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Evaluation of vibration measurements on human face using median and maximum frequencies

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Abstract: There are some studies in the literature in order to make the interpretation of human tissues having different characteristics. Some of these studies focused on the evaluation of human face tissues. Vibration signals generated from vocal cords have been used in these studies about human face tissues. However, any study using the vibration signals recorded by applying the external vibration source having fixed frequency value is not available in the literature. In this study, it is aimed to investigate the frequency characteristics of the vibration signals recorded from the human face. These signals obtained from nine different regions on the faces of subjects are analysed using frequency characteristics. In the analysis stage, median and maximum frequency values are calculated and evaluated. So, the softness and hardness interpretation about these regions on the face can be made and the frequency ranges of these regions can be determined. As a result, it is observed that low-frequency signals are dominant in hard regions and high-frequency signals are dominant in soft regions.

1 Introduction

It is known that human tissues show different characteristics and various studies have been carried out to interpret these differences. In these studies, vibration signals recorded from human tissues are used and proposed solutions that can help in the detection of various types of diseases. Coyte *et al.* realised a study on the whole-body vibration analysis technologies and modelling. This study provides a literature review of topics including recent researches about vibration signal processing and modelling of the bio-dynamic response of the human sitting to vibrations [1]. It is also possible to explain the effects of vibration sources on different human tissues [2–5]. Dong *et al.* proposed a system called vibration energy absorption to examine the distribution of the absorption of vibration energy in the human finger–hand–arm system. A new model has been designed to measure the energies of the areas exposed to vibration in the fingers, hands and arms, and the effects having different frequencies in the finger arm and palm have been observed [6]. Balbinot *et al.* realised the development of a system integrated with the ZigBee network to measure human vibration. The developed system allows the separation of human vibrations of ∼40 Hz on three axes. They explained that vibration in workers working on machines such as tractors and diggers can contribute to the occurrence of back pain [7, 8]. Amar *et al.* tried to explain the damping properties of the human body as a spring and damper system against vibrations applied to human tissue. The main purpose of the study is to reveal the damping properties of human tissue and to extract the spring and damping constants of the system [9]. In another similar study, a method was developed to estimate the damping properties of human tissues using a theoretical mass–damping spring model [10]. Vibration signal analysis has been included in research on the human face as well as on the human body. In these researches, the analyses have focused on the vibration signals that are usually occurred in the vocal cords during the talking [5, 11–14]. However, these studies are realised using vibration signals having frequencies that exhibit variation depending on the vocal cords. However, the vibration signals obtained by applying a source of vibration at a constant frequency on human tissues can provide better information [15].

In this study, a system consisting of a vibration motor, micro-electro-mechanical systems (MEMs) accelerometer sensor and microcontroller-based hardware, which gives vibration excitation at constant frequency, was designed. Then, 20 volunteer subjects were identified, and their clinical examinations were performed to determine whether they were healthy in terms of the nasal cavity. Vibrations were generated by a direct current motor (DC-motor) which would provide excitation on the facial regions of the subjects. Also, vibration signals were measured from nine regions around the sinus regions by means of hardware including the MEMs sensor. So, a database was created for all subjects and their frequency characteristics have been examined for nine regions on each human face. During the analysis part of vibration signals, median and maximum frequency methods were used.

2 Material and methods

Microcontroller-based vibration meter designed in this study is shown in Fig. 1. The designed device consists of Arduino Uno R3 [16], MPU6050 accelerometer sensor [17] and vibration DC-motor having size 10×3 mm. In this system, vibration excitation is applied to the face regions using DC-motor and the vibration signal is recorded with the MPU6050 sensor [18].

The frequency of the vibration excitation motor was measured by an oscilloscope in the laboratory of Akdeniz University Faculty of Engineering and fixed to 160 Hz.

2.1 Creating the database

Firstly, 20 healthy volunteer subjects were identified in order to create the database. The subjects were identified as 12 males and 8 females, between 25 and 35 years of age. The weight range of male subjects is 65–105 kg, the height range is 1.68–1.86 m, and the body mass index range is 20.52–30.82. The weight range of female subjects is 53–75 kg, the height range is 1.58–1.80 m, and the body mass index range is 19.00–26.89. Subjects were not allowed to

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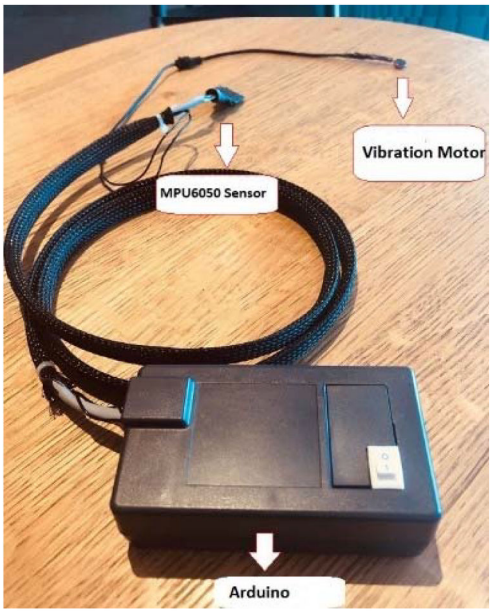


Fig. 1 *Designed microcontroller-based system*

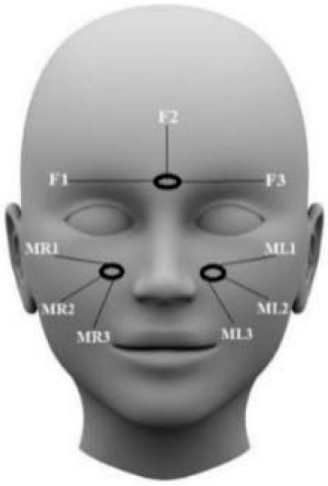


Fig. 2 *Vibration motor and measurement points*

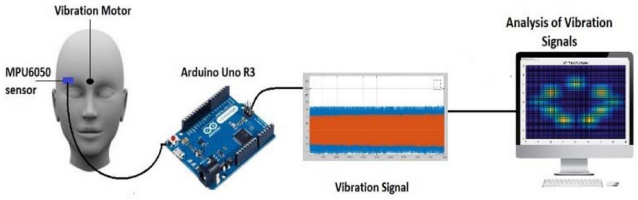


Fig. 3 *System block diagram*

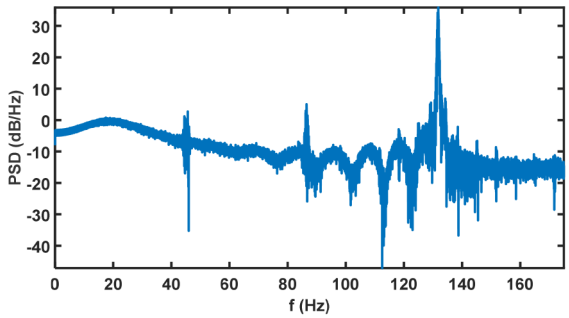


Fig. 4 *Power spectral density of the vibration signal*

move during the measurement. No glasses were found to affect data acquisition in facial areas. The clinical examinations were performed on the health of the nasal cavity. Then, the vibration signals from the regions determined on the face were recorded and a database was created.

2.2 Measurement regions and measurement setup

The measurement regions were obtained from the Frontalis muscles denoted as F (forehead region), regions and around the zygomaticus minor and zygomaticus major muscles denoted as MR (right cheek region) and ML (left cheek region) regions [19]. These regions consist of nine points in the near regions of the frontal and maxillary sinuses and each region point is away 3 cm from the vibration motor. These points are shown in Fig. 2.

In this figure, the measurement points are identified as F1, F2, F3, around the frontal sinus in the forehead; MR1, MR2, MR3 close to the maxillary sinuses in the right cheek, and ML1, ML2, ML3 close to the maxillary sinuses in the left cheek [20, 21]. Also, the vibration motor points are shown as black circles.

In the study, the sampling frequency of the vibration signals is determined as 350 Hz. Microcontroller-based hardware consisting of a DC-motor unit and a sensing module at a fixed distance (3 cm) to this unit for each measurement has been designed. An interface has been developed for the communication of this equipment with the computer and the analysis of the obtained signals.

MPU-6050 accelerometer sensor and vibration data were taken from the measurement points on the face and transferred to Arduino Uno R3. The vibration data were separated by Arduino Uno R3 software and transferred to the computer as x–y–z values. The x–y–z values of the obtained vibration signals were examined. Only x–y values were evaluated owing to that the z-values exhibit similarity for all measurements in the study as the MPU-6050 sensor is held in the same position at the z-axis during the measurement. Then median and maximum frequencies of the signals were calculated to evaluate the vibration data. The overall block diagram of the system is shown in Fig. 3 [22].

2.3 Median and maximum frequency calculation

The vibration signals measured from the subjects were analysed using median and maximum frequency calculations. Median frequency is defined as the median value of the frequency values of the signal. Fifty per cent of the power area of the signal is below the median frequency and 50% of the power area values of the signal are above the median frequency. Shortly, the median frequency divides two equal parts of total power spectral area. The median frequency provides a simple way to analyse the power spectral analysis [23]. The median frequency is theoretically defined as

$$\text{Median frequency} = \frac{1}{2}\sum_{j=1}^{m} P_j \tag{1}$$

where P_j is denoted as power spectral density (PSD) values of the signal. Parameter m explains the length of the frequency vector [24, 25].

The maximum frequency is the frequency magnitude value corresponding to the highest power value.

3 Results

In this study, firstly, PSD analysis of all vibration signals is analysed. It is shown that a PSD representation of an example of a vibration signal recorded from the F1 region in Fig. 4. PSD indicates the power spectral density of the vibration signals and f explains the frequency values.

Secondly, the median and maximum frequency values of each signal were calculated. The mean of the median frequency values of the F–MR–ML regions of the vibration signals obtained from 20 volunteer subjects is shown in Fig. 5. The median frequency values in this plot showed that F region has corresponded to the lowest frequency values and the ML region has corresponded to the highest frequency values. Moreover, these values showed that the

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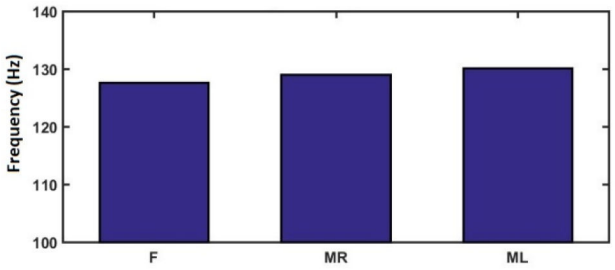


Fig. 5 *Median frequency values of F–MR–ML regions*

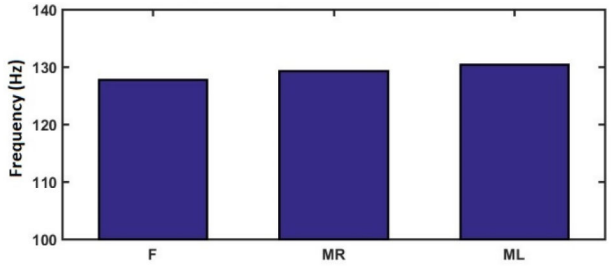


Fig. 6 *Maximum frequency values of F–MR–ML regions*

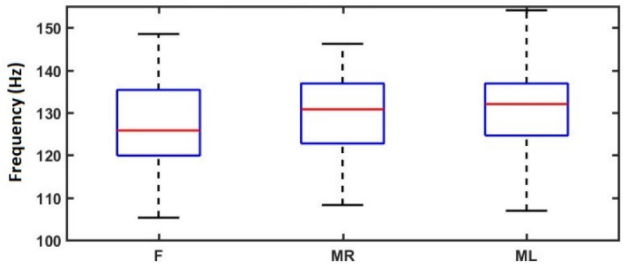


Fig. 7 *Median frequency evaluation of F–MR–ML regions*

hard regions on the face are related to low frequency while the soft regions are related to high frequency.

The maximum frequency values of the F–MR–ML regions are shown in Fig. 6.

As in the median frequency, the face region having the lowest frequency values is F and the face region having the highest frequency values is ML. This analysis showed that the hard regions on the face are related to low frequency and the soft regions are related to high frequency, as in the median frequency values determination.

We can summarise the median and maximum frequency evaluation using the boxplot representation, which is shown in Fig. 7. As can be seen here, the median frequency value of the F region is 125.78 Hz and the frequency range is 119.81–135.33 Hz for all subjects. The median frequency value of the MR region is 130.77 Hz and the frequency range is 122.72–136.85 Hz and the median frequency value of the ML region is 132 Hz and the frequency range is 124.59–136.84 Hz.

The median and maximum frequency analyses can be summarised as follows (f is the frequency value of the specified region):

$$f_{\mathrm{F}} < f_{\mathrm{MR}} < f_{\mathrm{ML}} \tag{2}$$

the frequency comparison for F1, F2, F3 regions:

$$f_{\mathrm{F2}} < f_{\mathrm{F1}} \cong f_{\mathrm{F3}} \tag{3}$$

the comparison for ML1, ML2, ML3 regions:

$$f_{\mathrm{ML1}} < f_{\mathrm{ML2}} < f_{\mathrm{ML3}} \tag{4}$$

the comparison for MR1, MR2, MR3 regions;

$$f_{\mathrm{MR1}} < f_{\mathrm{MR2}} < f_{\mathrm{MR3}} \tag{5}$$

As a result, it is concluded that low-frequency signals are seen in hard tissues and high-frequency signals are seen in soft tissues.

4 Discussion and conclusion

In this study, vibration signals were measured with an MPU-6050 accelerometer sensor and transferred to the computer with the help of Arduino Uno R3. These signals are recorded with the designed computer interface and the database is obtained. The database contains vibration signals from nine measuring points identified in the face regions of 20 volunteer subjects. Then, the median and maximum frequency values were calculated.

The points in the F region are analysed and the frequency values at the F1 and F3 points are higher than the frequency values at the F2 points. The points in the MR region are analysed and the lowest frequency values are found at MR1 points and the highest frequency values are found at MR3 points. Similarly, the points in the ML region are analysed and the lowest frequency values are found at ML1 points and the highest frequency values are found at ML3 points.

In the literature, there are several studies for the analysis of vibration signals [26, 27]. These studies usually include models and simulations related to vibrations generated by variable frequency audio signals [12]. In addition, vibration signals analysis was used to diagnose diseases such as sleep apnoea and nasal polyps [11, 13, 20, 28, 29].

In this study, differently, vibration signals obtained by applying a constant frequency source of vibration to human faces were evaluated. Furthermore, their frequency characteristics were obtained. So, better measurements were realised applying to fix the vibration source to the human face. This idea is the most important novelty of the study.

The results show that this model gives successful results in distinguishing the hard and soft tissues on the face. This model is thought to be helpful in the diagnosis of nasal diseases in future studies. Thus, it is aimed to propose a more harmless and economical method.

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