The Design of An Electronic Stethoscope-Review

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Abstract - Stethoscope is the primary means for a doctor to diagnose thoracic and abdominal body. The original stethoscope invented was nothing more than a short wooden tube which was a monaural stethoscope. Then binaural stethoscopes were used. After which Electronic stethoscope was invented through which the heart sounds were heard clearly compared to previous methods. As with the technology there are possibilities of novel uses of Electronic stethoscope.

Electronic stethoscopes overcome the low sound levels by amplifying body sounds. Currently, a number of companies offer electronic stethoscopes and it can be expected that within a few years, the electronic stethoscope will have eclipsed acoustic devices.

In conclusion, it is possible to develop an inexpensive recordable digital stethoscope by making use of the technology.

Keywords - auscultation; electronic stethoscope; chest piece; condenser microphone; Heart sounds.

I. INTRODUCTION

History of Stethoscopes dates back to 460-377BC during which Hippocrates provided the foundation for auscultation when he put his ear against the chest of a patient and described the sounds he could hear from the heart. The next leap was made by Robert Hooke (1635-1703) who realized the diagnostic use of cardiac auscultation. The biggest breakthrough in auscultation came in 1816 when René Laennec(1781-1826) invented the stethoscope.

In 1851, Arthur Leared invented a binaural stethoscope, and in 1852 George Cammann perfected the design of the instrument for commercial production, which has become the standard ever since. By 1873, there were descriptions of a differential stethoscope that could connect to slightly different locations to create a slight stereo effect, though this did not become a standard tool in clinical practice. Rappaport and Sprague designed a new stethoscope in the 1940s, which became the standard by which other stethoscopes are measured, consisting of two sides, one of which is used for the respiratory system, the other is used for the cardiovascular system. In 1999, Richard Deslauriers patented the first external noise reducing stethoscope, the DRG Puretone. In 2004, Philips came out with an Electronic stethoscope model.

Stethoscopes, as any other medical instrument, have undergone a lot of variations and enhancements. These enhancements have mainly been carried out to ensure that doctors and other medical practitioners do not have any trouble whatsoever listening to body sounds while examining a patient. In the past and even today, the most commonly used stethoscopes are the acoustic ones. These stethoscopes transmit sound from the chest piece, via the hollow rubber tubes, to the ears of the listener. The chest piece normally consists of a diaphragm on one side and a bell or hollow cup on the other side to listen to the various body sounds of a patient. If you place the diaphragm on the body of a patient, the body sounds produce vibrations on the diaphragm creating sound waves that travel through the hollow rubber tubes to the ears of the listener. On the other hand, if you place the bell on the body of a patient, the vibrations on the skin directly produce sound waves that travel to the ears of the listener. The diaphragm is used to transmit high frequency sounds whereas the bell is used to transmit low frequency sounds. However, the major problem with acoustic stethoscopes is that the sound level is extremely low and can be a major concern in noisy environments.

Electronic stethoscopes function in a similar way, but the sound is converted to an electronic signal which is transmitted to the listener by wire. Functionalities often included in electronic stethoscopes are amplification of the signal, filters imitating the function of the diaphragm and the bell and in some cases recording abilities to allow storage of data.

The hardware design is composed of the following major parts: power supply, sensor, preamplifier, low-pass filter and power amplifier. Audio output and software includes the display of phonocardiogram.
II. SENSOR

The simplest and least effective method of sound detection was achieved by placing a microphone in the chestpiece. This method suffers from ambient noise interference and has fallen out of favor. Another method, used in Welch-Allyn’s Meditron stethoscope, comprises placement of a piezoelectric crystal at the head of a metal shaft, the bottom of the shaft making contact with a diaphragm. Litmann also uses a piezoelectric crystal placed within foam behind a thick rubber-like diaphragm. Thinklabs’ Rhythm 32 inventor, Clive Smith uses an electromagnetic diaphragm with a conductive inner surface to form a capacitive sensor. This diaphragm responds to sound waves identically to a conventional acoustic stethoscope, with changes in an electric field replacing changes in air pressure. This preserves the sound of an acoustic stethoscope with the benefits of amplification. Texas instruments makes use of a sensor which has three important parts:

- Diaphragm
- Condenser microphone
- 2.5 mm audio plug

Sound waves from the acoustic amplifier (diaphragm) are fed to the condenser microphone. The sound waves hitting the condenser microphone change its capacitance by changing its impedance, which produces a voltage swing proportional to the amplitude of the input sound waves. The voltage swing of the signal also depends on the bias voltage given for the microphone. A microphone bias voltage of 1.25 V is produced by the audio codec.

The coupling of the acoustic sensor to the microphone is critical to pick up noise free sound signals from the human body. An acoustic diaphragm can be coupled to the microphone as shown in Figure 1. Place the microphone as close as possible to the diaphragm; the microphone should be connected to a 2.5 mm plug to connect the 2.5 mm jack to the front-end board. The electric wire that connects the microphone to the plug is made long enough to ensure that there is sufficient length to place the sensor on the subject.

![Fig. 1: Sensor Coupled Microphone](image)

There are multiple types of sensors that can be used in the chest piece of an electronic stethoscope to convert body sounds into an electronic signal. Microphones and accelerometers are the common choice of sensor for sound recording. These sensors have a high-frequency response that is quite adequate for body sounds. Rather, it is the low-frequency region that might cause problems [11]. The microphone is an air coupled sensor that measure pressure waves induced by chest-wall movements while accelerometers are contact sensors which directly measures chest-wall movements [10]. For recording of body sounds, both kinds can be used. More precisely, condenser microphones and piezoelectric accelerometers have been recommended.

Both transducers are popular in sound recording. However, accelerometers are typically more expensive than microphones, are often fragile, and may exhibit internal resonances. Thus, this concludes that the microphone is prefect for the application.

Condenser microphones generally have flatter frequency responses than dynamic, and therefore mean that a condenser microphone is more desirable if accurate sound is a prime consideration as required in this design. There are two types of condenser microphones; standard condenser and electret condenser. A standard condenser microphone consists of a small diaphragm that vibrates in response to acoustic pressure. Standard condenser microphones have very high output impedance, so they are not suitable for transferring signals over even a very small distance. An electret condenser microphone combines a condenser microphone with a Field Effect Transistor (FET), which amplifies the signal and transforms the impedance to a more useful level. This characteristic of electret condenser microphones makes them very sensitive to small sounds.

![Fig. 2: Different types of microphones](image)

III. POWER SUPPLY

The design of a new digital collecting system of Heart sound signals based on XH-6 sensor by Chen et al makes use of a contact conduction type XH-6 heart sound sensor transforming heart sound signals into voltage signal[3]. Design of a Flexible Stethoscope Sensor Skin Based on MEMS Technology by Honghai Zhang et al makes use of a piezoelectric PZT thin films patterned on a silicon-based cantilever are used as sensor elements with fast response time and high sensitivity[12].

The sensing unit needs a power supply unit. Most digital stethoscopes use either one or two AAA 1.5 V
primary batteries. This design requires a step-up or boost switching regulator to increase the voltage to 3.0 or 5.0 V, depending on the circuitry utilized. Rechargeable batteries can be used. The best choice is found to be a single cell Li+ battery.

Bandage-Size Non ECG Heart rate monitor using Zigbee Wireless link by Tao et al had LiPo battery using power from a USB connection. A power management circuitry was used to charge the battery. A low voltage protection is built to prevent damage to the battery when its voltage getting too low[3].

A New Phonocardiographic Recording System The stethoscope by S Lukkarinen et al operates from standard 9V battery included in the enclosure[14].

Texas instruments has made a Digital Stethoscope Implementation on the TMS320C5515 DSP Medical Development Kit (MDK) the TMS320C5515 digital signal processor (DSP) which has been used for low power medical applications[15].

The MDK includes
- Analog front-end boards (FE boards) specific to the key target medical applications of the C5515 (ECG, digital stethoscope, pulse oximeter), highlighting the use of the TI analog components for medical applications
- C5515 DSP evaluation module (EVM) main board
- Medical applications software [15]

The main elements of the MDK digital stethoscope system are:
- C5515 EVM
- Digital stethoscope front-end board
- Sensor

Fig. 3: MDK Hardware Overview[15]

The EVM comes with a full compliment of on-board devices that suit a wide variety of application environments. It operates from a ± 5 V external power supply or battery and is designed to work with TI’s Code Composer Studio™ integrated development environment (IDE). Code Composer Studio communicates with the EVM board through the external emulator, or on-board emulator[15].

IV. AMPLIFICATION

The signals picked from a microphone are transmitted to Signal processing circuit. The design of electronic heart sound stethoscope developed by Yang et al. played a role of adjusting the signal from sensor with a series of amplification and filtering so that it would meet the follow-up A/D sampling demands and the signal to noise ratio was increased[1].

Fig. 4: A simple single pole high pass filter[2]

Bandage-Size Non ECG Heart rate monitor using Zigbee Wireless link by Tao et al had a low power dual amplifier (AD706). A simple single pole high pass filter was used to eliminate DC level of the heart beat signal from the bias of a microphone through 10K resistor[2].

The design of a new digital collecting system of Heart sound signals based on XH-6 sensor by Chen et al makes use of a high precision operational amplifier OP07 and instrument amplifier AD620 because of high precision[3].

Electronic stethoscopes were equipped with built-in analogue filter, they still failed to filter out certain noise due to the fixed pass-band constraints of analog filter. Conversely, digital filters have flexible cut-off frequency and can be designed effectively based on Labview[13].

The input signal from the sensor is very feeble; therefore, a pre-amplifier stage is included to increase the input signal. The pre-amplifier, with external mic bias circuitry, is implemented as shown in Figure 5. To do this, Texas instruments designed a preamplifier circuit with a gain factor of 31[15].
A low pass filter is provided to remove high-frequency noise and also to act as an anti-aliasing filter.

The values for R and C are calculated according to the following equation:
\[ F = \frac{1}{2\pi RC} \]

Where,
- \( F \) = Cut-off frequency required (2500 Hz) - based on the maximum frequency range of supported modes
- \( R = 620E \)
- \( C = 0.1 \text{ mF} \)

**V. DISPLAY**

Some digital stethoscopes have a small, simple display due to the limited space available, others have only buttons and LED indicators. Most of the user interface buttons can be eliminated by adding a touch screen display and controller.

The design of electronic stethoscope developed by Yang et al had LCD of 3.5 inches. The display was also through a serial port on PC where the heart sound waveform was displayed on the screen real time, data storage and playback, as well as computer-aided diagnosis. Bandage-Size Non ECG Heart rate monitor using Zigbee Wireless link by Tao et al had the data captured and displayed by sending it to the computer.

Development of an Intelligent PDA-based Wearable Digital Phonocardiograph by Matias Brusco et al had a PDAPocket PC iPAQhp5550. Here analog output of acquisition unit is connected to the microphone input of the pocket PC. The sound format is fixed at 8kHz, mono 8 bit resolution.

Portable Bluetooth Visual Electronic Stethoscope by Yi Luo made use of Labview 8.20, the virtual instrument software tool, because it is a rapid and efficient prototype development tools.

The design of a new digital collecting system of Heart sound signals based on XH-6 sensor by Chen et al makes use of VB-visualisation software development tools provided by Microsoft, heart sound sensor communicates with the computer through the serial communication. MSComm - controls were used to realize port transmitting and data receiving, providing serial communication function to the application.

Wireless Phonocardiography System based on PDA by Lijun Jiang et al made use of a PDA which is a Dell Axim X51v featured with 3.7” VGA LCD screen with 640x480 resolution, Intel XScaleTMPXA270 Processor at 624 MHz, 336MB of Memory (256MBFlash, 64MB SDRAM), built-in CompactFlash Type I expansion slot, Standard Built-In Bluetooth 1.2 Compliance as well as Microsoft Windows Mobile 5.0 software with Windows Media Player 10 Mobile.

Texas instruments makes use of MDK software which includes:
- C5515 software application
- PC application

The hardware is initialized by the DSP on the EVM. The DSP reads the digitized signals from the audio codec via the I2S interface and processes it. The processed digitized signals are sent back to the front-end board for conversion to analog signals and play back. The signal is also provided to the PC application over the UART interface for display.

The LCD display on the C5515 EVM shows the mode of operation of the digital stethoscope: volume indication bars, heart rate display and bell or diaphragm mode.
VI. CONCLUSION

Based upon the designs which have been discussed in the article technology is reaching a point where low cost options will soon become available. The force behind the low – cost movement may be due to low cost microphones that provide the desired output, accuracy and reliability of heart sound detection which directly influences the analysis and treatment of heart sound. Thus detecting cardiovascular diseases becomes easier by making use of the technology. Because the sounds are transmitted electronically, an Electronic stethoscope can be a wireless device, can provide noise reduction , signal enhancement and both visual and audio output.

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REFERENCES


