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Development of an embedded system to characterization of cortical bone phantom using a simple peak-detection algorithm

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Background, Motivation and Objective. The characterization of cortical bone by ultrasound, based on parameters such as attenuation and longitudinal propagation velocity, is useful to reflect its structure and elastic properties. Bone phantoms are largely used to mimic real bone properties in estimating its acoustic parameters. This work intends to deploy an embedded system able to measure the acoustic properties of a cortical bone phantom automatically. In addition, it is presented a simplified peak-detection signal processing procedure to estimate the thickness as well as the ultrasonic velocity of cortical bone phantoms.

Methods. The system under development can be split up in two fundamental parts: hardware and firmware designs. The hardware will be able to generating and receiving ultrasound pulses through a piezoelectric transducer. It consists of a pulse generator unit, 12-bit/20 Msps A/D converter unit and a 32-bit microcontroller unit (Figure 1a). The measurement results can be observed on the system's display and storage into a micro SD card to posterior assessing. The firmware consists of the configuration settings in accordance to the hardware designed, as well as the peak-detection algorithm. The microcontroller receives the 12-bit signal from the A/D converter then executes the algorithm, which locates the position in time where the peaks occurred. Besides, the longitudinal propagation velocity and thickness of the cortical bone phantom can be estimate according to the method presented in [1]. Hence, the peak-detection algorithm is composed by the following sequence: filtering, noise-gate threshold, differentiation and zero-crossing detection. The filter section was deployed to obtain the envelope signal. After that, a noise-gate was implemented towards to eliminate small noises. The differentiation produces zeros where the envelope signal has the maximum values. Therefore, at these points, the zero-crossing procedure detects the echoes' location on time.

Results. A hardware dedicated to ultrasound signal receiving and digitizing was deployed (Figure 1b), which is composed by: a pre-amplifier section; 12 bit A/D Converter, working on a sampling frequency of 20 Msps; and a FIFO data buffer. In addition, using the microcontroller, the proposed peak-detection algorithm based on zero-cross point detection using differentiation was implemented. It was conducted a preliminary experiment to measure acoustic characteristics of a cortical bone phantom using the system developed in addition to a 5 MHz piezoelectric transducer using the pulse-echo technique. In Figure 2, it can be seen three stages of the signal processing: received signal, envelope and peak detection signal. Furthermore, it can be observed the large dynamic range between echo 1 ($22.0\ \mu s$) and echo 2 ($28.9\ \mu s$) approximately 26 dB. Despite of that, the system could detect both echoes since the noise-gate threshold is set adequately.

Discussion and Conclusions. The hardware developed worked well at the task of receiving and digitizing a 5 MHz pulsed signal. Moreover, the peak-detection algorithm shows a simple implementation using a C# compiler for microcontrollers of the PIC32 family. The simplicity in the implementation is important when programming a microcontroller, due to limitations of memory and on using more complex mathematical tools like FFT and complex numbers manipulations.

However, the difference zero-cross technique detects all peaks whether stronger or not, generating false-positives. The way used to minimize it is to set the noise-gate threshold in the adequate value [2]. Herein, the proposed approach shows a feasible solution for the peak-detection issue when measuring signals in the ultrasonic frequency range presenting a dynamic range around of 26 dB.

Figure 1 – (a) Block diagram for the hardware conceived (b) Hardware PCB.

(a) (b)

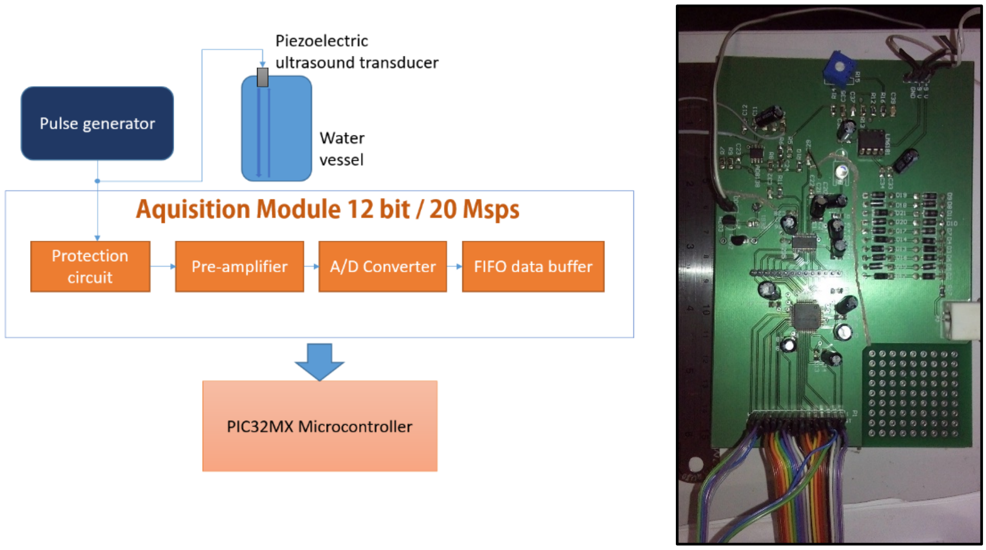
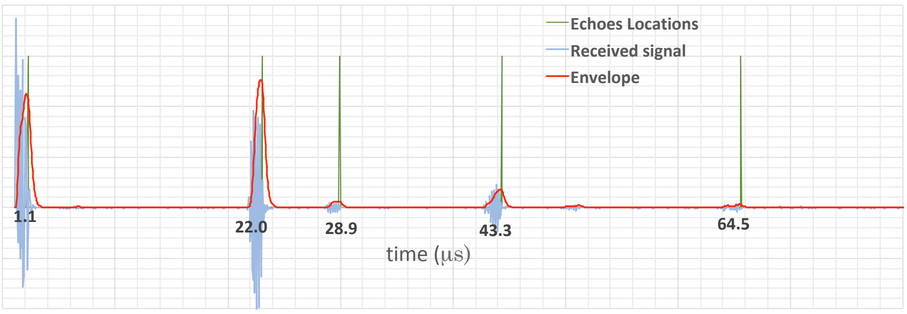


Figure 2 – Signal received from the cortical bone measurement experiment.



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Keywords. Bone phantom; ultrasound; peak-detection algorithm; embedded system; signal processing.

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