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Ultrasonic Therapy Device Using Fuzzy-Logic for Clinical Use

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Abstract

In this paper, an ultrasonic therapy device using fuzzy logic (UTD-FL) has been designed, constructed, and tested with phantom materials. Fuzzy logic rules have been determined using four parameters. In clinical practice, ultrasonic therapy is conducted solely based on the subjective evaluation of medical experts, but in UTD-FL, fuzzy-logic rules automatically decide the three critically important characteristic parameters of applicable output power to the patient, namely the power of the signal, the percent of the duty-cycle and the signal frequency. The signal frequency and specifically its amplitude have a critical effect on the temperature rise of the tissue test point or surface. Therefore, the intensity of the ultrasonic frequency and the duration of treatment time are absolutely vital, that is why this instrument has been developed. This instrument is expected to prevent possible side effects, injuries, and potential damages to real tissues due to experts' uneasiness. The test results of this newly developed medical device have been compared with the available clinical instruments' results in clinical practice. The instrument produces optimum output power due to its fuzzy logic rules-based mode design and IR-temperature sensor-based feedback effect, whereas the clinical mode inputs only clinical experience base gained medical data.

Key Words

"Ultrasonic Therapy Device, Fuzzy Logic, Clinical Mode, Fuzzy Mode, IR Temperature Sensor, Phantom Materials"

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1. Introduction

In medical practice, ultrasound has two broad application types, its diagnostic effect, and its treatment capacity. In its diagnostic effect, a low signal level is preferred so as not to cause any damage due to its propagation in human tissue. Human tissue is exposed to ultrasound accordingly and interactions occur, and hence diagnostic ultrasound distinguishes between various acoustic properties of human tissues. In case of ultrasonic treatment, the signal level is kept high based on the treatment targeted. For physical therapy applications, the preferred intensity level is about 2-10 W/cm^2, whereas, for ultrasound-based surgery, the intensity may be as high as 104 W/cm^2 (Yardimci and Celik 2005; Yasuil et al., 2005). Compared to the ultrasound diagnosis, therapeutic ultrasound is usually used at lower frequencies as it has low attenuation, and therefore, can penetrate into deep areas of human tissue.

Location is crucially important for the ultrasonic treatment of deep diseased tissues in vivo; therefore, focused ultrasound is needed for some types of tissues. The surrounding tissue must preferably not be affected at all, but the targeted tissue is deliberately exposed to highly intensified ultrasound leading to 70 °C (Yasuil et al., 2005).

The parameters of reversible and irreversible biological effects of ultrasound are mainly three; the signal intensity, its frequency and the biological tissue itself. Low-level acoustic intensity leads to a reversible effect but acoustic level exceeding the threshold limits causes irreversible effects. Important biological effects of ultrasounds are five based on tissue and applications, namely: Thermal, mechanical, acoustic streaming, cavitation, and thixotropic effects.

1.1 Thermal effect

Biological tissues absorb sound and hence ultrasonic energy creates a temperature increase in tissues. The rise of temperature of the tissue depends on three main parameters: the acoustic intensity, its frequency, and its duration. In case of constant sound intensity, the temperature rise is proportional to the acoustic wave irradiation time. Initially, time and temperature increase are proportional, but when the temperature increases to a pre-set or threshold value, then its rate of rise needs to be reduced to some extent until the thermal balance had achieved.

1.2 Bioheat Transfer

Heat transfer in living tissue occurs in two different ways, partly by perfusion (due to blood flow) and partly by conduction (due to diffusion). Pennes formulated the well-known bioheat transfer equation (Pennes, 1948), which has a source and a sink term leading to a draft explanation of heat transfer from blood perfusion with the parameters given in Equation 1.

$$dT/_{dt} = k\nabla^2 T - {}^{\Delta T}/_{\tau} + {}^{\dot{Q}}/_{C_b} \tag{1}$$

The parameters of the Pennes equation are defined as follows:

$dT/_{dt}$	:	Rate of change of temperature increase at a point
k	:	Thermal diffusivity
T	:	Temperature
ΔT	:	Temperature increases above ambient
τ	:	Perfusion time constant
$\dot{Q}$	:	Metabolic heat production
C_b	:	Specific heat of blood

Although the Pennes equation is not perfect (Weinbaum *et al.*, 1984), due to its compatibility with analytical implementation, it is widely preferred and used for thermal model of living tissue. Due to the imperfect Pennes equation, new methods of tissue characterization have been investigated (Gambin *et al.*, 2016), one of which is based on backscattered echoes of heated breast and integrated with statistical analysis techniques. It has been demonstrated that an increase in breast temperature modifies three parameters of the samples: "the intensity, the spectrum of echo signals and the probability density functions" (Gambin *et al.,* 2016).

1.3 Tissue thermal conductivity

The main goal of therapeutic applications of ultrasound is proper and sufficient heating of targeted organs, tissues, or tumors, respectively. Two key factors must be considered in order to successfully produce the necessary temperature rise: the tissue's thermal properties and the beam's acoustic properties. The test medium thermal properties for therapeutic practice, for local tissue heating, are mainly thermal conductivity dependent. A local temperature rise above physiological limits damages the cell protein structure. Very rapid (less than 3 seconds) and high (above 56 °C) local heating of tissues instantaneously kills the cells (Kujawska *et al.* 2014). Four key testing parameters, namely "the frequency, intensity, pulse duration, duty-cycle, and exposure time of generated tone bursts," must be regulated in order to observe the applications' limits. For hyperthermia applications, a typical ultrasonic beam has been used with the limits: "the intensity (low-0.12 W/cm^2), the duty-factor (average-about 0.2%), exposure time (long-up to an hour) and a beam width (between 10% and 20% of the transducer diameter)".

1.4 Mechanical effect

Ultrasound obeys to the propagation principles of elastic waves. It can be defined via mechanical parameters such as sound pressure, particle displacement, velocity and/or acceleration. In case of low sound intensity, the sound intensity is proportional to the amplitude of displacement by the square root law. If it is high enough, the mechanical vibration might become beyond the controllable limit for such a medium, leading to a damaged, fractured or crushed tissue. This effect is special and named as the mechanical effect of ultrasound with brilliant products such as ultrasonic operation knife and ultrasonic lithotripsy. Ultrasound has a variety of different uses as well, such as nerve healing, healing of muscle injuries, micro-massaging for getting an increase in localized blood circulation, and brain therapy. Having deep penetration ability into tissues and delivering energy to the parts under therapy is another superiority of ultrasounds for medical practice (1 MHz). It decreases the healing time and strengthens the bruised, fractured, and/or damaged parts after injury. If low frequencies are used, then less thermal energy is obtained in the tissues, especially around the bones. Therefore, the power of the ultrasound signal is important in therapy practice and its effect depends on the type of injuries. Then, ultrasonic therapies need a healthcare specialist to decide the power requirements (Mohammed et al., 2010). As a result, the healthcare specialist's decision depends on personal experience and it is subjective; that requirement leads to automated decision-making systems, such as the device developed: Fuzzy-logic based ultrasonic therapy device (FL-UTD).

1.5 Different applications of ultrasounds: Thermal Effect, bioheat transfer, tissue thermal conductivity and mechanical effect

Using ultrasound as a therapeutic tool, especially in physiotherapy and rehabilitation, is a rising field worldwide. The wider ultrasonic range usable for medical therapy is from 1 MHz up to 1000 MHz. However, 1 MHz and 3 MHz frequencies are preferably used in ultrasound-based medical instruments. But the frequency range preferred for rehabilitation is a bit narrow band, from 0.8 MHz to 3 MHz. Because the increase in tissue temperature has a direct effect on the human body's metabolic rate, 1 ºC increase changes the metabolic rate by 13%. A moderate heating range of 2-3 ºC has been recommended (Yardimci and Celik, 2005). A 200-microseconds burst of 1.5 MHz sine wave repeating at 1.0 kHz has been applied to the treated limb. The incident intensity has approximately been recorded as 30 mW per cm^2. Experimental findings clearly show that "biomechanical healing" is accelerated using ultrasound by a factor of nearly 1.7 (Pilla *et al.* 1990). It has mainly been accepted that ultrasonic treatment time must depend on the size of the tissue. Lehmann suggests that the maximum treatment time must be restricted to 15 minutes for a treated maximum area between [75 - 100] square centimeters (Yardimci and Celik, 2005). A fuzzy logic-based control system has been developed in order to obtain the optimum treatment time during ultrasound therapy applications (UT) (Yardimci and Celik, 2005).

As a biophysical safe energy form used in the treatment of fracture-repair processes, low-intensity ultrasound (LIUS) accelerates and enhances not only the healing of fresh fractures but also callus formation in delayed unions and non-unions (Yasuil *et al.* 2005).

An embedded system using ultrasound has been designed and realized for achieving the most suitable treatment conditions for physiotherapy patients based on the five parameters (Isik and Arslan 2011): Age of the patient, the coordinates of the tissue, the thickness of the tissue, the surface area of the treated region and the fat rate in the tissue (Isik and Arslan, 2011).

The quantitative effect of therapeutic ultrasound has also been studied, as it contributes to the formation of new blood vessels of adult rats. The frequency used is either 0.75 MHz or 3 MHz, the exposure time to ultrasound is 5 minutes on a daily basis, and its intensity is 0.1 W per cm^2. It had been demonstrated that the repair process is considerably high in ultrasound-treated wounds; the blood vessels have been returned to normal conditions due to the ultrasonic treatment applied (Young and Dyson, 1990).

The stimulation of bone repair, and fibular fractures by using ultrasound had been reported using rats groups. The delivered ultrasound has an intensity of 0.5 W per square centimeter. The pulse duration applied is 2 ms ON and 8 ms OFF for 5 minutes time for 4 consecutive days. The frequency range applicable is 1.5 MHz and 3.0 MHz. The effectivity of treatment with ultrasound has been compared with micro-radio-graphical and histological methods (Dyson and Brookes, 1983).

Three groups of rats were used in experimental testing to determine the optimum dose; however, it was found that the right dose varies on a variety of factors, making it difficult and unnecessary to recommend a single dose that is successful in all types of applications. As each application has its own characteristics and application procedures (Emsen, 2007)

A major use of the low megahertz ultrasound frequency range is its treatment capability to treat tumors. The tumors must be heated to temperatures between 42 and 45 degrees Celsius in order to cause cellular damage (Quan et al., 1989).

An ultrasound-based thermal conductivity measurement of tissues ex vivo has been experimentally carried out on a phantom material in vitro to determine and measure the time dependency of temperature-rise, T(t), in the phantom material. After the application of 1 MHz ultrasonic pulse inside the phantom material, its temperature-rise has been recorded from thermocouples readings. For comparison of the temperature readings, Pennes bio-heat transfer equation has been used and solved via finite element methods. In vitro, temperature rise of the phantom material has been verified by the correlation of the experimental results with the numerical simulation results (Erbas, 2012; Kujawska *et al.,* 2014)

Ultrasound is a method that can be used as a heat-promoting thermal source. But the skinfold thickness effect and skin temperature upon ultrasound heating have not yet been investigated extensively. To measure the change in skin temperature upon ultrasound heating remains to be investigated and measured. This was achieved by doing an ultrasonic treatment test at 1.0 W/cm2 and 3 MHz frequency up until the absolute temperature reached 3° above the baseline-reference temperature. Then the recorded data were analyzed with two methods: ordinary least squares regression-hierarchical linear modeling (HLM) and mixed methods repeated measures (MMRM) techniques. Based on the proper data analysis, the HLM method was concluded to be a better fit for the analysis (Miller, 2011).

2. Methods

2.1 Full block diagram of the fuzzy logic-based ultrasonic therapy device

The fuzzy logic algorithm works on IPC. IPC is a PC made of high-tech components and designed for industrial applications. The touch panel is a high-tech LCD monitor commonly used as an input-output interface unit in industrial applications. The Microcontroller board controls the signal board and communicates with IPC. IR temperature sensor module reads surface temperature and in case of temperature overflow higher than 2 ºC, it cuts the power connection of the therapy device completely. A full overall block diagram of the fuzzy logic-based ultrasonic therapy device H/W is given in Figure 1.

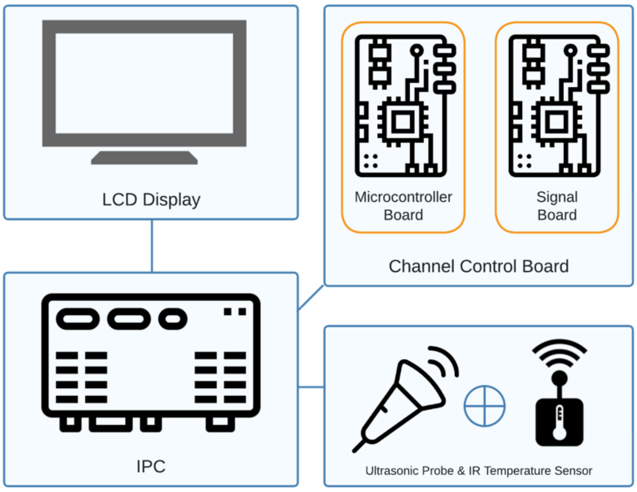

Figure 1. A Complete block diagram of the fuzzy logic based ultrasonic therapy device H/W

2.2 Component based hardware design of the fuzzy logic ultrasonic therapy device

The designed ultrasonic therapy device is made of two modules: An industrial PC (IPC) based main control module, which uses Windows XP as an embedded operating system and a channel control board. The channel control board has three sub-modules: a microcontroller-based control board, a duty module consisting of oscillators and logic gates to produce ultrasonic signals, and an IR temperature sensor board. The detailed hardware of FL-UTD is given in Figure 2 below.

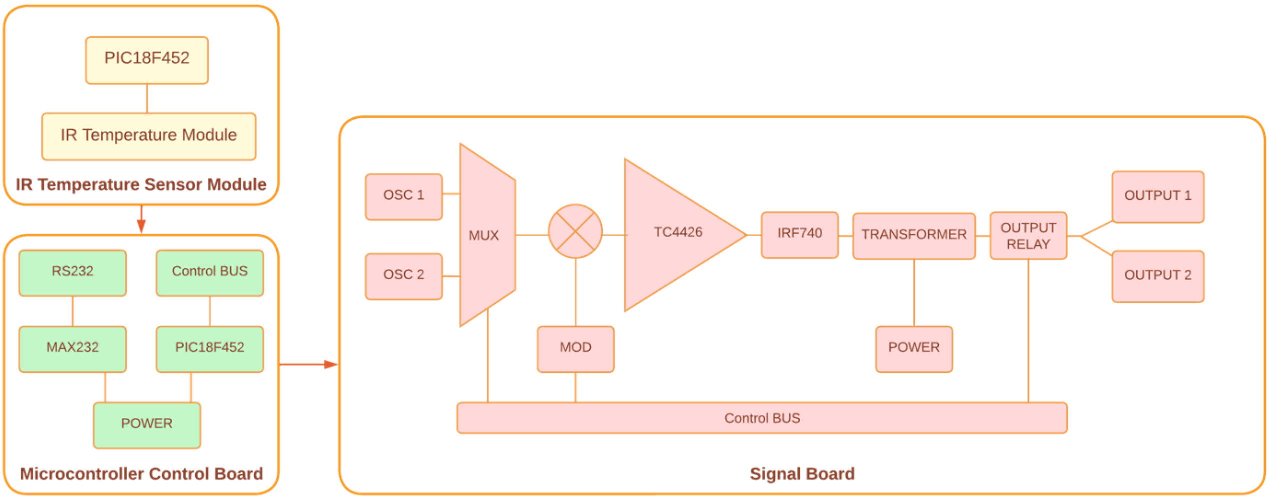

Figure 2. The Detailed Block Diagram of H/W Structure of the Ultrasonic Therapy Device

Microcontroller board communicates with IPC withRS232 interface. It also controls the multiplexer circuit, modulator circuit and output relay on the signal board. MAX232 IC is an RS232 to TTL signal converter. And it has its own power circuit with LM7805 linear regulator to supply regulated 5V DC.

The signal board has two different frequency NAND Gate-based oscillators producing/outputting frequencies of 1MHz and 3MHz, respectively. PIC microcontroller in the microcontroller control board connects oscillators output to carrier signal line with multiplexer circuit and modulates a carrier signal with duty-cycle signal on modulator circuit. TC4426 is a MOSFET driver. It accepts modulated signals and controls IRF740 power MOSFET. A sequence of modulated square waves is given as input to IRF740 MOSFET, which switches 30 V DC source of the coupling power transformer to the ground. The output of the transformer is connected to output terminals with the output relay.

IR temperature sensor module has its own PIC18F452 microcontroller. Microcontroller reads surface temperature with an IR temperature sensor and calculates deep tissue temperature. If the temperature change is larger than 2 °C, the system automatically stops by the software program developed.

2.3 The contactless sensing mechanism for ultrasonic absorbed energy on tissue with IR temperature sensor

Precise measurement of temperature rise induced in tissues due to the ultrasound effect is very important for the treatment underway. The rise of the temperature depends on some crucial parameters of the test medium and measuring system togetherness and compatibility. The determining parameters are the acoustic properties of the beam used and the acoustic and thermal properties of tissues intended for heating. An instrument or system measuring local tissue heating level is highly appreciated as it saves life and integrity of the human body (Kujawska *et al.* 2014)

This paper contributes to the development of a novel system for UTDs by using a feedback control mechanism. The conventional UTDs do not have a feedback control method. Medical experts cannot see accepted ultrasonic waves in deep tissues. This may cause various damages with different degrees in the tissue. This paper provides a solution protecting the tissue from overheating due to US wave exposure. An IR temperature sensor can detect that by, for instance, reading skin temperature. The temperature of tissues targeted by US waves has been calculated by expert system. If the temperature change is less than 1 °C, the therapy will continue. If the temperature change is larger than 2 °C, the system automatically stops by the software program developed. The contactless sensing mechanism for ultrasonic absorbed energy on tissue with an IR temperature sensor is given in Figure 3.

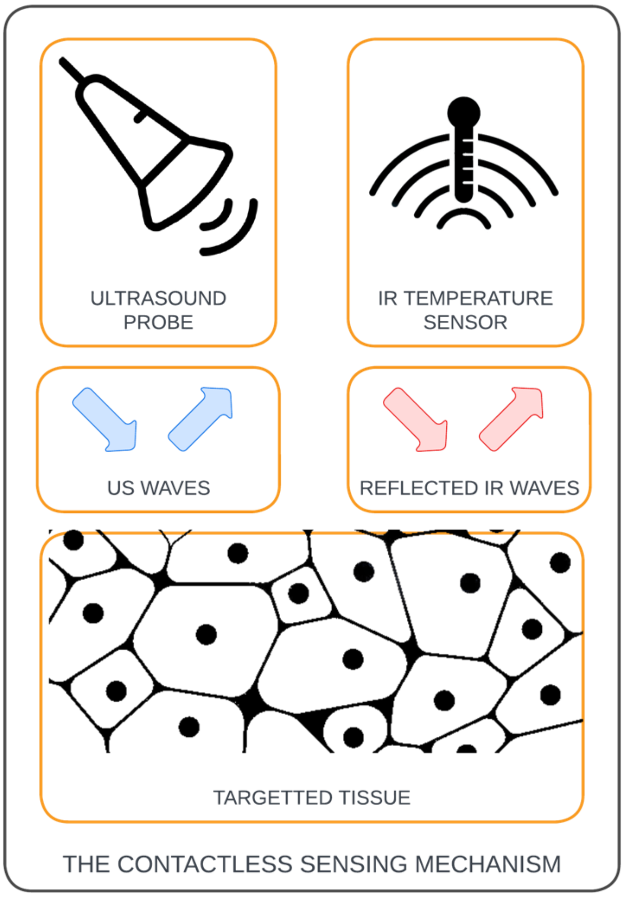

Figure 3. The contactless sensing for ultrasonic energy absorbed on tissue with IR temperature sensor.

2.4 Thermocouple temperature sensor shield design for phantom material test

Placing the temperature sensors in test mediums properly and correctly is crucial, and it is one of the main problems encountered in such applications. Thermocouple-based temperature sensors are widely used. However, conventional temperature sensors are flexible and defenseless to physical impacts and bending. This research produced a rigid and robust hybrid case for thermocouple temperature sensors. The developed sensor shield has a sharp ending for easy substitution in test mediums. Engrave a brass pipe with a 5.22 mm diameter to 60^o abrupt ending and platted with chrome. Then K-type thermocouple has been installed in this pipe. The epoxy resin had been used to fill the gaps between thermocouple joints and pipes.

2.5 Fuzzy logic-based ultrasonic therapy device (FL-UTD) software design

Advanced membership functions and the FL-UTD screen are given in Figure 4 and Figure 5, respectively. Parameters used in ultrasonic therapy devices, such as power, frequency, and duty cycle, must be changeable based on the therapy type and the patient's requirements. This feature of interchangeability increases the efficiency of therapy. FL-UTD uses patient-specific treatment parameters based on discussions with expert physiotherapist and available literature survey. Therapy parameters decided are the patient's age, the number of therapy sessions, the tissue thickness of the patient, patient's weight, and height. The developed program use fuzzy logic rules to calculate the optimal range of therapy parameters for each patient individually by using defined input parameters.

Ultrasonic therapy device output frequency can be defined as 3 MHz for 0≤Tissue-Thickness<2 cm, and 1 MHz for 2 cm ≤ Tissue-thickness≤ 8 cm. Inputs and outputs-based membership functions are given in Table 1 below.

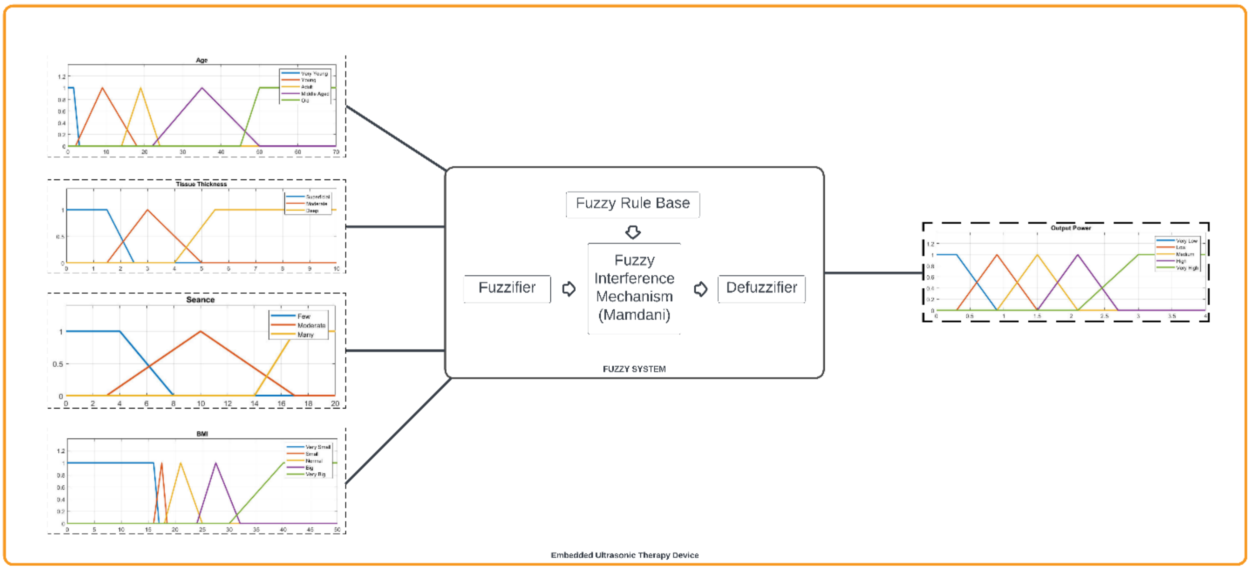

Figure 4. The Block Diagram of the Embedded Fuzzy Logic-Based Ultrasonic Therapy Device

Figure 5. The Fuzzy and Clinical mode display of fuzzy logic-based ultrasonic therapy device

Membership functions of the fuzzy logic system have been generated. Obtained data shows that the power density of the generated ultrasonic waves must be in the range of [0-3] W per square centimeter. The output power of the ultrasonic waves has been calculated with these membership functions. Four input membership functions and one output membership function have been defined only; all input membership functions are given in Table 1(Erbas, 2012). Classifications between body mass index (BMI) and individual weight on adults' age have been used to develop and improve the patient's age group membership functions (Emsen, 2007). Age groups are defined as follows: 0-4 baby, 5-14 child, 15-29 young, 30-49 adult, 50-55 middle-aged, 55-65 pre-old, 65-85 old, and finally 85 and over is very old.

Table 1. Functions, variables, and boundaries of Fuzzy logic membership

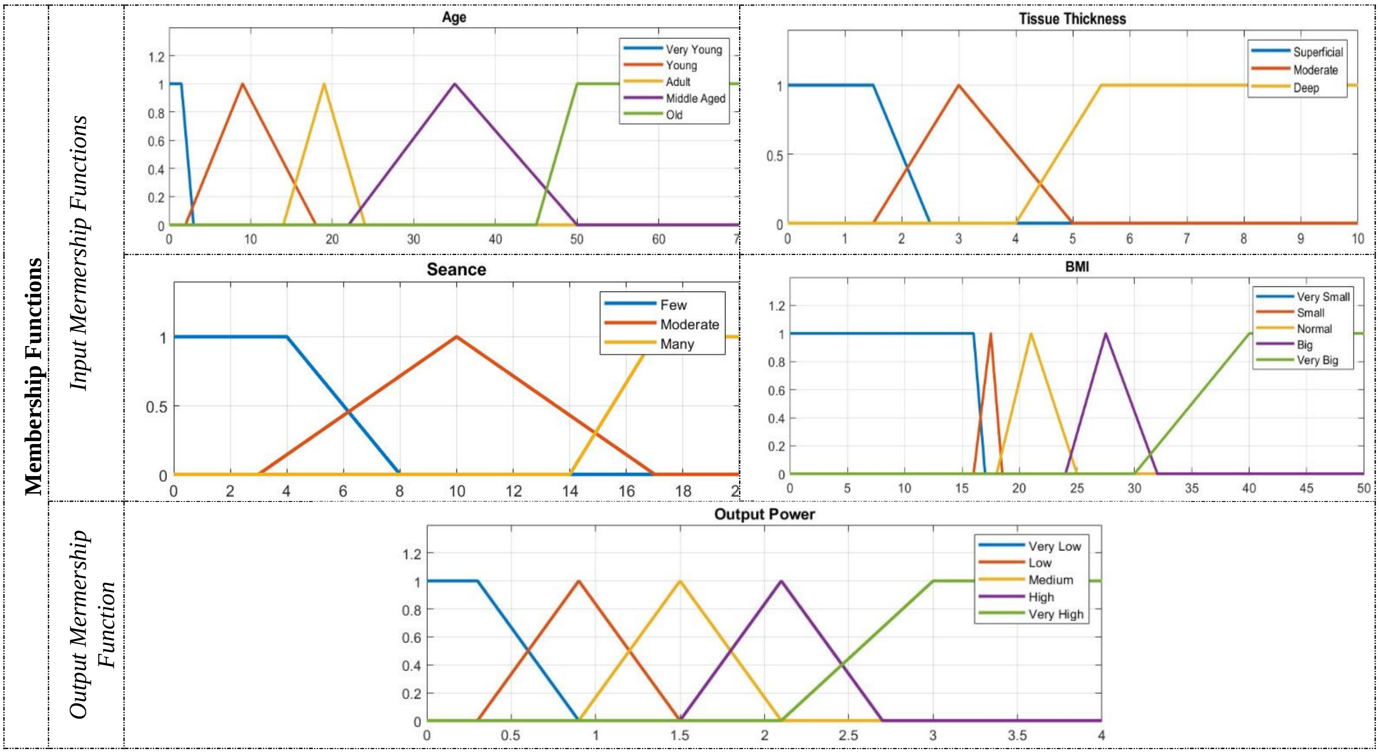

Table 2. The Clinical Mode test data of FL-UTD, temperature sensor and ACC of phantom materials

Patients' Parameters - Four Fuzzy Logic Inputs				BMI						Time (minutes)						
Subject	**Patient's age**	**Séance**	**Tissue thickness (cm)**	**W (Kg)**	**H (m)**	**% Error**	**Physiotherapist Personal Suggestion-Clinical Practice (W/cm2)**	**P_{out}(W/cm^2)**	Medium density	**1st**	**2nd**	**3rd**	**4th**	**5th**	ACC in 1st minute= [LD temp reading/ HD temp reading]	The Readings of Therapy Device' Output power on phantom mediums temperature changes (°C)
1	24	First	2.5	95	1.75	7.4	2.5	2.7	LD	0.5	1.0	1.6	2.4	3.2	0.83	
									HD	0.6	1.3	1.9	2.6	3.4		
2	28	First	2.5	56	1.68	0	2.1	2.1	LD	0.3	0.5	0.9	1.6	2.0	0.75	
									HD	0.4	0.7	1.3	2.2	2.8		
3	53	First	2.5	85	1.72	-4	2.6	2.5	LD	0.4	0.7	1.4	1.7	2.2	0.66	
									HD	0.6	1.0	1.5	2.1	3.0		
4	34	First	2.5	63	1.74	0	2.0	2.0	LD	0.4	0.6	1.2	1.5	2.1	0.80	
									HD	0.5	0.9	1.5	1.9	2.8		
5	29	First	2.5	88	1.74	3.7	2.6	2.7	LD	0.4	1.0	1.6	2.4	3.2	0.66	
									HD	0.6	1.3	1.9	2.5	3.4		

The mostly used fuzzy interference methods are Mamdani and Tagaki-Sugeno-Kang methods. This paper preferred to use Mamdani fuzzy interference method. The main disadvantage of Tagaki-Sugeno-Kang fuzzy method is built on fuzzy rules. Thus,-adapting this method and adjusting of parameters on accurate words is very complex. In contrast, Mamdani's fuzzy interference method rules are linguistic and easy.

Mamdani model has been used for calculating output power with an applicable fuzzy logic system. Mamdani's model is applicable in four steps. These steps define rule base, fuzzification, rule evaluation, the intersection of fuzzy membership crippled functions, and de-fuzzification. Developed membership functions, their variables and boundaries, and membership functions' graphics are given in Table 1.

2.6 Therapy Probe with IR Temperature Sensor Board Design

Conventional therapy device probe design is simple in therapy equipment. The probe has a single lead zirconate titanate ceramic transducer or multi-transducer array. The transducer element accepts electrical signals and produces US waves. The novel idea in this paper is a security mechanism for US therapy overheating effects. In this paper, we developed a protection method for overheating effects of US therapy. The sensing mechanism is based on an IR temperature sensor and microcontroller-based board. An IR temperature sensor reads surface temperature and calculates targeted tissue temperature. If the temperature change exceeds 2 °C, the IR temperature sensor board cuts off US waves to protect tissues. The developed probe transmits US waves and receives IR signals to calculate the temperature. The sensors' output data was calculated in the PIC18F452 microcontroller. The developed system has an integration capability of ordinary/conventional therapy device. The developed probe has a sensor holder, which is reshapeable for every US therapy probe. The control mechanism builds as an external device and is adopted in every US device. The control device switches and transmits the power on its power plug, and it cuts off the power in emergencies.

Figure 5. General View of Fuzzy Logic-Based Ultrasonic Therapy Device

2.7 Phantom material tests

Testing the ultrasonic device developed directly on tissues is safe by adequately investigating the probable side effects. Therefore, the instrument has been tested with phantom materials. Phantom mediums are developed at home for the sole purpose of experimental work used during the research of this paper (Erbas, 2012). Phantom materials are broadly two types: low-density (LD) and high-density (HD) phantom mediums. All tests have successfully been done; the data obtained from experimental tests are given on Table 2.

The carried-out tests have proved that the tested medium's density is affecting the ultrasonic waves' absorption ability. The absorption coefficient correlation (ACC) between the low-density medium and high-density medium of phantom materials developed is given in Table 2.

A thermocouple-based temperature sensor was inserted accordingly in the phantom medium about 2.5 cm deep, and an ultrasonic was gel added to the ultrasonic probe. Then the ultrasonic waves were applied to phantom materials (special medium), and the temperature changes were recorded.
It is experimentally observed that the temperature rise in a high-density medium is higher than in a low-density medium. Test data obtained with five subjects are given in Table 2 below. Patient-specific parameters have correctly been inputted into the therapy device as fuzzy rules suggested. As a result, the required power of the ultrasonic wave has been calculated by FL-UTD using the

fuzzy logic-based program developed. The output data from the fuzzy logic-based program was given in Table 2. In addition, patients' parameters from different age groups, the correlation between output power and physiotherapist' suggestion (Clinical Practice), and the percent error were given in Table 2.

3. Conclusions

In this paper, an embedded ultrasonic therapy device using fuzzy-logic rules has been designed and constructed by integrating an industrial PC (IPC) with a PIC18F452 microcontroller. The device has two main modules, a control module and a microcontroller-based duty module that can produce ultrasonic signals.

Defining correct physiotherapy parameters need experienced physiotherapists. In clinical practice, physiotherapists widely use medical therapy systems working mainly in binary logic (1 or 0), especially in developing and underdeveloped countries. Nevertheless, patients require optimum and correct parameters for treatment; therefore, fuzzy logic rules-based decision-making systems need to be used in medical instrumentation, as diseases cannot be diagnosed and treated using only binary logic-based instrumentation. Due to that reason, different levels of therapy parameters (such as output power) for various patients and conditions could be suggested by fuzzy logic algorithms developed. For example, in ultrasonic therapy, the parameters affecting the output power are many and as follows: age, number of treatments, tissue thickness, patient's weight and height, blood group, nutritional habit, geographic region, and patient's sex. This paper has only used four of the main parameters. The four variables are evaluated on fuzzy logic rules developed; the computerized system uses them based on the software developed. The medical instrument developed for this paper uses fuzzy-logic rules to decide the three primary parameters of the output signal (the power of signal, percent of duty-cycle, and the signal frequency). The software is written in C# programming language. The software enables inputting and saving therapy parameters, communicating with peripherals devices, and calculating therapy parameters with fuzzy logic. The comparison between the designed fuzzy logic-based ultrasonic therapy device and other therapy devices published in the literature is shown in Table 3.

The design and construction of a medical instrument using a feedback mechanism and a sensor, in this case, an IR temperature sensor-based feedback, was/is a must for medical instrumentation, as in clinical medical applications, there is no method of measurement of the temperature rise in the tissue when treatment is applied/conducted. That may lead to many injuries undetected and untold. For example, the ultrasonic intensity used for traditional ultrasonic physical therapy is about 2-10 W/cm^2. In contrast, for ultrasonic surgery, such as high-intensity focused ultrasound (HIFU), the ultrasonic intensity may reach as high as 104 W/cm^2. This requires accurate and sensitive control of the temperature rise in the tissue.

The medical instrument developed in the content of this paper has the following characteristics, as shown in Table 4 above. Those features are: The use of two frequencies (1 MHz and 3 MHz, preferably 1 MHz), two modes of operation (clinical mode-already available in clinics and fuzzy mode developed by this research for clinical use), the use of fuzzy logic rules based on four parameters (the age of patient, séance undertaken, tissue thickness, and body mass index), and most importantly IR temperature sensor based feedback mechanism, which helps safe treatment and no injuries due to over-dose conditions.

Developed instrument targets ultrasonic therapies as they usually require low frequency because low frequency has low attenuation in the medium and, therefore can penetrate the deeper area and cure diseases more underneath.

Table 3. The comparison of various generations available and FL-UTD developed

	1st Generation (Isik and Arslan 2011)	**2nd Generation (**Akdag *et al.* 2008)	**Commercial Product**	**3rd Generation (FL-UTD)**
Frequency Range	0.880 MHz	Not clearly given	1MHz & 3MHz	1 MHz & 3MHz
Expert Systems Developed	Clinical Mode	Fuzzy Logic Mode	Clinical Mode	Fuzzy Logic and Clinical Mode
Therapy Parameters/ Fuzzy Logic Inputs	-Invidual Decision	-Patient's age -Séance -Tissue thickness	-Invidual Decision	-Patient's age -Séance -Tissue thickness -Body mass index
Safety Consideration	-N/A	-N/A	-N/A	IR temperature sensor-feedback effect

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