Digital Stethoscope Design

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Abstract. This paper details a new design for a digital stethoscope, which has the ability to filter out ambient noise and reduce playback speed. The design largely resembles a traditional acoustic stethoscope but with a digital embedded system to handle the filtering and reduced playback speed. Initial signal processing testing of the design has been conducted with results showing successful reduction in ambient noise and faithful replication of sound at a reduced speed.

Key words: Butterworth filter, Digital stethoscope, heart defect, time domain harmonic scaling
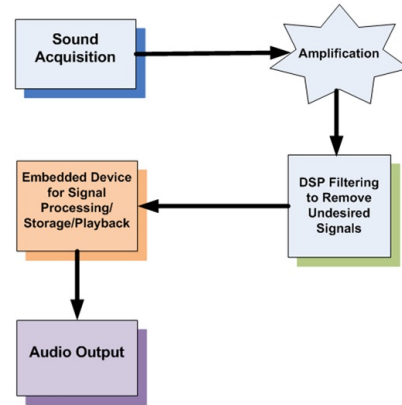

Fig. 1. Stethoscope Architecture Overview

1 Introduction

ON Semiconductor Inc. requires an improved stethoscope to allow physicians to detect heart defects from newborn babies whose hearts beat too quickly and quietly to be reliably heard from a conventional stethoscope. Every year more than 1,000,000 babies are born worldwide with a congenital heart defect making it the most common birth defect in the world. [1] The proposed device should be portable, easy to use, and appropriate for use in a hospital environment for crib side analysis. In addition, the device should not require any additional training over using a conventional stethoscope.

The design offers a strong alternative to some existing solutions. Acoustic stethoscopes have traditionally been used for diagnosis, however, the inability to slow down or optimize the sound makes it difficult to detect defects in newborn children. Similar digital stethoscopes include the 3M-Littmann and Thinklabs Digital Stethoscope. The design discussed in this paper offers a lightweight and simplistic alternative that is catered towards the heartbeats of newborns. The device offers a powerful integrated system that can optimize sound as well as accurately slow-down sound without distortion.

2 Conceptual Design

The design is comprised of audio capture unit, which sends a digital signal through a filter after being amplified. The sound is processed by an embedded microcontroller for reduced playback speed and finally output via headphone. This is summarized in Figure 1.

The physical design of the digital stethoscope will resemble a conventional stethoscope with an embedded unit, including a LCD, to control playback. It is visualized in Figure 2.

Fig. 2. Conceptual Stethoscope Design

The estimated weight of the stethoscope is 269g g. The total power consumption of the system is 3.5 W. The total cost for a prototype is estimated at $441.94 per unit, using off-the-shelf components.

3 Detailed Design

3.1 Audio Capture

The audio capture device converts sound pressure into an electrical signal. The CM-01 contact microphone was selected. It employs a piezoelectric crystal, which generates an electric voltage upon physical deformation. Heartbeat sounds are within a subset of the microphones 8 Hz to 2.2 kHz frequency range.

3.2 Filtering

A 4th order Butterworth filter is used to reduce ambient noise, which will be implemented on the embedded board. Experimentally, a 1 kHz cut-off frequency has been selected. A Butterworth style filter is implemented due to its smoothness in the pass band.

3.3 Time Stretching

A time domain harmonic scaling algorithm is used to reduce playback speed. It was selected due to its competence with simple, beat-like sounds. A 8.5 ms Hann window is applied. Autocorrelation is first used to determine the pitch of the sound.

With knowledge of the pitch, the Waveform-Similarity-Based Overlap-and-Add (WSOLA) algorithm then takes segments of the signal, of the size of the period, and lays it over the original signal at an offset. This algorithm stretches the signal, while maintaining the original signal frequency.

3.4 Audio Output

The system will produce 16-bit mono audio at a playback rate of 44.1 kHz through noise-cancelling ear buds. The sound will be delivered by Cyber Acoustics ACM-9801 passive noise canceling earbuds.

4 Implementation and Testing

The two main areas that the digital stethoscope design must perform are heartbeat signal optimization and signal slow down. A prototype was built in order to test the functionality of the proposed design. The prototype was built in 2 separate components to perform the objectives separately.

To optimize the signal, MatLab was used to filter the signal according to the filter design. The low pass filter removes all undesired sounds in the signal leaving only the heartbeat. Removing the background noise allows the listener to hone in on heartbeat sounds so that they can better assess problems. Shown in Figure 3 is a comparision between the original heartbeat and the filtered signal that shows frequencies above 1 kHz are removed. When listening to the samples, it is easily apparent that the filtered signal sounds much clearer.

The next component in the design was to slow down the heartbeat signal so that defects in fast beating hearts can be properly assessed. The Time Domain Harmonic Scaling Algorithm was implemented using a C++ application that is capbable of accepting the filtered signal and accurately slowing it down, while correcting for any resulting distortion. Shown in Figure 4 is a comparison between the original heartbeat signal, and one that has been slowed down by a factor of 2 using the algorithm.
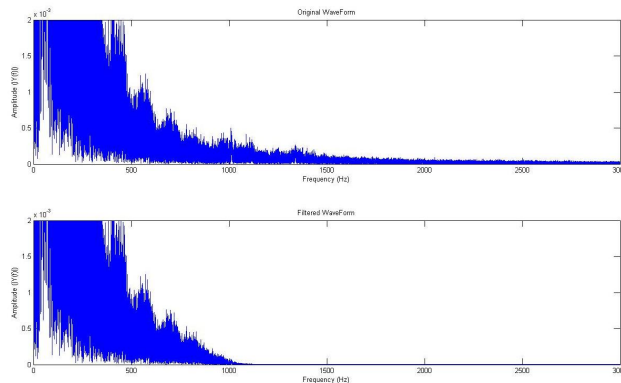

Fig. 3. Comparison of Original and Filtered Heartbeat Signal.

It can be seen from the graphs, that the algorithm produces a very good representation of the orignal signal because the amplitude peaks which represent heartbeats in the original signal are very similar in shape to the time stretched signal, meaning that very little distortion has been introduced.
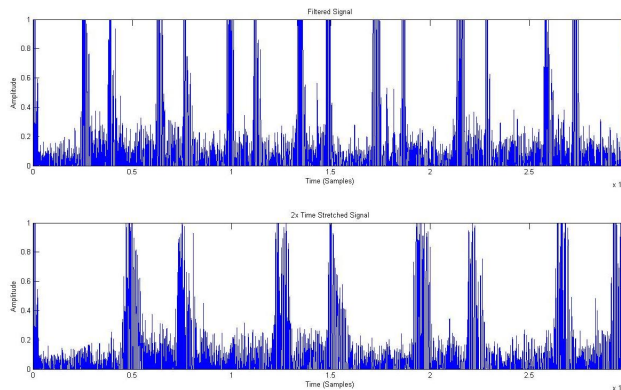

Fig. 4. Comparison of Original and 2x Slowed Down Heartbeat Signal.

5 Conclusion

A digital stethoscope has been designed to filter out ambient noise and reduce playback speed to better detect heart defect in newborns that have quick, quiet heartbeats. Results have shown improvements in regards to both sound optimizations. Further development could be made towards expanding assessment beyond local audio. Examples include the ability load the audio data to portable storage and upgrading the LCD display to allow for visual analysis of the signal.

References

1. The Children's Heart Foundation Factsheet - `http://www.childrensheartfoundation.org/about/factsheets.html`