller and the pulse is later amplified by using an IR2101 and the result is shown in Figure 8.

The transducer probe that was used has the frequency of 2.25 MHz, therefore the generated excitation pulse from the PIC microcontroller needs to be at least between 2 MHz and 2.25 MHz to fully utilize the high frequency ultrasound. The 2 MHz amplified excitation pulses generated from the PIC microcontroller are as shown in Figure 9. Figure 10 shows the excitation pulses for the transducer to operate in a pulse-echo mode where the duty ratio is 0.1%. The duty cycle of the crystal is about 1 μs and the crystal waits for the returned echoes for 1 ms.

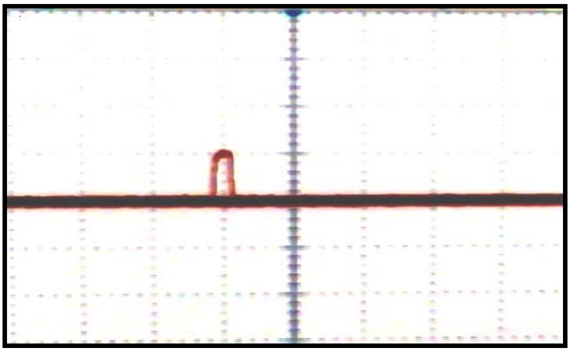


Figure 7 The excitation pulse from the PIC microcontroller
Scale: Y-axis = 5 V/Div, X-axis = 1 μs/Div

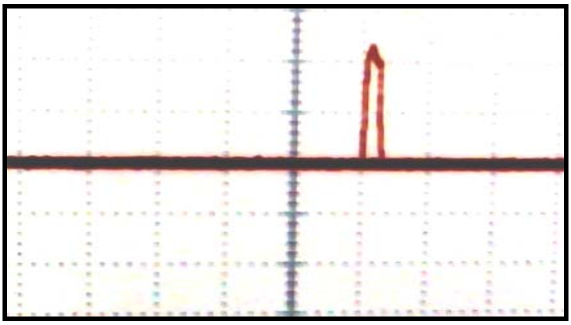


Figure 8 The amplified excitation pulse
Scale: Y-axis = 5 V/Div, X-axis = 1 μs/Div

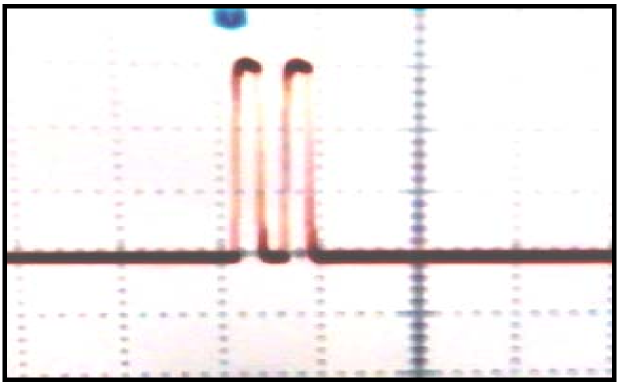


Figure 9 The 2 MHz amplified excitation pulses.
Scale: Y-axis = 5 V/Div, X-axis = 1 μs/Div

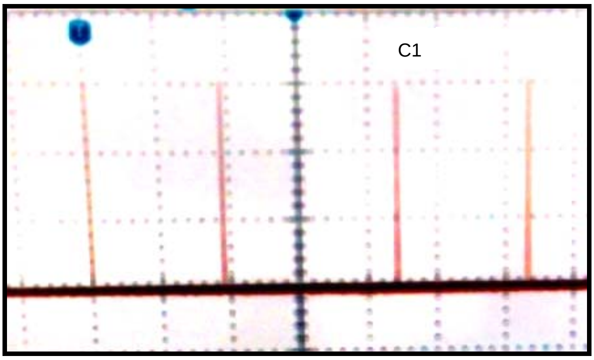


Figure 10 The pulse-echo mode with the duty ratio of 0.1%.
Scale: Y-axis = 5 V/Div, X-axis = 400 μs/Div

The results obtained at the transmitters and the receiver's port when nothing is being scanned is as shown in Figure 11. The signal in red represents the transmitter's signal at the transmitter port whereas the signal in blue represents the reflected signal detected by the receiver when there is nothing in front of the transducer probe. It can be seen that the ringing effects exist due to the early detection of the transmitted signal. In other words, the transmitted signal is detected by the receiver upon transmitting because the output was tapped simultaneously with the transmitted signal even though it was supposed to wait for 1μs to let the transmitter transmit the ultrasound wave.

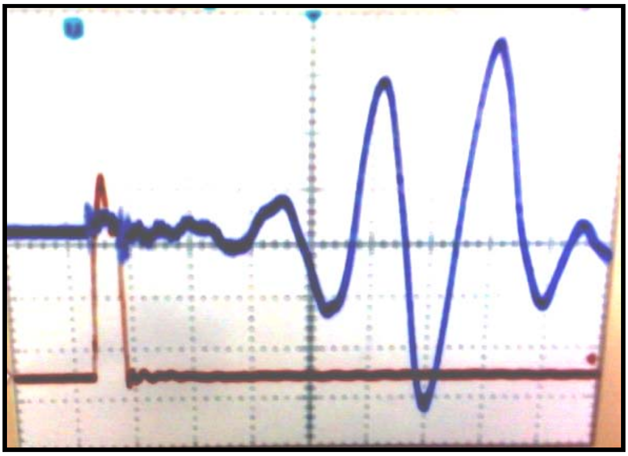


Figure 11 The transmitter's and receiver's signal.
Transmitter scale: Y-axis = 5 V/Div, X-axis = 1 µs/Div.
Receiver scale: Y-axis = 1 V/Div, X-axis = 400 ns/Div

4.2 Papaya

At first, the whole papaya was scanned by using the prototype ultrasound scanner where the whole papaya that was being experimented on is as shown in Figure 12 and the reflected signal that was captured from a digital oscilloscope as shown in Figure 13.

Figure 12 The whole papaya

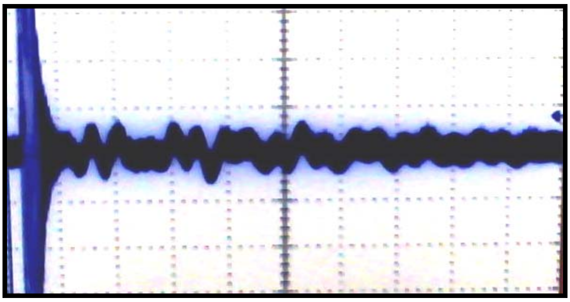


Figure 13 The reflected signal obtained from the whole papaya.
Scale: Y-axis = 5 V/Div, X-axis = 40 μs/Div

At this point, the raw reflected signal could not be interpreted correctly; therefore the papaya's seeds were later taken out and the seedless papaya was scanned by using the same prototype ultrasound scanner. This is done so that the reflected signal obtained from both cases could be compared for dissimilarities.

The seedless papaya and the reflected signal obtained can be seen in Figure 14 and Figure 15, respectively. If the reflected signal for both cases were to be compared side by side, the signal that is circled with red appears in the seedless papaya reflected signal which does not appears in the reflected signal obtained from the whole papaya. Therefore it can be assumed that the signal in the red circle might appear due to the air compartment that exists in the seedless papaya.

The comparison between the reflected signal of the whole papaya and the seedless papaya is as shown in Figure 16.

Figure 14 Seedless papaya

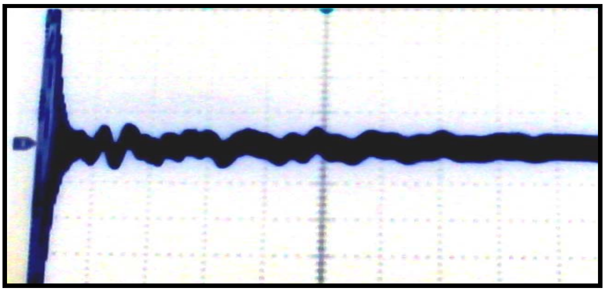
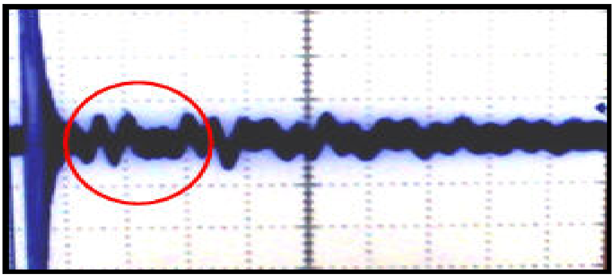
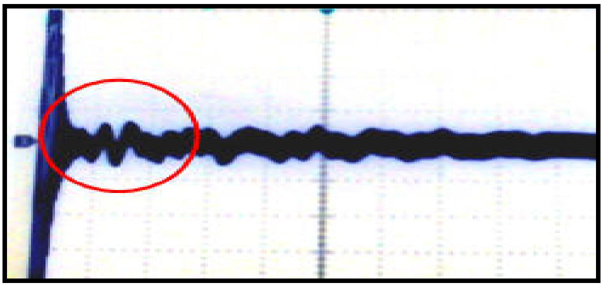


Figure 15 The reflected signal obtained from a seedless papaya.
Scale: Y-axis = 5 V/Div, X-axis = 40 μs/Div



(a)



(b)

Figure 16 The comparison between the reflected signals obtained from the whole papaya and the seedless papaya; (a) The reflected signal obtained from the whole papaya (b) The reflected signal obtained from a seedless papaya
Scale: Y-axis = 5 V/Div, X-axis = 40 μs/Div

The seeds that had been taken out from the papaya were placed in a very thin plastic bag as shown in Figure 17 which is later scanned. The reflected signal obtained for the seeds are as shown in Figure 18. It can be seen that the reflected signal for the seeds of the papaya differs a lot from the previous two results.

Figure 17 The seeds from the papaya placed in a very thin plastic bag

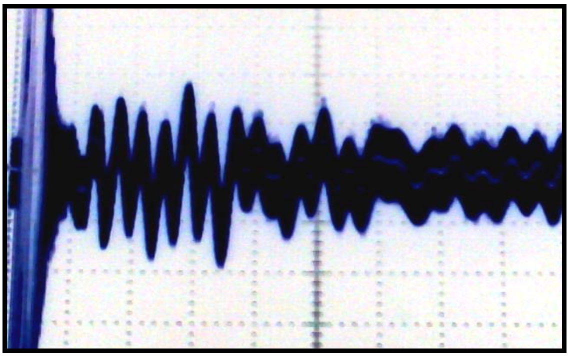


Figure 18 The reflected signal obtained from the seeds
Scale: Y-axis = 2 V/Div, X-axis = 40 μs/Div

4.3 Additional Results

As mentioned before, other than a papaya, there are other things that had been scanned; such as a human palm, wrist, a plastic material, a paper material, and also a metal material.

4.3.1 A Human's Palm and Wrist

The papaya was selected amongst any other fruits available because of its composition that is similar to a human body parts. Therefore, to verify whether this assumption is valid, a human palm is scanned using the same ultrasound system prototype and this is shown in Figure 19 and the reflected signal obtained is as shown in Figure 20. When the reflected signal obtained for a palm is compared with the previous reflected signal obtained for the whole papaya, it can be seen that the signal obtained is similar to each other. This shows that the palm contains similar composition compared to the whole papaya.

Figure 19 Palm

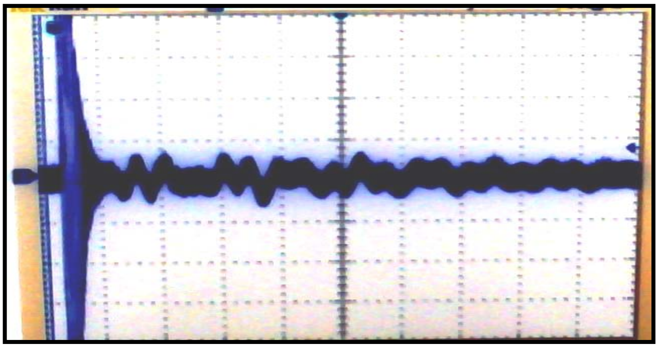


Figure 20 The reflected signal obtained for a palm
Scale: Y-axis = 5 V/Div, X-axis = 40 μs/Div

The wrist was also scanned and the reflected signal obtained is similar to the reflected signal obtained for the seeds of the papaya in the thin plastic bag. It can be assumed that the veins in the wrist cause the discontinuity in the wrist that is similar to the discontinuity between the seeds in the thin plastic bag. Figure 21 shows the wrist being scanned and the reflected signal obtained is as shown in Figure 22.

Figure 21 Wrist

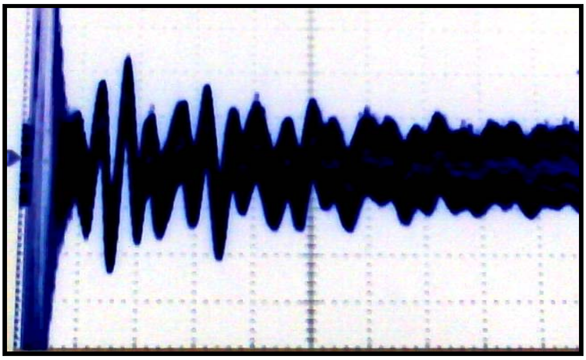


Figure 22 The reflected signal obtained for the wrist
Scale: Y-axis = 2 V/Div, X-axis = 40 μs/Div

5.0 CONCLUSION

In this paper, the reflected signal obtained for a papaya was presented for verification purposes. Different conditions of the papaya are scanned and the reflected signal was briefly analyzed. The results from the papaya were compared to the reflected signal obtained for wrist and arm.

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