DEVELOPMENT OF COMPUTER-BASED ACOUSTIC CHARACTERISATION OF MEDICAL PHANTOM

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ABSTRACT

The aim of this research is to develop a computerised measurement system for acoustic characterisation of medical phantom. The method used is the adaptation of insertion technique and the introduction of the stepped shape design of sample into the system. The developed system consists of an ultrasonic pulser/receiver, two transducers, a digital oscilloscope, a thermometer and a computer. Special computer interfacing is used in the system software development. The resulted software display contains the connection and control panel, the display panel and the calculation panel. The block diagram for software algorithm contains the connection block, the signal acquisition display block, the analysis block and the help block. The performance of the system is tested on agar and poly(methyl methacrylate) (PMMA) samples for different positions from transmitter (0.00 to 90.00 mm), different shape of samples (rectangular and stepped shape of sample), different thicknesses of samples [(2.88 ± 0.06), (3.15 ± 0.08) and (6.03 ± 0.07) mm for PMMA sample and (12.70 ± 0.02), (24.56 ± 0.02) and (30.94 ± 0.02) mm for agar sample], different temperatures of medium (23.0, 24.0 and 25.0 ^{o}C), different frequencies of transducers (2.25, 5 and 10 MHz) and different densities of medium (878, 961 and 1000 kg m^{-3}). The results indicate that the developed system is independent to the position of sample from the transmitter and it can be used to determine the acoustic properties of the medical phantom for different thickness of sample, temperature of medium, frequency of transducers and density of medium. The implication is that the developed system offers user-friendly procedure, yet producing reliable and consistent measurement results, which are comparable to the reference values.

PEMBINAAN SISTEM PENGUKURAN BERKOMPUTER UNTUK PENCIRIAN AKUSTIK BAGI FANTOM PERUBATAN

ABSTRAK

Tujuan kajian ini adalah membina sistem pengukuran berkomputer untuk pencirian akustik bagi fantom perubatan. Kaedah yang digunakan adalah dengan mengadaptasi teknik sisipan dan memperkenalkan sampel berbentuk tetangga dalam sistem tersebut. Sistem yang dibina terdiri daripada pendenyut/penerima, dua transduser ultrasonik, satu osiloskop digital, satu termometer dan satu komputer. Pengantaramukaan komputer khas digunakan dalam pembinaan perisian sistem. Paparan perisian yang terhasil mengandungi panel sambungan dan kawalan, panel paparan dan panel pengiraan. Blok gambar rajah untuk algoritma perisian pula terdiri daripada blok sambungan, blok paparan pengambilalihan isyarat yang dipilih, blok analisis dan blok bantuan. Sistem yang dibina diuji ke atas sampel agar-agar dan poli(metil metakrilat) (PMMA) untuk kedudukan yang berbeza dari penghantar (0.00 hingga 90.00 mm), bentuk sampel yang berbeza (bentuk segi empat tepat dan tetangga), ketebalan sampel yang berbeza [(2.88 ± 0.06), (3.15 ± 0.08) dan (6.03 ± 0.07) mm untuk sampel PMMA dan (12.70 ± 0.02), (24.56 ± 0.02) dan (30.94 ± 0.02) mm untuk sampel agar-agar], suhu medium yang berbeza (23.0, 24.0 dan 25.0 ^{o}C), frekuensi transduser yang berbeza (2.25, 5 dan 10 MHz) dan ketumpatan medium yang berbeza (878, 961 dan 1000 kg m^{-3}). Keputusan menunjukkan bahawa sistem yang dibina tidak bergantung kepada kedudukan sampel dari penghantar dan boleh digunakan untuk menentukan ciri akustik untuk fantom perubatan untuk ketebalan sampel, suhu medium, frekuensi transduser dan ketumpatan medium yang berbeza. Implikasinya, sistem yang dibina menggunakan prosedur yang mesra pengguna, menghasilkan keputusan pengukuran yang mempunyai kebolehpercayaan yang tinggi dan konsisten, setanding dengan nilai rujukan.

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LIST OF ABBREVIATIONS

ABBREVIATIONS	MEANING
GPIB	General Purpose Interface Bus
GS/s	gigasamples per second
IEC	International Electromechanical Commission
INRIM	L'Istituto Nazionale di Ricerca Metrologica
IP	Internet Protocol
Mpts	mega points
OS	Operating System
PAA	polyacrylamide
PC	polycarbonate
PEEK	Polyetheretherketone
PMMA	polymethyl methacrylate
PP	polypropylene
PS	polystyrene
PVA	polyvinyl alcohol
PVC	polyvinyl chloride
SAM	Scanning Acoustic Microscope
SWA	Sonic Waves Analyzer
TCPIP	Transmission Control Protocol/Internet Protocol
TMM	tissue mimicking material
USB	Universal Serial Bus
VI	virtual instrument
VICP	Versatile Instrument Control Protocol

LIST OF SYMBOLS

SYMBOL	MEANING
Z	Acoustic impedance
A	Amplitude
α	Attenuation coefficient
ρ	Density
v	Speed of ultrasound
T	Temperature
d	Thickness of sample
t	Time

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter introduces the study on the development of a computer-based acoustic characterisation of medical phantom. The chapter consists of six parts; background of study, problem statement, research objectives, research questions, significance of the study, scope and limitation of the study and scope of the thesis.

1.2 Background of Study

Ultrasound is a sound wave with higher frequency than the upper limit of human audible range. In practical application, ultrasound is usually used to propagate in a medium and measure the reflection signature or supply focused energy of the targeted material. The production of ultrasound waves has been used in many different fields. The most well-known application of ultrasound is in medical sonography.

The medical sonography refers to the ultrasound-based diagnostic medical imaging technique used to visualise muscles, tendons and many internal organs, to capture their size, structure and any pathological lesions with real time tomographic images. However, the performance testing of an ultrasound system is usually evaluated using the tested material called phantom instead of the real human tissue before they are put into practice. Phantoms are made of materials that mimic acoustic properties of human soft tissue (Zell, Sperl, Vogel, Niessner, & Haisch, 2007; Maggi, Kruger, Pereira, & Monteiro, 2009).

Tissue mimicking phantoms are important tools for performance testing and optimization of medical ultrasound systems and photoacoustic devices as well for medical training purposes (Zell et al., 2007). Photoacoustic imaging is the combination of optical excitation and acoustical detection (Karabutov, Savateeva, Podymova, & Oraevsky, 2000; Niederhauser, Jaeger, Lemor, Weber, & Frenz, 2005; Zell et al., 2007). Hence, an ideal phantom material possesses acoustic and optical properties similar to those human tissues. The ideal phantoms should have ultrasound speed (1435 to 1631 m s^{-1}) and attenuation (0.22 to 1.47 dB $cm^{-1}MHz^{-1}$) (Maggi et al., 2009).

Previous studies have shown that hydrogels can be efficiently used for phantom design (Viator & Prahl, 1999; Spirou et al., 2005; Zell et al., 2007). These gels are hydrophilic, cross-linked polymers which are expanded in water. They also can be shaped into arbitrary solid structure. Furthermore, they have low acoustic attenuation and the acoustic impedance and the speed of ultrasound are similar to tissue because they contain large amount of water (Zell et al., 2007). The most common materials used as phantom are polyvinyl alcohol gel (PVA) (Kharine et al., 2003; Zell et al., 2007), polyacrylamide gel (PAA) (Lafon et al., 2005; Zell et al., 2007), gelatin (Quan, Christison, MacKenzie, & Hodgson, 1993; Zell et al., 2007) and agar (Cubeddu, Pifferi, Taroni, Torricelli, & Valentini, 1997; Zell et al., 2007).

There are two common techniques for determining the acoustic properties of phantom; pulse echo (Carlson, Deventer, Scolan, & Carlander, 2003; Fraser, Poepping, McNeilly, Megson, & Hoskins, 2006; Spirou et al., 2005; Umchid, 2008; Wróbel & Pawlak, 2007) and through transmission technique (Lochab & Singh, 2004; Maggi et al., 2011, 2009; Musacchio, Durando, Bernardi, & Troia, 2011; Othman, Jaafar, Rahman, Othman, & Rozlan, 2011a; Wróbel & Pawlak, 2007; Zell et al., 2007). Both techniques have their own advantages and disadvantages. The pulse echo technique requires well-trained operators only and susceptible to voids (Wróbel & Pawlak, 2007). Meanwhile, the through transmission technique requires the accessibility of two sides of phantom. According to Wróbel and Pawlak (2007), the through transmission technique is faster in determining the time flight of the ultrasound wave compared to the pulse echo technique.

Therefore, a study should be carried out to focus on the measurement method of the acoustic properties of the phantom using the through transmission technique. The acoustic properties are referred to the speed of ultrasound, acoustic impedance and attenuation coefficient. These are determined by transmission measurements of ultrasound waves through phantom under controlled conditions.

1.3 Problem Statement

The insertion technique is adapted from the through transmission technique. It is the most common technique used by previous researchers to measure the acoustic properties of medical phantoms (Maggi et al., 2011, 2009; Musacchio et al., 2011; Othman et al., 2011a; Othman, Jaafar, Rahman, Othman, & Rozlan, 2011b; Zell et al., 2007). This technique is a relative measurement method which uses water as the reference to study the transmission of longitudinal ultrasound waves through solid media embedded in an aqueous environment (Zell et al., 2007). The technique consists of two parts. The first part involves the transmission of ultrasound pulse through the aqueous medium and the second part involves the transmission of the pulse through the phantom in the aqueous medium.

There were three major problems faced by previous researches while measuring the acoustic properties of a medical phantom; (1) transducers was directly contact with the phantom, (2) the calculation of acoustic properties of phantom depends on the physical properties of the medium and (3) the acoustic properties of the phantom was calculated manually by the researchers. The latest study in the measurement of acoustic properties of medical phantoms by using the insertion technique was carried out by Maggi et al. in 2011. Although they developed a program in Labview 8.6 to perform data logging and calculate all the acoustic properties of the phantom, they also faced several problems in the research.

The first problem is the direct contact between transducers and phantom. As the transducers were in direct contact with the phantom, it might change the acoustic path through the phantom because the phantom may be compressed by the transducers. Therefore, it is exposed to measurement errors. The second problem is the calculation procedure of the acoustic properties of the phantom for the research. From the stated equation in the research and other previous researches (Maggi et al., 2009; Musacchio et al., 2011; Zell et al., 2007), the speed of ultrasound in the phantoms depends on the physical properties of the medium. Therefore, the experiment was carried out by using the distilled water as the medium and the speed of ultrasound in the phantom could not be determined if the density of the medium was changed.

Therefore, the previous researches only carried out studies to determine the dependency of acoustic properties of phantom on density of phantom (Kim, Park, Kim, & Ha, 2011; Lochab & Singh, 2004; Treeby, Zhang, Thomas, & Cox, 2011), frequency of transducers (Brewin, Pike, Rowland, & Birch, 2008; Browne, Ramnarine, Watson, & Hoskins, 2003; Carlson et al., 2003; Fraser et al., 2006; Musacchio et al., 2011; Umchid, 2008; Zell et al., 2007) and temperature of medium (Brewin et al., 2008; Browne et al., 2003; Carlson et al., 2003; Fraser et al., 2006). However, there is no previous research carried out studies to determine the dependency of acoustic properties of phantom on the density of medium.

Based on the above points of concern faced by the previous researchers while carrying out their measurement, this study focuses on the development of a computer-based acoustic characterisation of medical phantom to overcome the problems. This study also introduces the stepped shape design of phantom to eliminate the dependency on the use of distilled water as the calibration medium.

1.4 Research Objectives

The objectives of this study are:

1.4.1 to develop an ultrasound integrated computer-based system for acoustic characterisation of medical phantom.

1.4.2 to develop a computer programming to control, process and display the acoustic properties of the tested medical phantom.

1.4.3 to test the performance of the developed acoustic measurement system on medical phantoms.

1.5 Research Questions

The research questions are:

1.5.1 How to develop an ultrasound integrated computer-based system for acoustic characterisation of medical phantom?

1.5.2 How to develop a computer algorithm to control, process and display the acoustic properties of the tested medical phantom?

1.5.3 How does the performance of the developed acoustic measurement system on medical phantoms for thicknesses of samples, temperatures of medium, frequencies of transducers and densities of medium?

1.6 Significance of Study

At the end of the study, a complete user-friendly measurement system is expected. The system is accessible to researchers who are involved in the development of phantoms.

1.7 Scope and Limitation of Study

The main aim of the study is to develop the acoustic characterisation measurement system. The apparatus used in the system are Olympus Panametric NDT model 5072 PR pulser/receiver generator, Olympus Panametrics NDT transducers and LeCroy

Wave Surfer 42 MX-s 400 MHz 5 gigasamples per second (GS/s) digital oscilloscope. As the measurement system adapts insertion technique with the restriction that the transducers used in this study could not be used in the aqueous medium, the system used the non-contact insertion technique.

The measurement system also involves the development of computer-based system to analyse the acoustic signals and determine the acoustic properties of the phantom. Hence, the digital oscilloscope is connected with the personal computer via Transmission Control Protocol/Internet Protocol (Versatile Instrument Control Protocol) or TCPIP (VICP) control. The acoustic properties of phantom involved in this study are speed of ultrasound, acoustic impedance and attenuation coefficient. The other acoustic properties such as absorption coefficient and reflection coefficient are not discussed in this study.

The study is also carried out to test the performance of the system on medical phantoms for four parameters which could affect the acoustic properties measurement; thicknesses of samples, temperatures of medium, frequencies of transducers and densities of medium. Besides, the position of samples from transmitter is also tested to determine the independency of acoustic properties measurement on the position of samples from transmitter since the transducers are indirectly in contact with the sample. Meanwhile, the shapes of samples is also tested to determine the results using the stepped shape of sample are comparable to the rectangular shape of sample since this study introduces the stepped shape of sample to eliminate the dependency on the use of distilled water as the calibration medium.

1.8 Scope of Thesis

This thesis is divided into five chapters. The first chapter, CHAPTER 1 covers the background of study, problem statement, research objectives, research questions, significance of the study and scope and limitation of the study. CHAPTER 2 describes about the theory of the ultrasound and the previous studies of measurement system for acoustic characterisation of medical phantom.

CHAPTER 3 describes about the development of acoustic characterisation system, the development of computer-based acoustic characterisation system, the preparation of samples, the physical properties measurement of samples and the acoustic properties measurement of sample. CHAPTER 4 describes about the performance testing and validation of the computer-based acoustic characterisation system on the medical phantoms. Finally, CHAPTER 5 covers the conclusion and recommendation for further study.