Handheld Bone Densitometry Configuration on Development of Bone Model Density Testing

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Abstract - **Handheld bone densitometry is a bone model density testing system using ultrasonic spectroscopy with pulse-echo method. In this study, we characterize a handheld bone densitometry configuration that uses a bone model made of PLA (Polyactic Acid) as the test object. This research also includes the use of a specially designed bone holder to hold and stabilize the bone model during measurement. The bone holder aims to improve the consistency of measurement results and reduce variability. Experiments were conducted using a handheld bone densitometry equipped with an ultrasonic transducer. Tests were conducted on TGC (Time Gain Compensation) configuration and ultrasonic wave frequency to obtain precise and accurate data on the density of the PLA bone model. The results of this study show that the use of PLA bone models as test objects for handheld bone densitometry has the potential for further development so that it can become a density measurement tool in human bones. By using a bone model holder, bone density measurements become more consistent and reliable. Proper TGC settings also affect the accuracy of the measurement results. In addition, the optimal frequency of ultrasonic waves also plays an important role in obtaining adequate data on bone density.**

Keywords - Ultrasonic spectroscopy, pulse-echo, holder, Polylactic acid (PLA)

I. INTRODUCTION

Osteoporosis is a common disease that primarily affects menopausal women and is characterized by low bone density and an increased risk of fractures [1]. The impact of osteoporosis on quality of life is significant, especially in older individuals. The condition can lead to functional impairment, prolonged immobilization, and restriction of activities of daily living, resulting in a decline in health-related quality of life [2]. It is important to consider the impact of osteoporosis on quality of life, as life expectancy and economic status are increasing among older adults. Thus, mitigation is needed as a preventive measure to minimize the occurrence of osteoporosis by screening with the simplest and superior method [2]. The current gold standard for diagnosing bone loss and osteoporosis consists of the determination of total bone mineral density-BMD-as measured by the Dual Energy X-ray Absorptiometry (DEXA) system [3]. DEXA cannot be applied to large populations due to the high cost and non-portability of the equipment, as well as the risk of radiation/ionization exposure, especially with certain patients such as pregnant women [4] [5].

Handheld Bone Densitometry is an ultrasonic spectroscopy instrument with pulse-echo method that works by sending ultrasonic waves into the test specimen (bone model) and detecting the reflected waves (echo) reflected by various internal structures in the specimen. The data from the reflected ultrasonic waves is then processed to obtain information about the mechanical and structural properties of the specimen.

In data collection on test samples, data consistency is very important. Consistency is key to obtaining accurate and reliable results. In bone model density testing, consistent data is required so that measurements are objective and repeatable. One reason for the importance of data consistency is to reduce measurement error. If the data used to measure the bone model is inconsistent, the measurement results will be variable and unreliable. This can lead to errors in determining the true density of the bone model being tested. In addition, data consistency is also important to more accurately compare measurement results and understand density differences between different bone models.

This study aims to develop a method of testing the density of bone models using ultrasonic spectroscopy techniques on a phantom. The ultrasonic spectroscopy method has proven to be a very useful tool in analysing the physical and mechanical properties of bone tissue. By applying this method to phantom bone models, we endeavoured to find representative candidate parameters for performing density testing on bone models. The results of this study are expected to provide deeper insights into the development of non-invasive diagnostic techniques and a better understanding of the characteristics of bone materials, which could have a positive impact in a variety of medical applications, including bone health monitoring and the development of innovative medical devices.

In the continuation of this paper, section II will discuss the results of the literature review covering the selection of PLA material for the fabrication of bone models as well as the use of ultrasonic spectroscopy technology in this study. Section III will detail the research method, which is divided into four main points. The first point will discuss the process of moulding the bone model, including the techniques and materials used. The second point will discuss the implementation of a holder to ensure the stability of the bone model during measurement. The third point will discuss the pulser configuration of the handheld bone density testing device, which is a key aspect of data collection. The last point of this section will explore the data processing used to analyse the measurement results. Section IV will review the test results and initiate an in-depth discussion of the findings. Finally, section V will present the conclusions of this study, summarising the results and providing insight into the implications of the findings in the context of the development of ultrasonic spectroscopy technology in bone density measurement.

II. LITERATUR REVIEW

This literature review presents an overview of previous research that is relevant to the focus of the research being conducted. We detail the research that has been done previously and provide a deeper understanding of the theoretical framework that supports this research.

The material used for making the bone model is Polylactic Acid (PLA) material. PLA material has relatively similar acoustic properties and elasticity to human bone. Ultrasonic waves will interact with the material based on its speed and elasticity. Since PLA has close mechanical properties to bone, ultrasonic waves will behave similarly when passing through this material as they do when passing through human bone [6].

On the other hand, Ultrasonic waves require precise energy transfer from the transmitter to the sample and then to the receiver. If the sample is unstable or moving during the test, this can result in inconsistent and inaccurate data. Holders are essential for data capture on bone models as they play a role in ensuring stability and proper positioning of the bone model sample during testing. By using the same holder, the test can be reproduced consistently for each sample tested as well as reducing external variables that can affect the test results.

In previous studies, the use of ultrasonic spectroscopy methods was employed to model ultrasound simulations to look for variables related to bone (e.g., density, fraction, volume, mineralisation, marrow properties, architecture, geometry, and biomechanical stiffness and strength) and system (e.g., operation in echo-pulse, frequency, bandwidth, signal shape, and characterisation of transducer apodisation). Of course, simulated forms of ultrasonic spectroscopy have potential limitations in the form of validation. Whether or not a particular simulation can provide useful information requires testing in physical experiments [7].

While previous studies provide important insights into the use of PLA materials and ultrasonic spectroscopy, it is worth noting that the integration of these two aspects in a single study has not been done much. This study aims to use ultrasonic spectroscopy with pulse-echo method in physical experiments to collect data and seek information about density values in bone models. The bone model is used as a 3D model to represent bone density with various densities. The use of 3D models opens up opportunities for the development of ultrasonic spectroscopy to find solutions to the need for more affordable bone model density testing equipment.

This literature review shows that, despite the advances in previous research, there is still a need for in-depth research in this area. This research is expected to provide new insights into the application of ultrasonic spectroscopy as bone density testing as well as contribute to recent developments in the field of medicine.

III. METHODS.

In this section, the methodological approach applied for bone model testing with ultrasonic spectroscopy is detailed. This subsection consists of several main points, including Bone Model Printing (a), Holder Implementation (b), Pulser Configuration in Handheld Bone Densitometry (c), and Data Processing (d). The use of PLA as the bone model material was chosen because PLA material has relatively similar acoustic properties and elasticity to human bone. (a). Next, the design of the stand that serves to ensure the stability of the bone model during testing is described in detail (b). The next subsection covers the details of the pulser configuration applied to obtain accurate and consistent test results (c). Finally, the data processing process applied to be able to analyze the test results and present the findings in a systematic and measurable way is described (d).

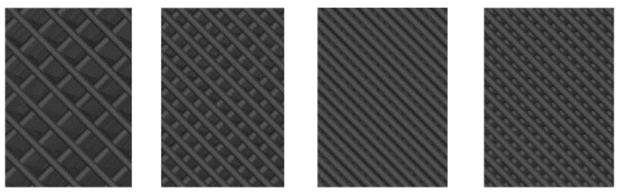
A. *Bone Model Printing*

The use of 3D printing has been widely used in various medical applications, including the creation of anatomical models for surgical planning and training. The use of 3D printing technology enables the creation of complex geometries with specific inner structural parameters, such as porosity, pore size and trabeculae diameter [8].

(a) Osteoporosis bone *(b) Normal bone*

Fig. 1 Porosity in bone

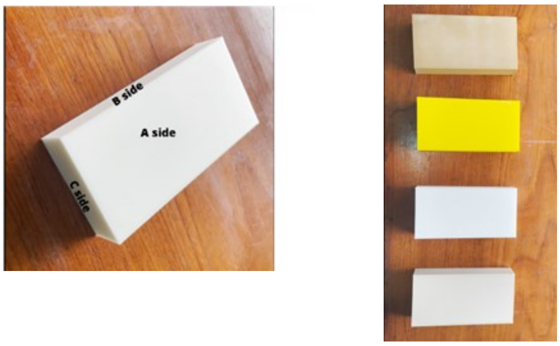
Osteoporotic bone (a) has a thin and less organized trabecular structure as shown in Figure 1 so that it has a lower density value than normal bone (b).



(a) Density 30% *(b) Density 50%* *(c) Density 70%* *(d) Density 90%*

Fig. 2 3D Printed Infill Density

3D printing has an adjustable *Infill Density* that can represent the porosity and trabecular diameters of the bone. In Figure 2, starting from the far left is the bone model design with a density of 30%(a), followed by 50%(b), 70%(c) and on the far right is 90%(d).



(a) Side Bone Model *(b) Type of Bone Model*

Fig. 3 3D Printed Bone Model

3D printed are 4 types of bone models(b) with different density levels based on the colors used. The white color is a bone model with 30% density, the yellow color is a model with 50% density, the grey color is a model with 70% density, the brown color is a model with 90% density. Each model interpreted normal bone (90%), osteopenia bone (70%), osteoporosis bone (50% and 30%). All models have the same print dimensions of 15cm x 7.5 cm, 3cm.

To make it easier for examiners in the data collection process, each bone model is given a mark in the form of coordinates such as variables A, B, C, 1, 2, 3, 4, and 5(a). The coordinate function on this model is useful to make it easier to determine the point in the data collection process as well as consistent and accurate data.

B. *Holder Implementation*

Using the right holder, data collection on bone models using ultrasonic spectroscopy can be performed in a more controlled, accurate and efficient manner. This helps researchers or medical practitioners to obtain valuable information about the bone model being tested.

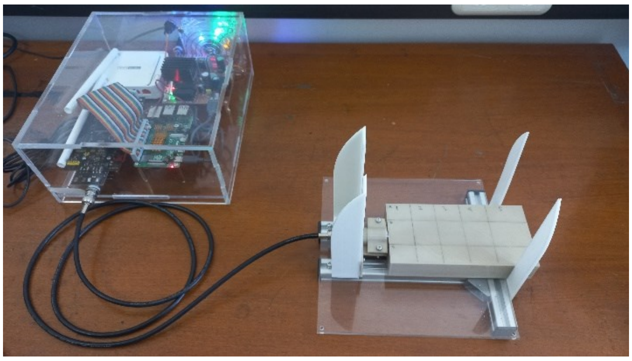


Fig. 4 Bone model holder

The pulser holder is designed so that the transducer can be used at several different height points with adjustable transducer placement. The holder uses three main materials: acrylic, aluminum profile, and 3D printing. The holder design is configured for pulse-echo type transducers with a holder type of position adjustment. Holder and transducer with position adjustment and pulse-echo types of work with 1 transducer that can be moved forward or backward and also the height of the transducer can be adjusted to the point to be measured on the model. The function of the holder aims to adjust the dimensions of the measured bone model and reduce the occurrence of inconsistent data during measurement. This position adjustment holder has dimensions of 20cm long, 20 cm wide, and 18 cm high.

C. *Pulser Configuration on Handheld Bone Densitometry*

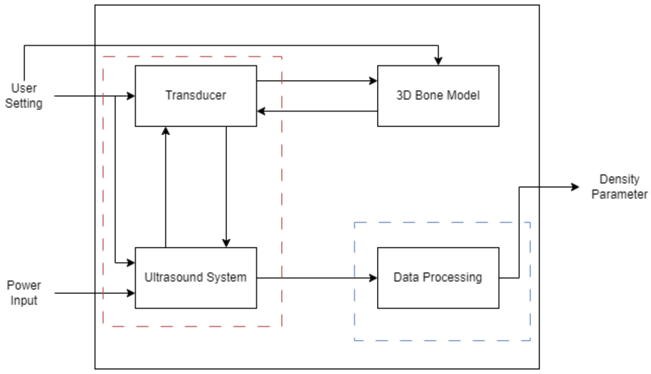


Fig. 5 Block diagram of handheld bone densitometry

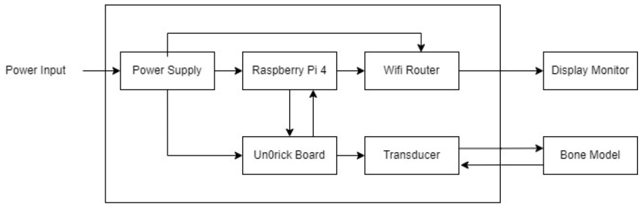


Fig. 6 Block diagram of ultrasound system

Figure 5 shows the configuration of the handheld bone densitometry system, and Figure 6 shows the configuration of the ultrasound system on the red dotted line.

To get good test results in bone model density testing requires the right pulser configuration. This pulser configuration includes several parameters that need to be considered so that the ultrasonic waves can be used optimally. Some of them include: Pulser Frequency, Waveform, Pulse Width, Transducer Selection, and Calibration.

The selection of the transducer is in the form of size and shape according to the test application and position on the bone model sample. Inappropriate size can affect the focus and quality of the waves produced. In handheld bone densitometry a cylindrical transducer is used, model Sonatest IMG 2550 immersion type with a diameter of 6.35 mm and an ultrasonic wave frequency of 5MHz.

The Un0rick board uses a Field-Programmable Gate Array to manage the data acquisition process and configuration in the form of frequency and Time Gain Compensation (TGC). The configuration used to measure the bone model is with a frequency value of 4MHz and TGC of 400 [9]. The un0rick board requires a 5V (at 350mA-450mA) input voltage provided either via USB or RPI (SPI selection via jumper). The pulser voltage can be selected at 3 levels (24V, 48V and 72V) via a jumper. The FPGA and other logics on the board are operating at 3.3V.

D. *Data Processing*

The signal that is generated by the piezoelectric probe is sampled by an ADC10065 analog digital converter. However, before the electrical signal gets sampled, it first gets amplified by the time gain compensation (TGC) and filtered by an aliasing filter. To control the un0rick board, as well as configure the acquisition settings an official GitHub repository of the un0rick board is required which contains two open-source python libraries for use with a Raspberry Pi or PC, depending on the source.

the pyUn0.py script is the heart of the acquisition software for the Un0rick board, providing all necessary methods for acquiring and processing ultrasound signals. The software entails a class = us_spi which includes a few methods communicating with the FPGA via the SPI. Commands such as write_fpga() and ClearMem()are writing into the FPGA's registers. It also provides methods for setting ultrasound acquisition parameters and Un0rick board testing functions [10].

After data acquisition, Unorick generates output in JSON format. However, this file needs to be converted to CSV format before it can be read. Using a Python algorithm, the JSON file is converted to CSV, and then the average values at each bone model point can be calculated.

IV. Test Result and Discussion

A. Testing Objectives and Steps

The purpose of testing this sub-system is to get the data value in measuring a sample of consistent value. Several stages are carried out to carry out the following tests:

1) Testing is done by marking each coordinate on the bone model to be measured. There are 3 sides taken on each sample, namely: A side, B side, and C side as shown in Figure 3. On the A side, 15 data samples were taken, while on the B and C sides, 5 data samples were taken.

2) Adjust the height of the transducer to the sample point to be measured, apply gel to the transducer and measuring point on the bone model evenly and bring the transducer holder close to the point on the bone model to be measured.

3) Run the program to get RAW data on each sample with the information obtained in the form of RAW signal, envelope, and filter in JSON and png formats.

B. Testing Results

Testing on 4 bone models with different densities (30%, 50%, 70%, and 90%) taken on 3 sides; A side, B side, and C side. The results of the average plot mean values are shown in the following table and figure.

Table 1 Average of Raw Data Value

Table Head	**RAW Data Average Value(V)**
A30	0.429948
A50	0.37474
A70	0.346615
A90	0.538281
B30	1.135156
B50	0.555469
B70	0.345313
B90	0.690625
C30	1.217969
C50	0.841406
C70	0.727344
C90	0.683594

Table 1 shows the average results of raw signal data in testing the density of bone models with handheld bone densitometry.

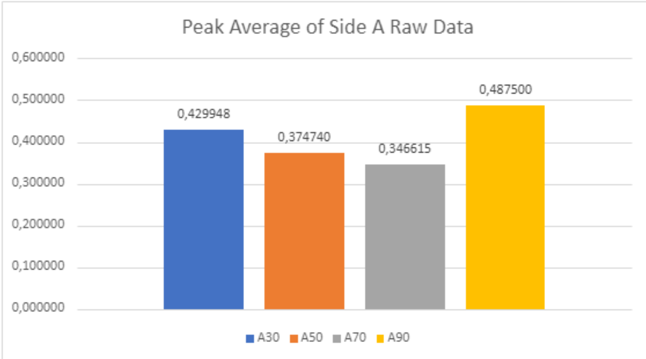


Fig. 7 Average Peak of Raw Side A data

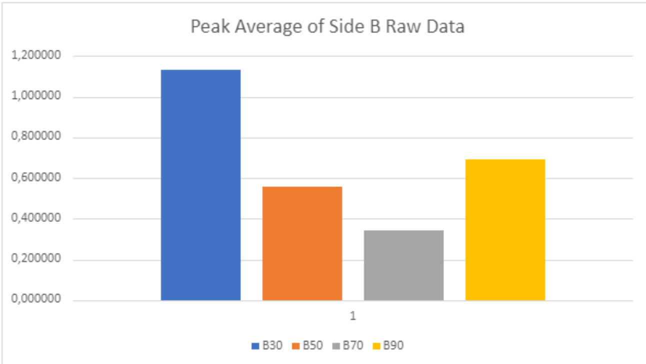


Fig. 8 Average Peak of Side B data

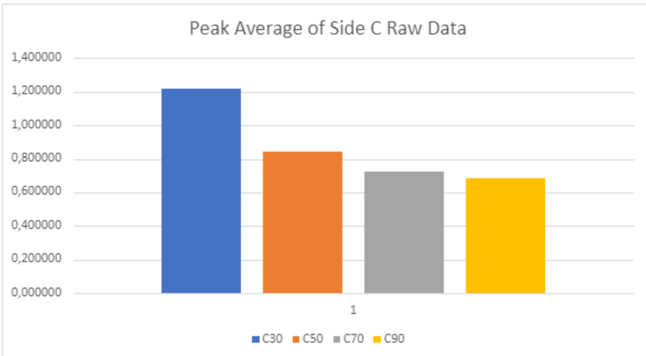


Fig. 9 Average Peak of Side C data

Figures 7, 8, and 9 show plots of the average data on each side of the bone model

C. Analysis

Based on the tests that have been carried out on several samples of the bone model, which are displayed in a plot of the average raw data value on each side, it appears that the data values taken can be seen in plots 7, 8, and 9.

In Figure 7 and 8 there is an anomaly in the 90% density bone model data. That is where the other density values have a downward trend, but the 90% density has a higher value. In Figure 9 the data has a downward trend in the data from the lowest density to the highest.

There is a peculiarity in the difference in results from the 90% model, this can be influenced by the poor position of the sample points, or the different quality of the 3D model material so that there is a very large difference in value with the 30%, 50%, and 70% models.

Good data values should follow a decreasing trend in density from the lowest level to the highest level. Anomalies in the data at 90% density can occur due to various factors. These include inconsistent point coordinates during measurement due to manufacturing defects. When the measurement is taken, the transducer is placed on a non-defective surface. Another factor is air interference; when applying the gel and positioning the transducer on the bone model, there are gaps that allow air to enter, thus interfering with data collection. Finally, insufficient sample data can lead to too much difference in density levels in the bone model.

V. CONCLUSIONS

The configuration of handheld bone densitometry using PLA-based bone models and ultrasonic spectroscopy shows that this is still in the development stage and consistent results cannot yet be produced.

The recommended future work for this study involves further development with an increased amount of testing data. In future research, approaches using machine learning methods to determine the most representative bone density parameters can be explored. This can be achieved by collecting a larger dataset, including data from different types of bone models with varying degrees of density. The data collection process should be performed at the same point repeatedly to ensure the consistency of the measurement results according to the measured density. In addition, it is important to determine the measurement parameters such as frequency, pulse width, and Gain Time Compensation (TGC) settings that are optimal for the object being measured. These parameters should be adjusted to represent various bone density conditions, including normal bone (90%), osteopenia (70%), and osteoporosis (50% and 30%) models. Thus, this research can provide a solid foundation for the development of a more accurate and applicable ultrasonic spectroscopy technology in human bone diagnostics.

VI. REFERENCES

[1] B. Kim, C. J. Y. and W. Lim, "Osteoporosis therapies and their mechanisms of action," *Experimental and Therapeutic Medicine,* vol. 22, p. 1379, 2021.

[2] H. Park, "The impact of osteoporosis on health-related quality of life in elderly women".

[3] steiger, "standarization of measurement for assessing BMD bu DXA," *Classified Tissue International,* vol. 57, p. 469, 1995.

[4] M. A. Laskey and D. Phill, "Dual-Energy X-Ray Absorptiometry and Body Composition," *Nutrition,* vol. 12, p. 1, 1996.

[5] I. Fogelman, Blake and a. G. M., "The clinical role of dual energy X-ray absorptiometry," *European Journal of Radiology,* vol. 71, pp. 406-414, 2009.

[6] A. Gremare, V. Guduric, R. Bareille, v. Heroguez and S. Latour, "Characterization of printed PLA scaffolds for bone tissue engineering," *Journal Biomedical Materials Research A,* vol. 106, p. 4, 2018.

[7] J. Kaufman, G. Luo and a. R. Siffet, "Ultrasound simulation in bone," *IEEE Trans Ultrasound Ferroelectr Freq Control,* vol. 55, p. 6, 2008.

[8] S. H. Jariwala, G. S. Lewis, Z. J. Bushman, Adair and J. H. Donahuue, "3D Printing of Personalized Artificial Bone Scaffolds," *MARRY ANN LIBERT,* vol. 2, p. 2, 2015.

[9] "Open Source Ultrasound," [Online]. Available: Available: www.un0rick.cc.

[10] "Implementing a Low-Cost, Open-Source Raspberry Pi Development Environment With a Single Element Ultrasonic Transducer," *MASTER'S THESIS,* 2019.