On the Construction of an Electronic Stethoscope with Real-Time Heart Sound De-Noising Feature

Chun-Tang Chao, Nopadon Maneetien, and Chi-Jo Wang

***Abstract*—In this paper, we investigate the aspects of constructing an electronic stethoscope with the capability to filter out heart sound from the lung sound pickups in real time. Such a capability is most useful for the clinical diagnosis of pulmonary diseases. The proposed filter design is based on the adaptive line enhancer (ALE) filter structure to be implemented in an FPGA based platform. The DE2-70 development board and Audio CODEC are used in the design. Experiments on a preliminary setup of the proposed design demonstrate its efficacy.**

***Keywords*—Adaptive Filter, Adaptive Line Enhancer, Electronic stethoscope, Heart sound noise, Lung sound.**

I. Introduction

Significant advances on health care, especially medical devices have been made in the past few decades. However, albeit basic, stethoscope is still essential for the diagnosis of many diseases. In fact, electronic stethoscope is one medical instrument that was studied recently by many groups of researcher [1]-[5]. It was also developed with various added features [6], [7]. These efforts were mainly focused on background noise reduction, heart sound enhancement and telecommunication capabilities.

The preliminary diagnosis of pulmonary diseases hinges on the identification of key abnormal audible features in breath sounds, such as crackles and wheezes. These "adventitious breath sounds" are superimposed over normal breath sounds. In view of the intrinsic audio spectra overlap of heart sound and lung sound, it will be advantageous for the diagnosis, especially in the outpatient clinics, if there is an electronic stethoscope which can filter out the audio components result from the heart beat instantaneously.

Some studies looked into the separation of recorded heart sound and lung sound [11]-[16] by using software in personal computers in an off-line fashion. Nonetheless, a convenient setup "extracting" lung sound *in real time* has never been developed. In view of this situation, here we evaluate various aspects of construction and propose a preliminary design for an electronic stethoscope that can filter out heart sound (noise) from lung sound in real-time.

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II. Heart sound becomes noise

A. Lung sound

Generally, lung sounds are produced during inspiration and expiration cycles, and are found in the frequency range 60-100Hz to 2 kHz [8]. Normal lung sounds originate from within each lobe of the lung when inhaling and are from central airways (trachea) when exhaling. Moreover, they have frequency distribution between 70 and 600Hz [8], [9]. Abnormal or adventitious sounds are mainly of two types–wheeze and crackles. Wheezes are musical or continuous abnormal lung sounds with a frequency distribution extending roughly from 100Hz to 1000Hz. They are originated from the air turbulence and oscillations of the walls of narrowed airways and are heard typically when checking patients with airway obstruction. Crackles on the other hand are short, non-musical sounds. They have a broad frequency distribution and originate from airways that open very abruptly in the lung fibrosis when retractile forces of the lung are increased. They are produced by movement of bubbles in airway fluid and secretions in patients with pulmonary edema or with chronic bronchitis.

B. Heart sound

Heart sounds are produced by the blood flowing in and out of the heart. The first heart sound results when blood is pumped from the heart to the rest of the body, during the latter half of the cardiac cycle. It is produced by closure of the two atrio-ventricular valves. After blood leaves the ventricles, the simultaneous closing of the semi lunar valves, which connect the ventricles with the aorta and pulmonary arteries, causes the second heart sound [10].

The main frequency components of heart sound signal are in the range of 20-100 Hz, which overlaps with the abnormal lung sound frequency range. This makes heart sound an incessant noise during pulmonary disease examination, especially in the identification of lower frequency wheezes or rhonchi.

III. Heart sound noise reduction methods

Researchers have proposed many methods to reduce heart sound noise in the recorded lung sound. Among them, high pass filters with cutoff frequencies between 50-150 Hz were the first ones used. However, they will inevitably filter out some frequency components of wheezes. The adaptive filtering techniques were the approaches taken to reduce heart sound noise in many works. We will also follow along this track.

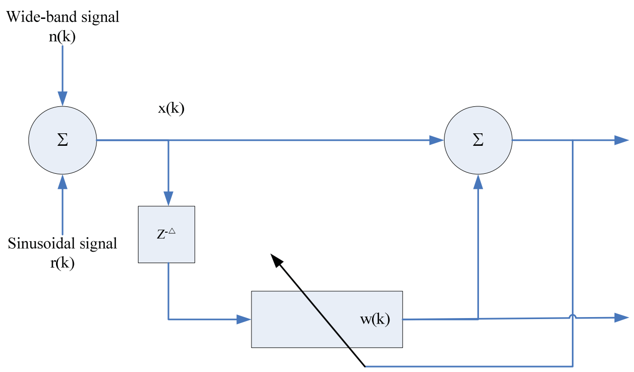

Fig. 1. Adaptive line enhancer structure.

A. *Adaptive Filter*

Adaptive filter was first used to reduce heart sound noise in [11]. The method therein used a modified electrocardiogram signal as a noise reference signal. A modification of [11] with a single microphone input was proposed by Kompis and Russi in [12], resulting in reduced heart sound by 24-49%. The adaptive filter applied with automated gain control was proposed by L.Yip and Y.T. Zhang [13] with a heart sound reduction rate ranging from 75% to 83%.

B. *Adaptive Line Enhancer*

Adaptive line enhancer (ALE) was first introduced by Widrow in 1975. The separation of heart sound signal from lung sound by using adaptive line enhancement was proposed by T. Tsalaile and S. Sanei [14]. The structure of ALE in that project is shown in Fig.1

ALE is formulated in an *L*-weight linear predictive FIR filter structure, with its output $y(k)$ being defined as:

$$y(k)=\sum_{l=0}^{L-1} w_k(k)x(k-l-\Delta) \quad (1)$$

Where △ is the prediction distance of the filter in terms of the sampling interval, L is the filter length and w_k are the ALE coefficients (adjustable FIR filter weights). Least Mean Square (LMS) adaptive algorithm is often used to adapt the coefficients.

It has been shown that ALE method has the potential to separate heart sound from lung sound with a low signal to noise ratio when applied to a one-input, artificially mixed heart-lung sound signal [14].

C. *Others methods*

A variety of methods were also presented in [15]-[20]. High order statistics were used to combine with adaptive filtering and result in higher heart sound noise reduction rate [15]. Some researchers have tried to develop filters based on wavelet transform. In [16] and [17], this method was applied to reduce heart sound noise from lung sounds. Time frequency filtering was used to filter out heart sound in [18]; however, according to their results, this method is not particularly efficient in term of computation load and speed. Independent Component Analysis (ICA) technique was applied to separate heart sound noise from lung sound in [19] and [20].

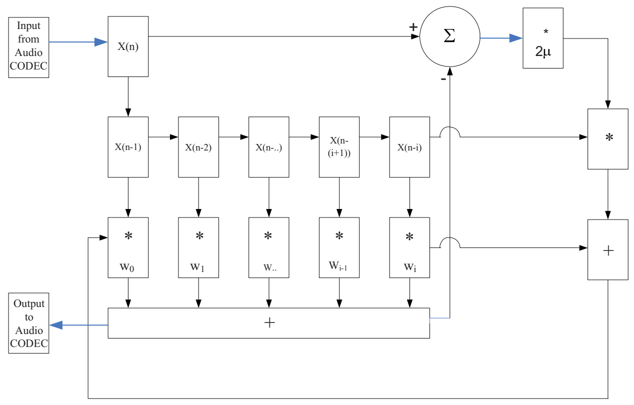

Fig. 2. Adaptive line enhancer in hardware implementation blocks

IV. SELECTION OF FILTER STRUCTURE

In general, algorithms like adaptive filtering or adaptive noise cancellation can't be implemented in general purpose MCUs because the real time computation requirement is beyond their specifications. Specific IC design is more complicated and requires more development time than the DSP based ones. In our proposed system, we would like to select FPGA to implement the real time heart sound de-noising filter stage of the electronic stethoscopes for they are more capable than general purpose MCUs, require less time for development than specific ICs and are more flexible than DSPs. One adaptive filter for audio signal processing was successfully implemented in FPGA [21]. FPGA is also used to realize transversal adaptive filter [22] and ICA algorithm for blind signal separation and adaptive noise cancellation [23], respectively.

Since there is no convenient noise reference for the adaptive filter in an electronic stethoscope, and we have only one input signal (from stethoscope pick up head) mixed with noise, ALE is a natural choice for us.

The computation of ALE can be explained in the following steps. First, initiate the weights with a starting value. Subsequently, compute filter output and the error; followed by the updates of the filter weights. This process continues till a satisfactory result is obtained. According to Fig.1 and the algorithmic steps, we can design the structure of ALE in the block diagram shown in Fig. 2 with hardware implementation simplicity.

V. THE PROPOSED SYSTEM

In our design, audio CODEC controller and Adaptive line enhancer will be coded in VHDL language. First, signal from pre-amplifier and anti-aliasing circuit will be sourced to Line-in input of DE2-70 board; audio CODEC will convert sound (analog) signal to digital 1 bit serial signal and then audio CODEC controller will parallelize this signal into digital 24 bits before sending it to the adaptive line enhancer.

After the processing in ALE, the signal will be sent back to audio CODEC controller to be serialized to 1 bit. Finally, the signal is sent to audio CODEC for DAC. The proposed system consist of 3 major parts as shown in Fig. 3

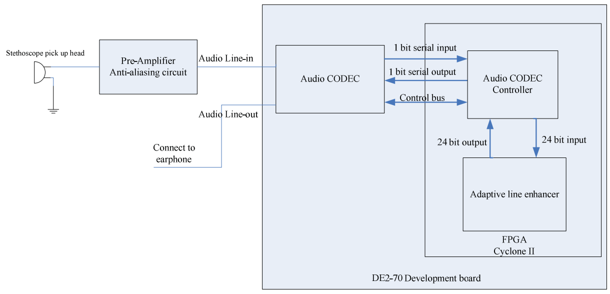

Fig. 3. Block diagram of propose system

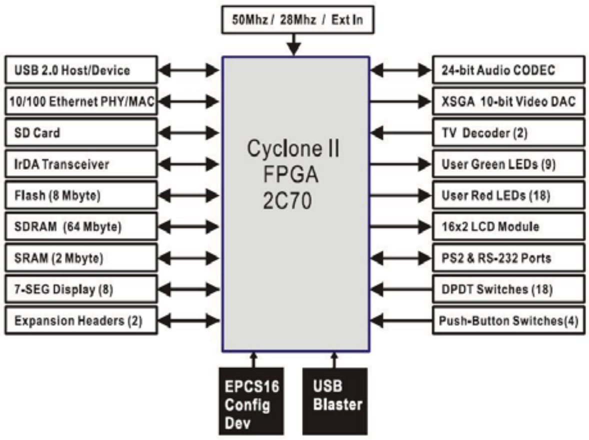

Fig. 4. DE2-70 Development board block diagram and peripheral devices [24]

A. DE2-70 development board

Altera DE2 board is one of the most widely used development FPGA board for the development and implementation of digital circuits and digital signal processing on FPGA. The purpose of the Altera DE2 Development and Education board is to provide an ideal environment for FPGA designs. The board has a Cyclone II FPGA from Altera with 68416 LEs, 250M4K RAM blocks, 150 embedded multipliers and 4 PLLs. DE2-70 board also offers many useful features such as LEDs and Switches, 16x2 LCD Module, USB 2.0 controller, SD Card, Flash, SDRAM, XSGA 10-bit Video DAC, TV Decoder and 24-bit Audio CODEC etc. [24], which make it suitable for use in a laboratory environment for a variety of design projects. Block diagram of the DE2 board and peripheral devices are shown in Fig.4.

B. Audio CODEC and Audio CODEC controller

DE2-70 development board provided WM8731 Audio CODEC with an integrated headphone driver. This is more suitable for electronic stethoscope than separate ADC and DAC chips. This chip supports microphone input, line-in and line-out ports, which are connected to Cyclone II FPGA on DE2-70 board. By serial I2C bus interface, the audio CODEC can be configured to meet the user requirements. The digital audio words lengths are from 16 bits to 32 bits and the sample rates are from 8 kHz to 96 kHz. The default values of the proposed design are 24 bits for input/output data bit length and 48 kHz for the sampling rate. A schematic diagram of audio CODEC circuitry is shown in Fig. 5.

Audio CODEC controller design and implementation are achieved through VHDL coding. Audio CODEC controller plays 2 roles. The first is to configure the audio CODEC to meet design requirement via control input pins such as ADCLRC, DACLRC and BCLK. Secondly, the audio CODEC controller parallelizes the data from audio CODEC and sends them to ALE. Also, the audio CODEC controller serializes the data from adaptive line enhancer and sends them to the audio CODEC chip.

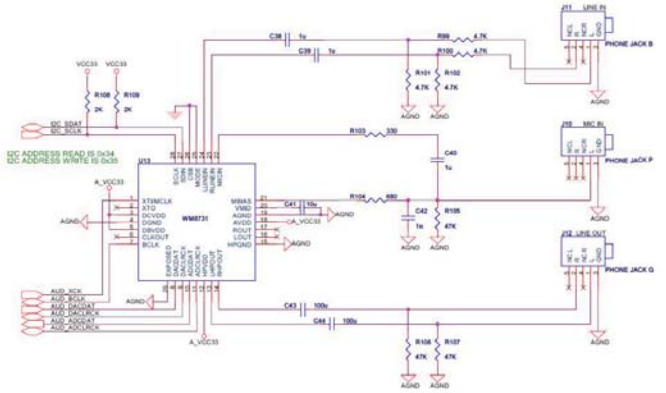

Fig. 5. Audio CODEC schematic diagram [24].

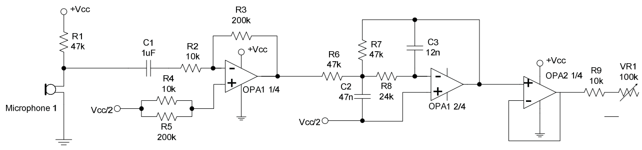

Fig. 6. Pre-amplifier and the anti-aliasing circuit.

C. Pre-Amplifier and Anti-aliasing Filter

Fig. 6 shows the first two stages of signal path from the stethoscope pickup. Signal from microphone will go through an amplifier with a gain of 20, followed by an anti-aliasing low-pass filter using OPA134 with a cut-off frequency at 2kHz .

VI. Experiment Results

In this section, we will show the experiment results. Two types of signal are used in this experiment: a heart sound mixed with a wheezing breath sound, and a heart sound mixed with a breath sound with crackles.

The signals are taken from 3M™ Littmann®[25]. We pass the mixed sound to a preliminary construction of the proposed setup and record the output. The outputs are then displayed against the original abnormal breath sound signal. The results are shown in Fig. 7 and Fig. 8. The proposed setup clearly attenuated the heart sound noise.

VII. Conclusion

This paper elucidates the system design, selected methodology and selected devices of the construction of the proposed electronic stethoscope with heart sound noise reduction feature which shall be most useful in the diagnosis of pulmonary diseases. We selected adaptive line enhancer as our filter based on its effectiveness and the fact that it is easy to implement. In addition, we selected an FPGA-based platform to implement our proposed design for the speed and flexibility. The experiment results show the proposed setup is promising.

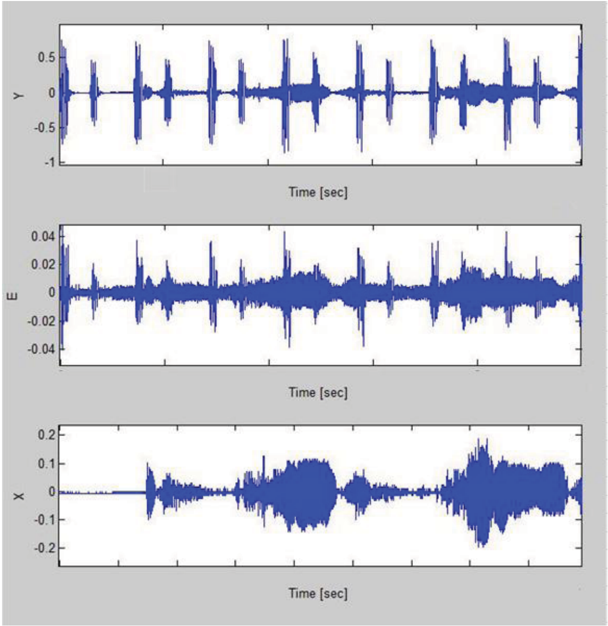

Fig. 7. The top, heart sound mixed with breath sound with wheezes. Middle, our output. Bottom, the original breath sound with wheezes.

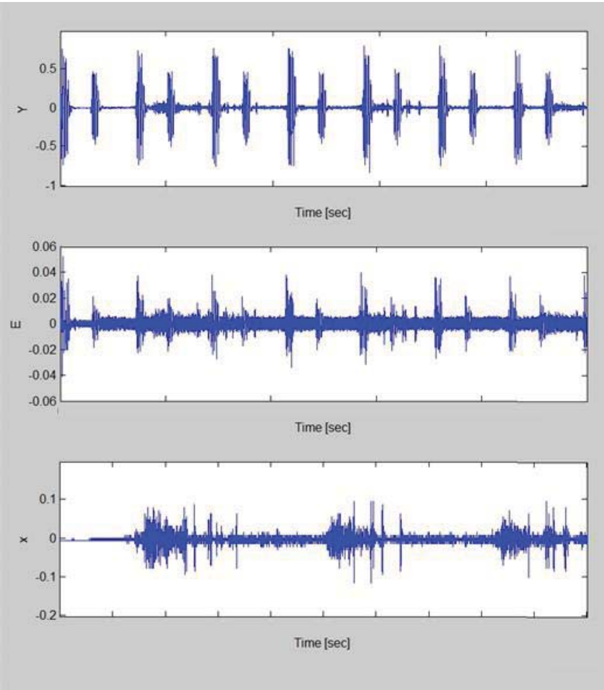

Fig. 8. The top, heart sound mixed with breath sound with crackles. Middle, our output. Bottom, the original breath sound with crackles.

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