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VIBRATION-BASED MEASUREMENT SYSTEM FOR BREAST TISSUE

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Keywords
Breast Tissue, Vibration Signal, Accelerometer Sensor, Power Spectral.

Abstract
When the studies in the literature on breast tumor diagnosis are examined, there are many studies because breast tissues have different characteristics. However, there is no study on the diagnosis of the tumor by constant frequency vibration stimulation and the response of healthy and tumorous breast tissues to this stimulation. This study, fixed frequency vibration was applied to the points determined on breast tissues and it was aimed to design a system that can measure vibration signals at certain distances from these points. The first part of the system consists of a motor and a driver that provides vibration. The other part includes accelerometer sensors that measure vibrations at certain points in the breast tissues. The hardware is controlled by a microcontroller-based module. With the help of this designed device, the power spectra of the vibration signals obtained by measurements on breast phantom models were analyzed. In response to 160 Hz vibration excitation, the dominant frequencies of the signals measured at a certain distance with the accelerometer sensor were found to be in the range of 120-140 Hz. These results show the damping effect of breast tissue and that the damping effect may differ between tumor and healthy tissues.

MEME DOKUSU İÇİN TİTREŞİM TABANLI ÖLÇÜM SİSTEMİ

Anahtar Kelimeler
Meme Dokusu, Titreşim Sinyali, İvmeölçer Sensörü, Güç Spektrali.

Öz
Meme tümörünün teşhisine yönelik literatürdeki çalışmalar incelendiğinde, meme dokularının farklı karakteristikler taşıdığı olgusuna dayanan birçok çalışmaya rastlanmaktadır. Ancak sabit frekanslı titreşim uyartımı ile sağlıklı ve tümörlü meme dokularının bu uyartıma vereceği tepki sayesinde tümörün teşhisine yönelik bir çalışmaya rastlanmamıştır. Bu çalışmada, meme dokuları üzerinde belirlenen noktalara, sabit frekansta titreşim uygulanmış ve bu noktalardan belirli uzaklıklarda titreşim sinyallerini ölçebilen sistem tasarımı amaçlanmıştır. İlgili sistemin ilk kısmı, titreşim sağlayan bir motor ve sürücüden oluşmaktadır. Diğer kısmı ise, meme dokularındaki belirli noktalarda titreşimleri ölçen ivmeölçer sensörlerini içermektedir. Donanımın kontrolü ise, mikrodenetleyici tabanlı modül ile gerçekleştirilmektedir. Tasarlanan bu cihaz yardımıyla, meme fantom modelleri üzerinden elde edilen ölçümlerle alınan titreşim sinyallerinin güç spektrumları incelenmiştir. 160 Hz. titreşim uyartımına karşılık, ivmeölçer sensörü ile belirli bir mesafeden ölçülen sinyallerin baskın frekanslarının 120-140 Hz. aralığında olduğu görülmüştür. Bu sonuçlar, meme dokusunun sönümleyici etkisini ve sönümleme etkisinin tümörlü ve sağlıklı dokularda farklılık olabileceğini göstermektedir.

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Highlights

- A new measurement system has been proposed for breast tissue that allows measurement with the help of fixed frequency vibration stimulation.
- This system provides 3-axis measurement and analyzes the vibration signals it measures, showing the damping effect of breast tissues on fixed-frequency vibration stimulation.
- Vibration signals measured with the designed vibration-based measurement system and GUI can be recorded and analyzed.

Purpose and Scope

The aim of the study was to design a system that can apply vibration at a fixed frequency to determined points on healthy or tumor breast tissues and measure the vibration signal at certain distances from the applied point. In addition, it is aimed to create a user interface that can analyze the vibration signals measured by this system.

Design/methodology/approach

Based on the aim of interpreting that breast tissues have different characteristics; a device was designed to receive vibration signals with the Arduino Uno R3-based ADXL345 accelerometer sensor. With the help of this device, the vibration signals received from the breast tissues were recorded in the GUI designed in the computer environment.

Findings

Values in the range of 120-140 Hz were obtained in the power spectra of the vibration signals taken from points determined at equal distances from a vibration motor that creates a fixed frequency excitation of 160 Hz. It can be said that the dominant frequencies in healthy and tumor breast tissues can be determined and information about soft and hard tissues can be obtained thanks to the designed vibration-based measurement system.

Research limitations/implications

Thanks to this proposed system, the frequency characteristics of breast tissues can be interpreted and it is anticipated that in future studies, interpretations of the conductivity and hardness of the tissues may assist the physician in the diagnosis of tumor tissues.

Practical implications

It has been observed that with this proposed system, the presence of a tumor can be interpreted by measuring the frequency characteristics of different breast tissues.

Originality

This study shows the behavior of breast tissue with constant frequency vibration stimulation and helps to interpret hardness and softness.

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1. Introduction

It is known that the tissues in the human body show different characteristics and various studies have been conducted to explicate these differences. In these studies, vibration signals received from people have been utilized and it has been concluded that they can help detect various types of diseases (Addison, 2017). In the studies, vibration signals that occur in the vocal cords during speech are generally examined, and there is no study on vibration signals recorded by applying a vibration source on the human body (Addison, 2017; Chen and Shih, 2013; Ak et al., 2019; Alkhaledi, 2010). Chen et al. investigated whether vocal training would increase facial bone vibration during resonant (high frequency and reverberant) sound production. They measured the vibration level of the face after training and during speech with a piezoelectric accelerometer and compared it with the vibrations in the voice (Chen and Shih, 2013). Based on vibration signals, it is revealed that it can help in the diagnosis of sleep apnea disease as well as modeling of nasal diseases (Morillo et al., 2010). In their study, Rendon et al. measured vibrations in the neck and chest region with an accelerometer to detect important signals that can be used in the diagnosis of sleep apnea. They aimed to diagnose sleep apnea by creating a vibration map by interpreting the signals they received with an advanced analysis program (Rendon, 2007). It is also possible to explain the effects of vibration sources on different human tissues (Amar, 2010; Anand et al., 2008). Dong et al. proposed a system called VEA to study the distribution of vibration energy absorption in the human finger-hand-arm system (Dong et al., 2006). Balbinot proposed the development of a system integrated into the ZigBee network to measure human vibration. The developed system allowed to separate human vibrations of about 40 Hz in three axes. They showed that vibration can contribute to back pain in workers working on machines such as tractors and diggers (Balbinot et al., 2008). Bourke et al. analyzed the signals received from triaxial accelerometer sensors mounted on the torso and thighs of elderly people. Thanks to these signals, they interpreted the simulated fall patterns they created. By giving various trainings to the same people, they aimed to see the success of their training by evaluating the fall patterns after the training (Bourke et al., 2007).

A literature review was conducted on the importance of analyzing vibration signals related to the diagnosis of breast tumors. When the studies in the literature are examined, it is seen that there are alternative methods for breast tumor diagnosis. One of these methods, which is usually image-based, is the elastography method. This method is an imaging method that displays and characterizes the elastic properties of normal and abnormal human tissues and identifies differences in elastic properties between tissues (Zhou et al., 2017). The basic fact here is that tumor breast tissue is 400 - 1000% stiffer than healthy breast tissue (Samani et al., 2008).

This study is based on the knowledge that human tissues show different characteristics as seen in the literature and that vibration signals recorded from human tissues can help in the detection of various types of diseases to interpret these differences. In their study, investigated simulation techniques by performing whole body vibration analysis (Coyte et al., 2015). Their study is presented as a review of the literature on various topics, including recent work on modeling the biodynamic human sitting response to vibrations. In addition to this study, there are studies describing the effects of vibration sources on different human tissues (Peter et al., 2013; Zhi-Fei et al., 2009; Yanxi and Qingxia, 2010; Kitamura, 2012). Investigated the damping properties of tissues against vibrations applied to the human body. The main purpose of their study was to reveal the damping properties of human tissues, spring, and damping constants of tissues (Amar et al., 2010). In another related study, similarly, spring, and damping models of tissues were developed to predict the damping properties of human tissues (Alkhaledi, 2010). When other similar studies in the literature were examined, it was seen that it was possible to explain the different effects of vibration sources on different human tissues (Coyte et al., 2015; Kitamura, 2012). In addition, they stated that vibration signals obtained by applying a constant frequency vibration source to human tissue can provide better information (Torvinen et al., 2002). In their study, they analyzed the vibration signals from 9 different points on the human face, which were determined at equal distances from a DC vibration motor generating constant frequency excitation. As a result, they detected different frequency damping in the forehead and cheek regions and concluded that different frequency signals were observed due to the different damping effect of hard and soft tissues (Ak et al., 2020). When the studies on the diagnosis of breast tumor and the analysis of vibration signals in the literature were examined, it was observed that there was no study on the softness and hardness interpretation of phantom models excited by a constant frequency vibration source. In addition, when other methods used in the diagnosis of breast tumors are evaluated, these methods have harmful effects on the human body. Therefore, there is a need to develop a cost-effective method that does not harm the human body (Valero et al., 2021).

In this study, a system consisting of a vibration motor that provides vibration excitation at constant frequency, Micro-electro-mechanical system (MEMs) accelerometer sensor and microcontroller-based hardware is designed. Vibration signals are generated by the vibration motor that will provide constant frequency excitation, and these vibration signals are measured from measurement points at certain distances by means of MEMs accelerometer sensors and drivers. The control of this hardware is realized with a microcontroller-based module. The vibration signals were recorded with the communication protocol between the interface created on the computer and the microcontroller. The power spectra of these vibration signals were analyzed with the help of the designed interface and analysis software. As a result of the analysis, the frequency characteristics of the vibration signals received from breast tissues were revealed. As a result, the frequency characteristics obtained are aimed to provide the interpretation of hard and soft regions in living tissues.

2. Material and Method

The components of the designed microcontroller-based system are listed below.

- Arduino Uno R3
- ADXL345 Accelerometer Sensor
- DC Vibration Motor Module
- SD card Module and SD Card

A sample image of the Arduino Uno R3 model used in this study is shown in Figure 1 (Cakir et al., 2021). The development board, which has an ATmega 328 based microprocessor, has 14 digital inputs/outputs and 6 analog inputs. It has a 16 MHz crystal oscillator, USB connection, power connection, ICSP connection and reset button. The board must be powered from an external power supply or the computer's USB port in order to operate.

Figure 1. Arduino uno R3

MEMS technology-based sensors are widely used in various fields, particularly in biomedical applications. The MEMs-based ADXL345 accelerometer sensor is a 3-axis accelerometer capable of 13-bit resolution measurement up to ±16 g. In addition to providing high accuracy with low power consumption, it supports digital communication protocols such as I²C and SPI. It works in different acceleration measurement ranges such as ±2g, ±4g, ±8g or ±16g (Böğrek and Sümbül, 2021). Within the scope of the study, the data received from the ADXL345 sensor was read by Arduino Uno R3 with I²C communication. The connection pins of the accelerometer sensor with Arduino Uno R3 are shown in Table 1.

Table 1. Arduino uno R3 and ADXL345 accelerometer sensor connection pins

Arduino Uno R3	ADXL345 İvmeölçer Sensörü
5 V	VCC
GND	GND
Analog A4	SDA
Analog A5	SCL

In this study, a 10x3 cm DC vibration motor was used as a constant frequency vibration source. Technical specifications of the vibration motor module used in the study are given in Figure 2 (Anonymous, 2023). The frequency of the DC vibration motor was set to a voltage value corresponding to 160 Hz according to the datasheet in Figure 2 with the help of the Arduino IDE interface. The reason for this is that the vibration frequency to be applied to living tissues should be in the range of 20 - 200 Hz. When frequencies in this range were tested, 160 Hz was found to be the resonance frequency of the tissue (Oral et al., 2022).

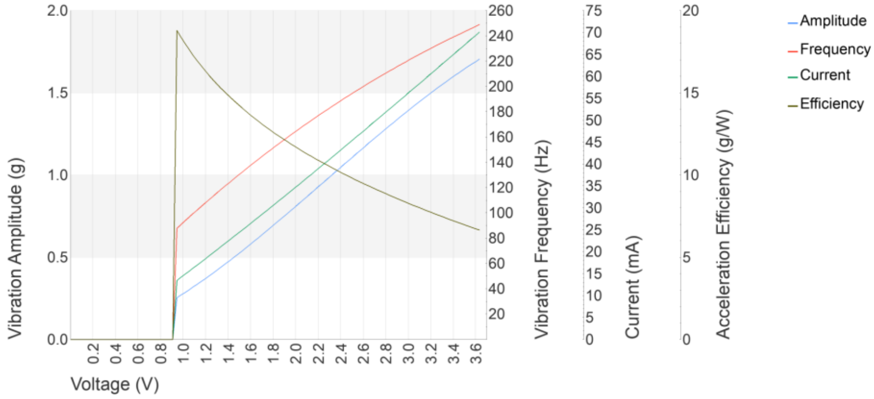

Figure 2. Technical specifications of the vibration motor module

The block diagram of the microcontroller-based vibration-based measurement system for breast tumor diagnosis, designed by combining all components, is shown in Figure 2 and the designed system image is shown in Figure 3.

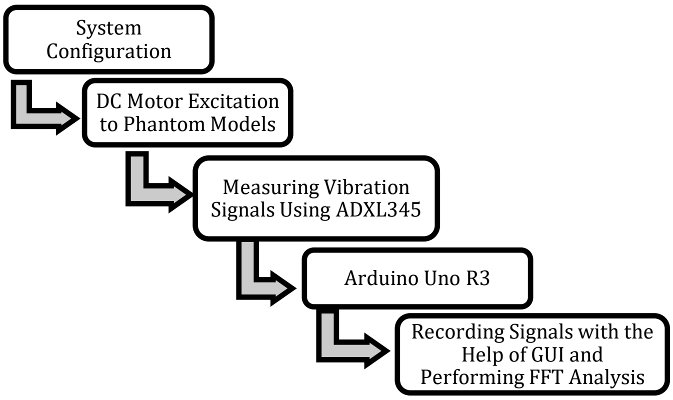

Figure 3. Vibration based measurement system flow chart

When the flowchart of the system is examined, it is seen that firstly, vibration excitation is given to the phantom models with a DC motor at constant frequency, and then measurements are made with the ADXL345 accelerometer sensor at certain distances. The measured vibration signals were transferred to the computer environment with the help of Arduino Uno R3, recorded and analyzed with the help of GUI. The block diagram of the vibration-based measurement system including components such as ADXL345 accelerometer, SD card module, Arduino Uno R3, vibration motor module is shown in detail in Figure 4.

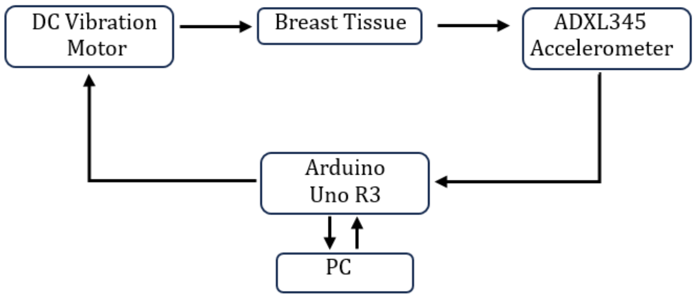

Figure 4. System block diagram

In breast phantom models, studies have been conducted with materials that can accurately mimic the dispersive dielectric properties of human tissues such as skin, fat, and tumors. As in the studies in the literature, vibration signals were measured on phantom models to show dielectric properties similar to actual breast tissues (Boparai and Popović, 2022; Murat et al., 2021; Palandoken et al., 2022).

In the literature, it has been observed that there are systems designed for the measurement of vibration effect in living tissues (Ak et al., 2019). In their study they used the MPU6050 sensor as an accelerometer sensor and offered the possibility of measuring from different points with a single sensor (Ak et al., 2020). In this study, the ADXL345 accelerometer sensor was chosen due to its low power consumption and focus on simple 3-axis acceleration measurement. In addition, the ADXL345 accelerometer sensor was chosen due to its widespread use in biomedical applications, low power consumption and ideal for portable devices. When the general specification parameters of the ADXL345 accelerometer sensor are examined, it can be said that it is preferred due to its low cost, triaxial and digital data processing, sensitivity, and nonlinearity (Böğrek and Sümbül, 2021). Moreover, these sensors work to detect motion or vibration by generating an acceleration value. And it has an A/D converter and a digital filter.

The image of the vibration-based measurement system realized within the scope of the study is shown in Figure 5.

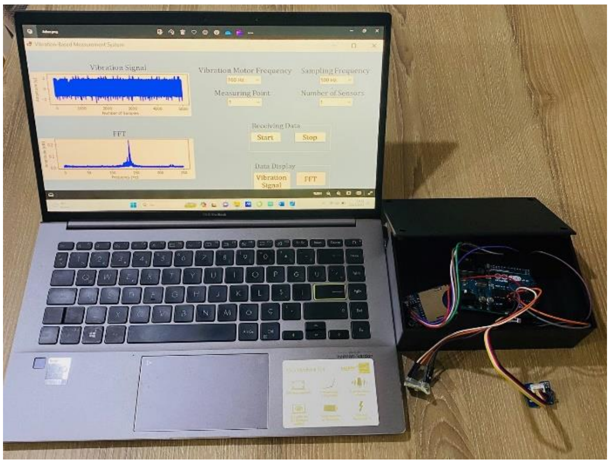

Figure 5. Image of a realized vibration-based measurement system

In addition, this system, which will enable measurements from different points on the breast tissue, will pave the way for multi-channel measurement, allowing the detection of the tumor area.

3. Experimental Results

3.1 Measurement and Computerization of Vibration Signals

ADXL345 accelerometer sensor can sample between 0.1 Hz and 3200 Hz. When the studies on vibration analysis are examined, besides the studies (Stork et al., 2017) in which the sampling frequency is 500 Hz, the sampling frequency was determined as 500 Hz, considering that the vibration motor frequency is 100-160 and 200 Hz. Thus, in the data set obtained with vibration signals obtained from breast tissues in the study, 10 s data with 5000 samples were measured and recorded with the help of SD card module.

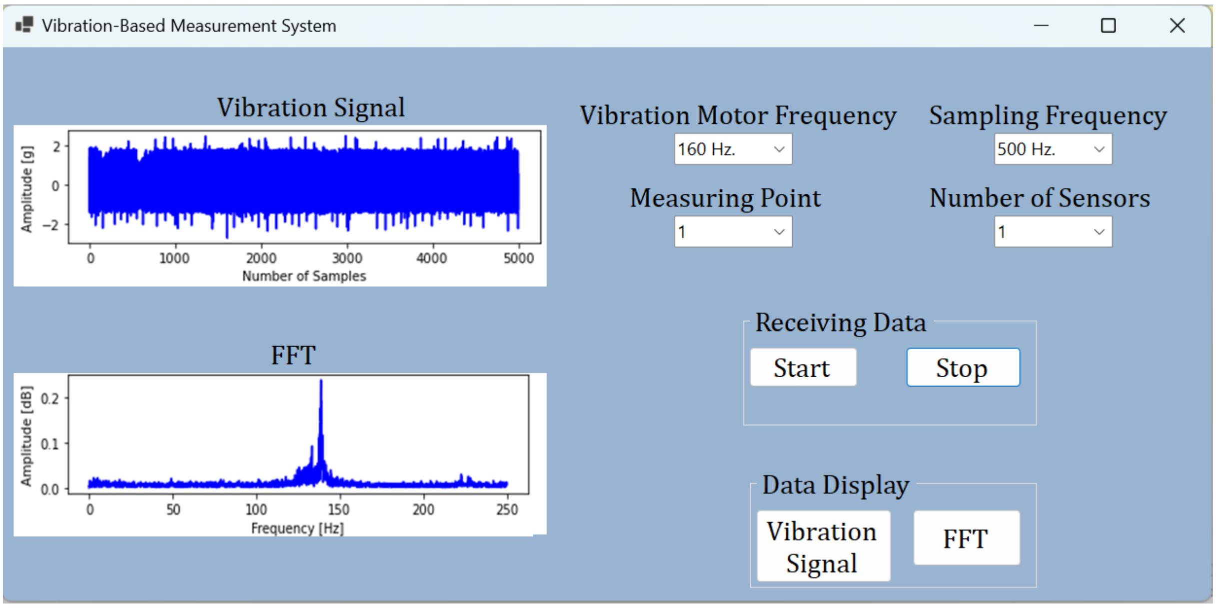

Figure 6. Interface designed for vibration-based system

A 10x3 mm direct current motor unit with a frequency of 160 Hz. and a microcontroller-based hardware consisting of a sensor module at a fixed distance from this unit, which provides vibration excitation at a frequency of 160 Hz. an interface has been designed to communicate this hardware with the computer and analyze the signals obtained. This designed interface is shown in Figure 6.

Vibration data was taken with the ADXL345 accelerometer sensor over the measurement points determined in the breast tissues and transferred to Arduino Uno R3. The received vibration data were parsed with the Arduino Uno R3 software and transferred to the computer as x-y-z values. The R vector is the combined force vector of the x-y-z values acting on the acceleration sensor and is shown in (1). The resultant of the x-y-z values taken from the accelerometer sensor was taken and the data set was obtained in this way. (Böğrek and Sümbül, 2021; Oral et al., 2022).

$$R = \sqrt{x^2 + y^2 + z^2} \quad (1)$$

A vibration signal composed of 5000 samples combined is shown in Figure 6. The Fast Fourier Transform (FFT) of the signals was used to analyze these vibration signals.

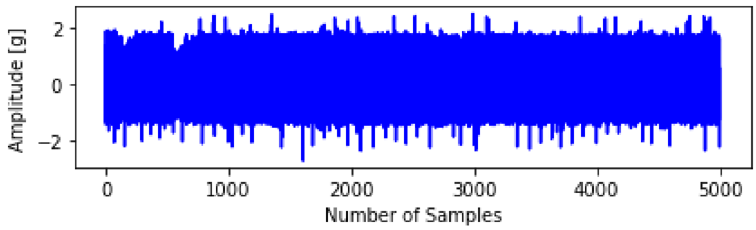

Figure 7. Received sample vibration signal

3.2 Power Spectral Representation of Vibration Signals

FFT was used to analyze the obtained vibration signals. The Fourier transform is an important method for obtaining signal information and processing these signals. However, since the Fourier transforms of real sequences cannot be calculated theoretically, it is not appropriate to use the Fourier transform for digital signals. The analog representation of frequency and the infinite number of samples required are the main reasons for this inconvenience. For this reason, a more practical method, the Discrete Fourier Transform (DFT), is used. A generalized version of the DFT is shown in Equation 2 (Chen and Shih, 2013).

$$x(e^{j\omega}) = \sum_{n=-\infty}^{\infty} x(n)\, e^{-j\omega n} \quad (2)$$

In this study, power spectral density analysis of all vibration signals was performed. Figure 8 shows the power spectral density (PSD) of a sample of vibration signals measured at a certain distance in response to vibration stimulation applied to breast tissues. The vertical axis indicates the power spectral density of the vibration signals, and the horizontal axis indicates the frequency values.

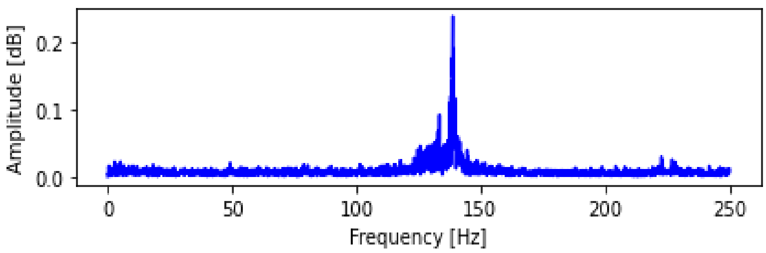

Figure 8. Power spectral representation of received vibration signal

When the power spectra of the received vibration signals were examined, it was observed that the frequencies of the signals measured at a certain distance with the accelerometer sensor were in the range of 120-140 Hz, in response to the vibration excitation given as 160 Hz. This showed the damping effect of the breast tissue. It is thought that this damping effect may differ in tumor and healthy tissues and these differences may provide information about the presence of tumors.

4. Result and Discussion

Unlike the studies in the literature on the analysis of vibration signals and breast tumor diagnosis, in this study, a device was designed based on Arduino Uno R3 with ADXL345 accelerometer sensor to receive vibration signals to interpret that healthy and tumor tissues have different characteristics. With the help of this device, the vibration signals received from breast tissues were recorded in the computer environment with an SD card module. The received vibration signals were filtered to remove noise and power spectra were obtained with the help of signal processing methods.

In future studies, it is thought that the number of sensors can be increased, and tumor regions can be detected with more detailed analysis to be performed with the simulation program. Therefore, in this study, the systems that are given vibration stimulation and measure the vibration signals thanks to the sensor placed at a certain distance are separated.

When the results obtained are examined, values in the range of 120-140 Hz were obtained in the power spectra of vibration signals obtained from points determined at equal distances from a vibration motor generating a constant frequency excitation of 160 Hz. It was possible to determine the dominant frequencies in healthy and tumorous breast tissues and thus, it could be said that information about soft and hard tissues could be obtained thanks to the microcontroller-based system designed. In future studies, it is foreseen that the conductivity and hardness interpretations of the tissues can help the physician in the diagnosis of tumor tissues in the studies to be carried out on breast tissues thanks to this system.

Conflict of Interest

No conflict of interest was declared by the authors.

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