Design and Implementation of a Low Cost Electronic Stethoscope

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Abstract

The rise of e-health and telemedicine is changing the way medical data is gathered and used. Recently, electronic stethoscopes have been developed by many companies, yet general adoption of the devices is yet to be attained. This is due to the fact that electronic stethoscopes are still quite expensive. Hence, we have developed a low cost implementation to promote the general use of the devices by the healthcare industry.

1. Introduction

The hardware realized in this paper is based on the preliminary design reported in [1]. The objective is to produce a high quality digital stethoscope that meets the needs for telemedicine and affordable enough for widespread clinical adoption, as well as for home use by general consumers. The device reported in this paper includes many desirable features; a production model only needs to have a subset of the features to achieve its intended use. The following is a list of features implemented in our proposed device:

- Low cost — basic version less than 100 dollars
- Small size — not much large than a traditional stethoscope
- Adequate sampling to record high quality audio
- Sufficient battery life, power management features
- Adequate auscultation audio response (15-1500Hz)
- Removable on board storage/means of transferring data to a computer for archiving/comparison
- Clear, low distortion audio amplification
- High/low frequency filtering
- Bluetooth interface for seamless data transfer
- Small liquid crystal display for a control/status interface
- Software to facilitate the transmission and retrieval of recorded signals
- Software on the display device that allows for display and transmission of auscultation data

2. System Design

Figure 1 shows a functional block diagram of the designed system. The device uses a codec and a controller to sample and process data. It is possible to do away with the codec by having the controller perform both data sampling and processing. However, using the codec improves the audio quality and system performance.

Figure 2 shows an image of the development kit and Codec/SD board used. The codec is soldered onto a pluggable mini board and bread boarded to ensure functionality. The basic control is verified using the bread board and an analog audio board is soldered together on one of the prototyping break out boards that came with the Explorer 16 development board [2]. The codec control interface is switched from an SPI to an I2C interface and code is written for digital filtering and recording. A micro SD card interface is added to facilitate recording. The recording subsystem is developed using a free SD/MMC card C library from Microchip. The SD card interface employed in the designed system can be replaced with a flash IC for temporary storage if wireless or USB is the primary transmission method.

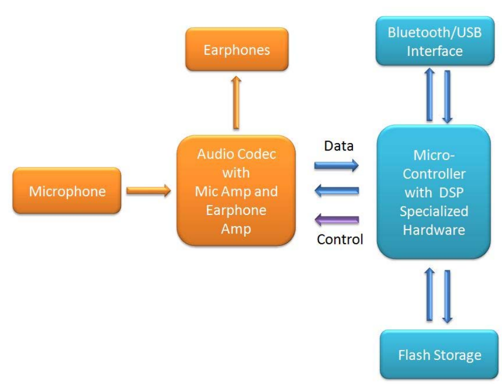

Figure 1: A functional block diagram of the designed system.

Figure 2: The electronic stethoscope development board using a 100pin dsPic33F, a Texas Instruments codec.

The microphone is an important component of any electronic stethoscope. Various types of microphones have been tested including 3 types of condenser mics, different size piezoelectric discs, converted mechanical speakers, and piezoelectric vibration strips. The results yielded the following conclusions. A piezoelectric disc (contact microphone) would be an ideal choice if implemented properly due to its excellent low frequency response and low cost ($1). Piezoelectric material deforms due to the pressure of sound waves, the material can be enclosed in a cavity to accurately capture the audio signals originating in the body. A condenser microphone, however, can produce higher inherent gain and can be easily interfaced with a codec.

A pre-amplifier circuit has been designed for a piezoelectric contact microphone and the prototyping daughter board is built to accept either the condenser or contact varieties. Figure 3 shows how the two main microphone candidates are mounted in the prototype stethoscope heads.

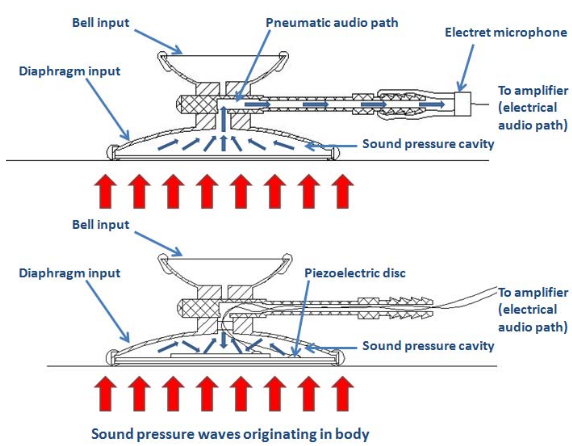

Figure 3: Condenser and piezoelectric disc mounting in preliminary microphone tests.

After validating all of the basic functionalities on the development board a first revision of the prototype board is designed. The most major change between the two boards is that the prototype uses a different microcontroller. A tiny device, dsPic33FJ128GP804 [3], in the dsPic33f line is chosen; the GP804 has only 44 pins versus the GP710 has 100. GP804 also has half the RAM of the GP710 at 16kB, and half the program memory at 128kB, which are sufficient for the implemented digital stethoscope code.

The GP804 has many functions that are useful for tailoring the device to specific applications. It has remappable peripherals, which means that the hardware for a serial port, or a UART port, or the DCI port are all present internally, but there are not enough pins to use all of the different ports at once. Only the ports that are needed are mapped to certain pins; such a design makes the board layout more efficient. There are some ports, however, such as the I2C port that cannot be remapped, but it is a useful feature nonetheless. Another helpful feature is the addition of internal weak pull up resistors, which can eliminate external pull ups and save board space.

Using the development board on the prototype, there would have been an 8MHz crystal for the Pic core, a 32.768kHz crystal for the RTC, and a 12MHz crystal on the codec. Using all three crystals would have been an inefficient use of board space and is not desirable when low cost is one of the design goals. The solution is to have the 12MHz crystal clock the codec, and the dsPic is clocked off of a clock output pin on the codec. The 32.768kHz RTC clock is connected to the dsPic for normal time keeping operations. Using this configuration, the dsPic would only be clocked at 6Mhz to achieve a 16Khz sampling rate, the registers inside the codec have to be set to a sampling rate of 32kHz and another register has to be set to clock the codec at MCLK/2. Operating at 16kHz gave excellent sound quality and the data could still be written to the SD buffer continuously. This configuration creates one design condition that must be addressed when writing the firmware: Before the device cuts power to the codec to enter standby mode, the main dsPic clock must be switched to the secondary RTC clock, and then switched back once the codec is powered back up upon resume.

Next, a LCD needed to be selected. A small 3.3V LCD from a major supplier cost $8.50 per unit; the same LCD in the 5V variety cost only $2 per unit. A prototype has been designed with both 3.3V and 5V power systems to facilitate the adoption of a low cost LCD independent of the operating voltage. However, the cost savings is not significant once the cost of a boost converter and support electronics are factored in. Also, extra PCB space is needed for the more complicated design. Hence the preferred design uses a 3.3V LCD.

The current prototype uses two 3.3V regulators, a 400mAH lithium polymer battery, and a lithium polymer charge controller. A FET is connected to the LCD power line and a dsPic control line to ensure the LCD can be powered off during low power/standby modes. Noise reduction is the single greatest challenge in this project. A large signal to noise ratio can be achieved by using a regulator for each of the digital subsystem and analog subsystem, as well as taking special consideration into the placement of ground planes. A beneficial result of this configuration is that the analog subsystem can be switched off due to a power enable line running from the dsPic to the analog regulator. A mini USB connector is added to facilitate 5V charging and a possible serial to USB IC.

The V0.3 prototype includes the addition of a Bluetooth module using the Bluetooth Serial Port Profile (SPP). The module is connected to a UART port on the dsPic and a control line to a FET can enable/disable power to it. A cost of $17 for the module vs. about $4 for a UART to USB transceiver IC would likely make a basic production model use a USB interface, as the user would be using this device in front of a computer during transfer operations. Also, the cost of Bluetooth functionality can be decreased by using monolithic manufacturing techniques, as most Bluetooth ICs use small BGA packages; this would allow the ICs to be placed directly on the board and a pre-built module would not be needed. Nevertheless, the current prototype has a range of 10-15ft and audio is down sampled before transmission to 4kHz due to a transfer limitation of the Bluetooth SPP of 128kbps. A Bluetooth module using an audio profile is being investigated.

The PCB design and hardware layout presented further engineering challenges. Originally, the board outline started as a 2” diameter circle. It was soon clear that it would be difficult to mount buttons in a way that would be ergonomic. It was then decided to widen the circle and protrude the bottom to gain board space and accommodate the buttons. The placement of the LCD was simple; it could only be in one place, on the top of the unit towards the front. Yet another point of consideration was how the board would sit on top of the stethoscope head. The diaphragm input of the stethoscope was to be cut off and used with a microphone mounted in/on it. The V0.2 iteration was designed to mount an electret condenser microphone directly on top of the head. This could only be kept compact if a hole was in the center of the PCB for the bulk of the microphone to protrude through. The latest design (V0.3) uses a contact microphone, so the hole in the board was removed to recover board space.

Due to the addition of the Bluetooth module, a microstrip is added on the PCB to connect the RF output of the module to a chip antenna. A 50Ω strip is added to the lower right are of the board. Figures 4 and 5 show the Gerber file layouts for V0.2 and V0.3 prototypes, respectively.

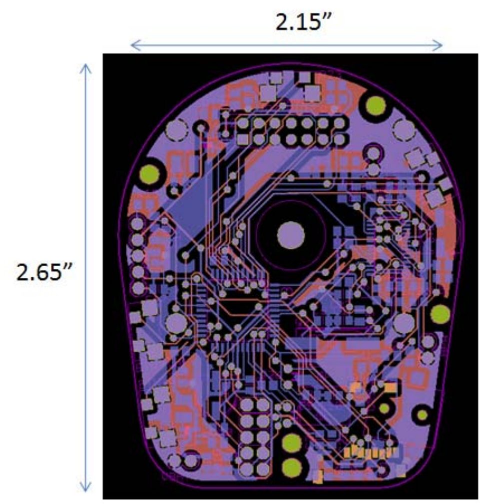

Figure 4: Electronic stethoscope PCB layout, V0.2

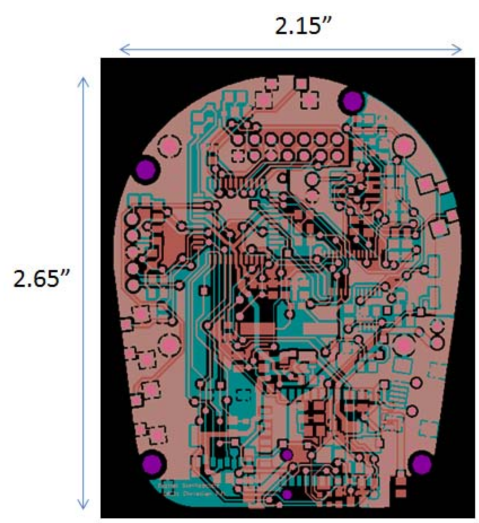

Figure 5: Electronic stethoscope PCB layout, V0.3

A PCB casing/housing for the unit with tubing and headsets resembling a mechanical stethoscope is yet to be designed. For auscultation validation purposes, any set of headphones may be plugged into the unit. The Evaldi earphones, made by Molex are recommended due to their low prices and good quality. Figure 6 shows a functional cross section of microphone mounting, figure 7 shows a functional layout of the stethoscope, and figure 8 shows various images of the project hardware.

Lastly, the firmware is written to take advantage of the power saving features of the dsPic including clock and frequency switching. The implemented digital filter comprises of a common 64 tap finite impulse response filter and a filter bank.

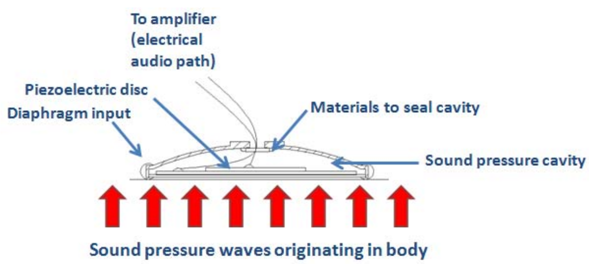

Figure 6: Functional microphone mounting on modified stethoscope head used in V0.3 prototype.

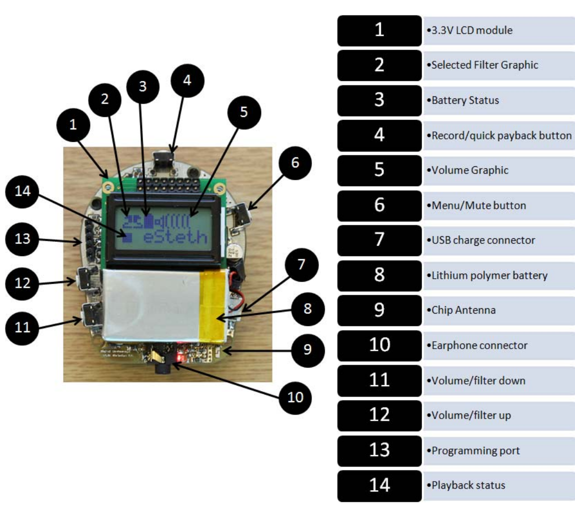

Figure 7: Functional layout of the electronic stethoscope layout V0.3.

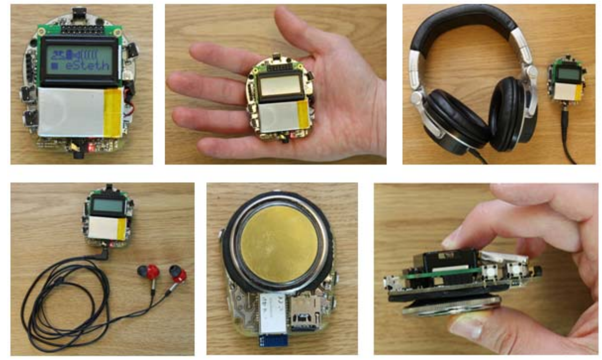

Figure 8: Various images showing the UVic digital stethoscope V0.3.

3. Sample Outputs

Figure 9 shows a magnitude vs. frequency plot of the behavior of the audio electronics with different digital filters selected. Figure 10 depicts a typical output obtained by this electronic stethoscope. This stethoscope can produce excellent sound quality, with a signal to noise ratio of 84dB and a maximum gain of 80, and has recording, playback and Bluetooth capability. Work is being done to include a software interface for data archiving and processing. We have demonstrated the feasibility for manufacturing a feature rich, yet low cost digital stethoscope. We believe devices such as this will play a crucial role in tomorrow's telemedicine industry.

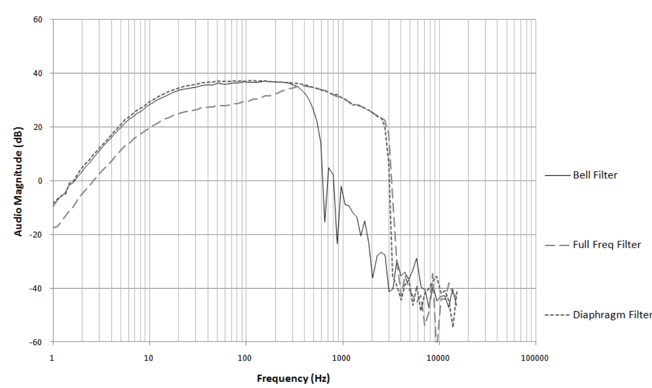

Figure 9: Measured frequency response of audio circuitry and digital filtering of stethoscope (excluding transducer).

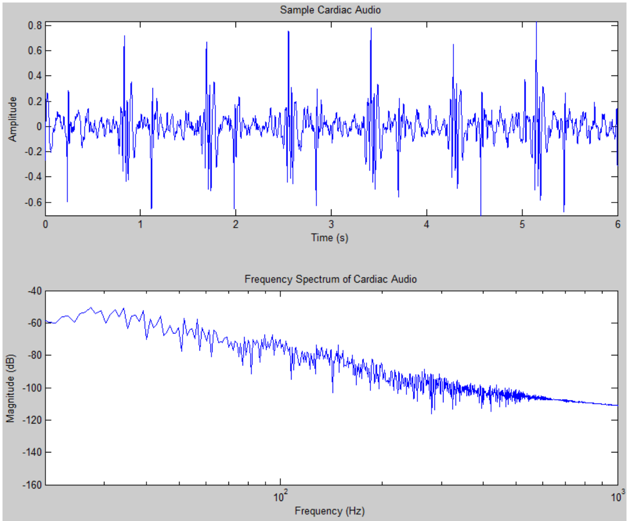

Figure 10: Sample cardiac audio from the third intercostal space, left sternal boarder.

4. Conclusion

The design and implementation of a low cost digital stethoscope has been presented. This stethoscope can produce excellent sound quality and has recording, playback, and Bluetooth capability. There is still much room for further development. A software interface for reviewing and transmitting auscultation data, a USB connection, and an improved transducer assembly are some of the features to be implemented. A feature rich low cost electronic stethoscope could play an important role in the future of telemedicine.

5. References

[1] C. McMechan, P.P.M. So, K.F. Li, G. Jasechko, and M. Poulin, "Electronic Stethoscope for Ehealth and Telemedicine", 33rd Conference of the Canadian Medical and Biological Engineering Society, June 15–18, 2010.

[2] "Explorer 16 Development Board User's Guide," Oct, 2005. [Online]. Available: http://ww1.microchip.com/downloads/en/DeviceDoc/Explorer%2016%20User%20Guide%2051589a.pdf. [Accessed: Sept 3rd, 2010].

[3] "dsPIC33FJ32GP302/304, dsPIC33FJ64GPX02/X04, and dsPIC33FJ128GPX02/X04 Data Sheet," March 2009. [Online]. Available: http://ww1.microchip.com/downloads/en/DeviceDoc/70292D.pdf. [Accessed: Sept 3rd, 2010]