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A Portable Low-Cost Electronic Stethoscope Design with Software Tools

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Abstract – We have designed a portable low-cost stethoscope with software tools. It is aimed to pre-diagnose heart diseases in a short time without exposing the patient to detailed examinations and additional procedures such as electro-cardiography (ECG) or angiography. It is important to develop such assistive systems, especially in order to reduce the burden of experienced physicians and to assist inexperienced physicians and thus saving time. For this purpose, first, the heart sound is converted into an electrical signal, and amplification and filtering in both hardware and software is implemented. The heart sound signal is obtained digitally and displayed on the monitor in segmented form. Physicians can classify the attributes of the cardiac cycles by examining the segmented S1 and S2 cardiac cycles, thereby establishing whether the heart sound is normal or abnormal.

Keywords – Electronic stethoscope, Auscultation, Heart sounds, Signal processing, Segmentation

I. Introduction

The method of auscultating with a stethoscope, which is primarily used in the diagnosis of heart diseases, is an important issue [1]. Separating and interpreting the sound heard with a stethoscope is a difficult and expert application. The sound signals received from the human body differ according to the surface on which the stethoscope is placed. In the diagnosis of the disease, it plays an important role in hearing the sounds in addition to the heart and respiratory sounds.

The stethoscope has a frequency response that attenuates the frequency components of the audio signal above 112 Hz. Although it is possible to hear heart sounds in this frequency range by amplifying low frequencies, the human ear is very weak in hearing sounds with low frequency components [2]. These deficiencies have led to the need to display or record received heart sound signals. For this goal, "Electronic Stethoscope" was invented. L. Yip and Y. T. Zhang built an electronic stethoscope to suppress heart sounds from lung sounds. They used Laplacian Electrocardiographic Signal (LECG) adaptive filter and amplified weak LECG signals with automatic gain control (AGC) algorithm. In their study, they separated heart sounds from lung sounds with a success rate of 75% [3]. K.Hung and Y.T. Zhang, in their study in 2002, designed a Bluetooth-Based Electronic Stethoscope to transmit the signal wirelessly without deterioration in signal quality. With the electronic stethoscope they designed, they transferred heart and lung sounds without loss via bluetooth.[4] J. Johnson et al., in 2006, aimed to design a very low power consumption electronic stethoscope, which performs digital filtering processes by using “Over-Sampled Filterbank” in the DSP system and performs the preliminary signal processing on the stethoscope [5]. J.Y. Shin et al., in 2013, in an application to detect s1 and s2 sounds and to calculate the number of heart beats, heart sounds can be recorded while being displayed simultaneously. They transferred the heart sound signals they received to iPhone or iPad and viewed and recorded the signal with the software they developed [6].

In this study, heart sound signals are obtained, segmented and displayed in real-time on a monitor. Thus, by looking at the attributes of the segmented S1 and S2 cardiac cycles, health personnel can determine whether the heart sound is normal or abnormal (for example, murmur). While the corresponding health personnel listen to the heart sound, they examine the segmented heart sound information on the screen and it will be easier to make a preliminary diagnosis. Detailed examinations can be requested (ECG, angiography, etc.) according to this pre-diagnosis.

II. Materials and Method

In order for the heart sound to be displayed clearly, the electrical signal obtained with the electret microphone integrated into the analog stethoscope passes through the preamplifier, low-pass filter (to prevent aliasing), high-pass filter (to prevent very low frequency sounds produced by pressure during stethoscope contact), respectively. Then it will be digitized with the analog-to-digital converter (ADC) built into the microcomputer. Then, noise-free clear imaging will be performed with a low-pass digital filter designed in the MATLAB environment to be encoded in the digital signal processing module.

The amplitude and phase response of a low-pass FIR filter with a coefficient of 100, designed using the hamming window in MATLAB, with a cut-off frequency of 700 Hz.

Then, by determining the local extreme points of the autocorrelation function of the signals, the heart rate (beat rate) will be determined and accordingly the segmentation of the S1 and S2 cardiac cycles in the time domain will be made.

A. Preprocessing

An electrical signal is obtained with the electret microphone integrated into the analog stethoscope for a clear visualization of the heart sound. Microphone driver circuit provides to find the appropriate voltage value to make the electret microphone work. The preamplifier circuit amplifies the low amplitude signal received from the microphone approximately 21 times and outputs it. Microphone driver and the preamplifier circuit is as shown in Figure 1.

High-Pass Filter (HPF) is used to prevent very low frequency sounds produced by muscle noise, friction and pressure during stethoscope contact. The cut-off frequency of

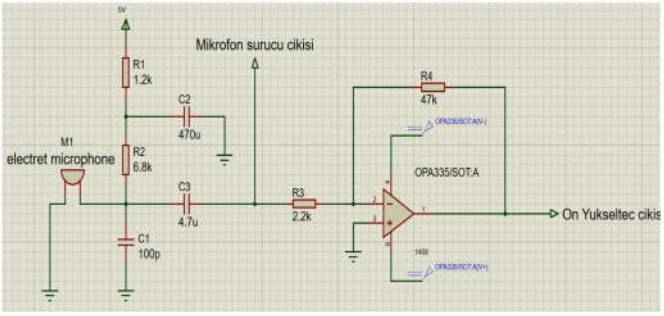

Fig. 1 Microphone driver and the preamplifier circuit

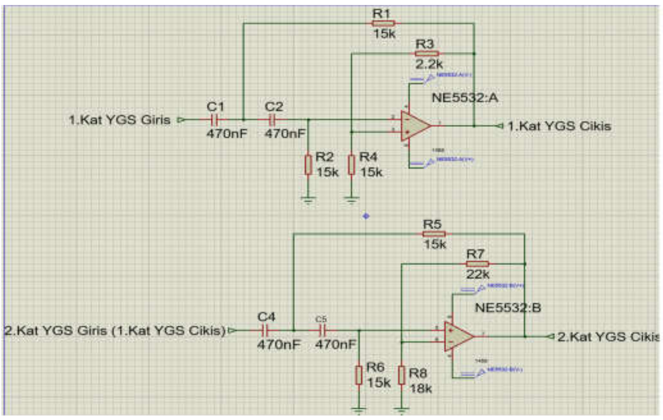

Fig. 2 High-pass filter

this filter is considered to be fc = 20-30 Hz. The designed high pass filter circuit is as shown in Figure 2.

B. Filtering

One of the important elements of digital signal processing is filters. They are generally used in electronic circuits for various purposes such as filtering out noise and separating certain frequencies from each other.

In order to use the audio signal in its simplest form, it is necessary to filter it from other signals. For this, digital filters are used. FIR filters are the most commonly used filters in such operations. The advantages of FIR filters are: 1) It is always in linear phase. 2) The FIR filter is always stable. 3) FIR filters are easier to implement than IIR filters. Due to these great advantages, a FIR filter is preferred. The structure of a FIR filter is as shown in Figure 3.

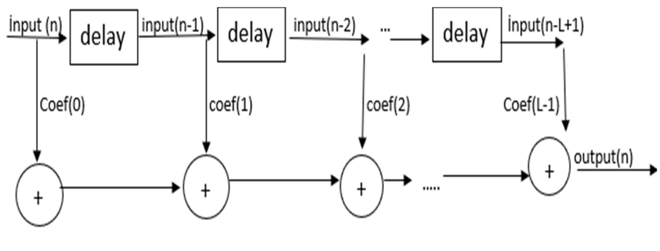

Fig. 3 The structure of a FIR filter

C. Autocorrelation

For segmentation process, the autocorrelation of the heart signal is calculated. The autocorrelation process is used to compare a signal with a time-delayed version of itself. This method, which is widely used to find repetitive signals, provides the determination of the fundamental period of a noise-corrupted periodic signal. If the time delay of the signal is one full period, the overlap between the *x(t)* signal and the *x(t-T)* delayed signal is maximum.

III. Results and Discussion

A low-pass FIR filter with 100 coefficients was designed using the hamming window in MATLAB environment with a cut-off frequency of 700 Hz. This is due to that when the spectrum of abnormal (murmur) noiseless heart sounds in the database is examined, it is observed that its spectrum reaches up to 700 Hz [7]. The amplitude and the phase responses are given in Figure 4. The coefficients of this filter were used in the software and can be updated very easily since it is implemented with codes.

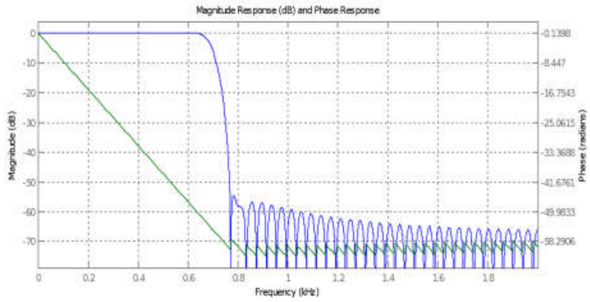

Fig. 4 The amplitude and the phase responses of the designed FIR filter

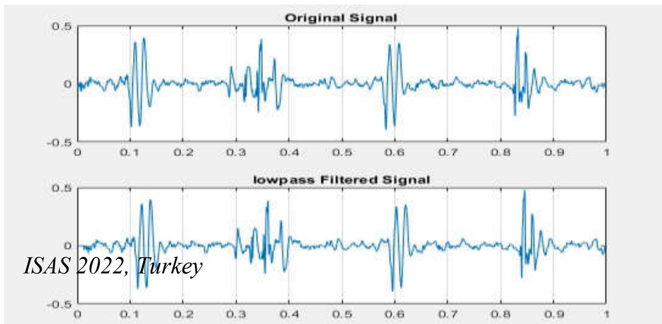

Fig. 5 The original and the lowpass filtered signals

The waveform of the signal used after applying the FIR filter is as shown in Figure 5. By determining the local extreme points of the autocorrelation function of the filtered signals, the heart rate (beat rate) was determined and S1 and S2 cardiac cycles were segmented accordingly in the time domain.

By applying autocorrelation to the signal, heart rate and systole time will be calculated for each patient record. The correlation of the signal at the first moment is maximum and the highest value obtained from this moment gives us the period of the heart signal, that is, the heart rate. The highest level in a period will give us the systole time interval value, and the second highest level will give us the diastole time interval value. A sampled heart signal and its sampled autocorrelation in MATLAB are shown in Figure 6.

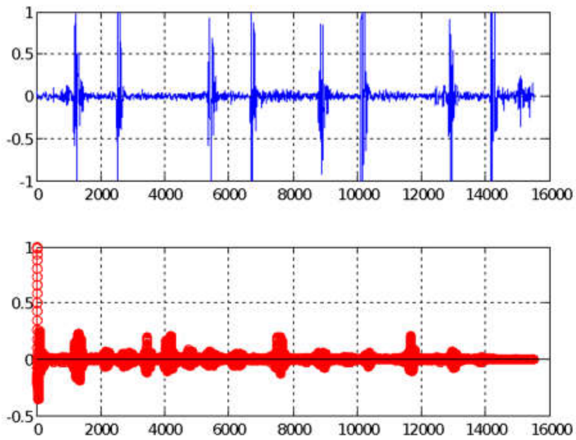

Fig. 5 The sampled heart signal and its autocorrelation

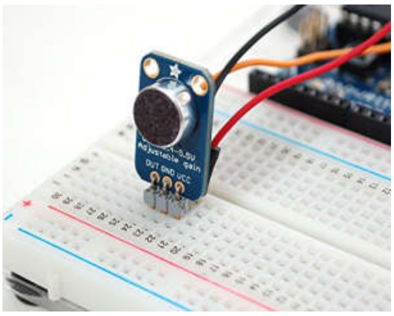

Fig. 6 The MAX4466 Electret Microphone

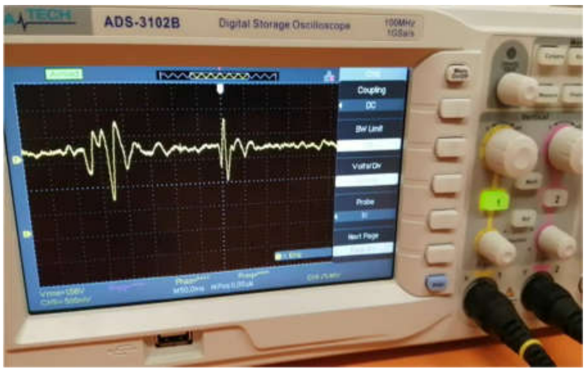

Fig. 7 The real-time heart signal obtained by the designed system

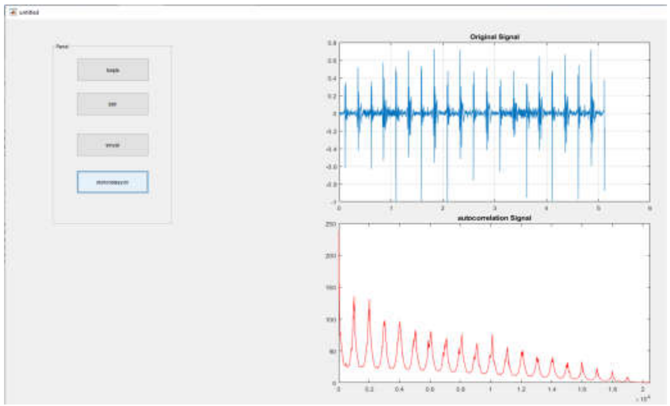

Fig. 8. The MATLAB GUI design for the electronic stethoscope

Fig. 9. The final prototype and the software

In this study, MAX4466 Electret Microphone model was used. MAX4466 Electret Microphone Module operates in the frequency range from 20 Hz to 20 kHz. With the integrated OPAMP and adjustable resistor on the back, the signal from the microphone can be amplified 25 to 125 times. It offers the opportunity to work with 5V and 3.3V sources with an operating voltage in the range of 2.4V - 5.5V [8]. The MAX4466 Electret microphone used in the design is given in Figure 6. The MAX4466 Electret Microphone Module, which was tested after the necessary voltage was provided, combined with the stethoscope after observing that it worked properly. After connecting with the stethoscope, it was tested and observed that there was no problem in the sound perception of the stethoscope. The real-time heart signal obtained by testing the whole system with a human is given in Figure 7 on the oscilloscope screen.

In the MATLAB environment, a graphical user interface (GUI) was designed. Using the codes written in MATLAB, the received heart sound signal and its autocorrelation were displayed simultaneously. The MATLAB GUI design is given in Figure 8.

After the stethoscope was combined with the electret microphone, it was supplied with a 3V battery and connected to the computer with an interconnection. By using the GUI design, the signal was displayed simultaneously from the stethoscope, and local max and local peaks were found by autocorrelation. The final stethoscope prototype and the software are shown simultaneously in Figure 9.

IV. Conclusion

With this designed system, it is aimed to pre-diagnose heart disease in a short time without exposing the patient to detailed examinations and additional procedures. While the corresponding health personnel listens to the heart sound, on the other hand, they can examine the related heart anomaly information on the screen thus making a preliminary diagnosis easier. Detailed examinations (ECG, angiography, etc.) can be requested according to this pre-diagnosis. It is important to develop assistive systems, especially in order to reduce the burden of experienced physicians, to assist inexperienced physicians and to save time.

In this study, unlike the primary studies, heart sound signals are displayed in real-time. It can be automatically diagnosed whether there is an anomaly in the heart or not. The system can be integrated into the mobile platform by developing an application for mobile platforms. The last but not the least, the filters in the analog signal processing unit can be removed and implemented digitally with the embedded computer.

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