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Development of a tele-stethoscope and its application in pediatric cardiology

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Over the years, many attempts have been made to develop special stethoscopes for the teaching of auscultation. The objective of this article is to report on the experience with the development and implementation of an electronic stethoscope and a virtual library of cardiac sounds. There were four stages to this project: (1) the building of the prototype to acquire, filter and amplify the cardiac sounds, (2) the development of a software program to record, reproduce and visualize them, (3) the testing of the prototype in a clinical scenario, and (4) the development of an internet site, to store and display the sounds collected. The first two stages are now complete. The prototype underwent an initial evaluation in a clinical scenario within the Unit and during virtual out-patient clinical sessions. One hundred auscultations were recorded during these tests. They were reviewed and discussed on-line by a panel of experience cardiologists during the sessions. Although the sounds were considered "satisfactory" for diagnostic purposes by the cardiology team, they identified some qualitative differences in the electronic recorded auscultations, such as a higher pitch of the recorded sounds. Prospective clinical studies are now being conducted to further evaluate the interference of the electronic device in the physicians´ capability to diagnose different cardiac conditions. An internet site (www.caduceusvirtual.com.br/ auscultaped) was developed to host these cardiac auscultations. It is set as a library of cardiac sounds, catalogued by pathologies and already contains examples from auscultations of the majority of common congenital heart lesions, such as septal defects and valvar lesions.

Keywords: Electronic stethoscope, Telemedicine

Hippocrates (460-370 B.C.), in his reports, addressed the fact that the heart produces sounds and murmurs; but it was only in the beginning of the 19th century that the French doctor René Théophile Hyacinthe invented a device that, later, would become one of the most important symbols of medicine: the stethoscope. In 1816, Doctor Laennec was called to attend on a female patient with symptoms suggesting a cardiac problem. She was young and obese. Her husband considered direct auscultation inadmissible. Dr. Laennec, recalling the acoustic properties of the materials, took some sheets of paper, rolled them up tightly and placed one end to the patient's chest and the other to his ear. He then realized that, with this technique, he could hear the cardiac sounds in a much clearer way than from direct auscultation. In 1819, Dr. Laennec published his results in his "*Traité de L'Auscultation Médiate*"[1].

Since those days stethoscopes have been used as part of the initial evaluation of all patients suspected of heart or lung problems, and indeed, an experienced physician can diagnose a large number of clinical conditions just from the initial auscultation of the patient's chest. It is also the first clinical tool that a medical student must master, prior to displaying it around his neck, as a symbol of his/her profession.

Auscultation of the heart sounds, however, is not considered an easy task. That is particularly so in certain clinical scenarios, such as the paediatric population. This is due to a number of reasons. The heart sounds are of low frequency and the timing between events is short. The high cardiac rates, respiratory movements and constant moving of a small child only add to the difficulty of this examination[2-4].

Over the years, many attempts have been made to develop devices for the teaching of auscultation. Phono-mechanocardiograms were large and costly machines that graphically displayed the cardiac sounds and impulses[5-8]. They were fairly popular tools for the teaching of cardiology and also used for diagnostic purposes until a few decades ago when they were surpassed by other non-invasive diagnostic techniques, such as Doppler echocardiography[9-12].

Attempts to develop special stethoscopes have also been common since the 1960´s[13-15]. Some devices allow for groups of people to hear the cardiac sounds

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simultaneously. They do, however, have the disadvantage of requiring the plugging of many tubes to a single machine that disperses and makes the sound less intense[16]. In contrast electronic stethoscopes, since 80's, had some extra functionality in relation to the common acoustic stethoscopes such as various degrees of amplification and analogic filters[17-19]. However, these functionalities also had some problems, such as distortion or attenuation of certain sound frequencies[20].

The objective of this article is to report on the experience with the development and implementation of an electronic stethoscope and a virtual library of cardiac sounds.

Materials and Methods

There were four stages to this project: (1) the building of the prototype to acquire, filter and amplify the cardiac sounds, (2) the development of a software program to record, reproduce and visualize them, (3) the testing of the prototype in a clinical scenario, and (4) the development of an internet site, to store and display the sounds collected.

Construction of the prototype—For the construction of the prototype, a device similar to a diaphragm of an acoustic stethoscope was developed using a commercial membrane and an acoustic chamber to enclose and filter the acquired sound. The acoustic chamber was made in stainless steel as shown in Fig. 1. Inside the acoustic chamber an electronic microphone was inserted. After being acquired by the diaphragm these sounds were applied to an amplifier and filtered to limit their frequencies at around 1.085 Hz, which attenuates the high frequencies external noises, without losing the spectral range in which the heart sounds are situated. The circuit was tested in the CircuitMaker[21] software. The prototype is powered by common AA batteries and has low consumption. The output from this system was plugged into a soundcard device (Fig. 2) with maximum sample rate of 44.100Hz and 16 bits of resolution in a microcomputer IBM-PC with

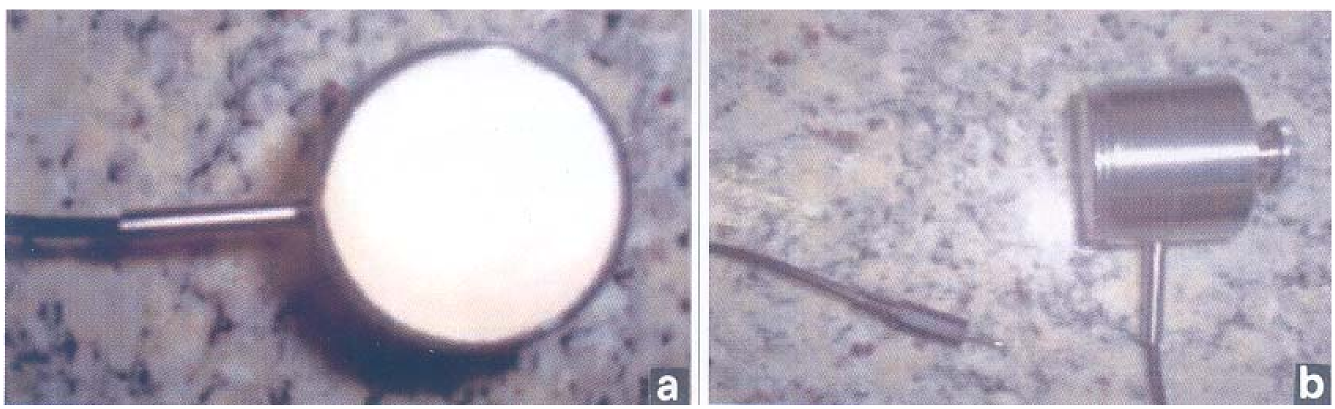

Fig. 1—The acoustic chamber (a) front view, (b) side view

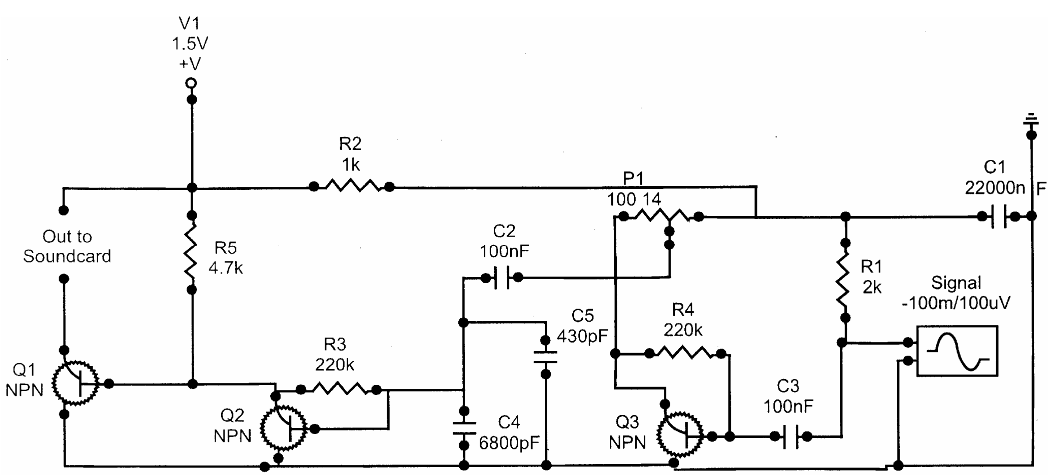

Fig. 2—Electronic diagram of the Amplifier/Filter

Windows XP, but any Windows version above 95 could support the system. Figure 3 shows various parts of the system, schematically.

Development of a software program—A software program was developed to capture and reproduce the sounds. It was written in the C++ language, since this language is widely used in the PC platforms, palmtops, pocket PCs and can be embedded in DSP devices. Besides being extremely fast, C++ allows the OOP modularization, and that makes the software easier to port to different devices. As a development tool, the Borland C++ Builder was used, since it provides a fast graphical development, incorporates a robust compiler and allows for the use of the Microsoft Foundation Classes. Figure 4 shows a sound wave in real time, as the sound is being captured or reproduced. The *OpenGL* [22] library was used, since it is hardware implemented and widely accepted. As the most basic sound codification, the *Pulse Code Modulation* (PCM) was adopted. To obtain an image similar to a phonocardiogram it is necessary to apply digital audio filters and this could not be done online at this initial stage. For that, the program SoundForge from Sony was used with a low-frequency filter fixed in 100 Hz, which is the frequency commonly used by professionals of phonocardiograms for graphical recording of the heart sounds. The UML diagram with the Main classes of

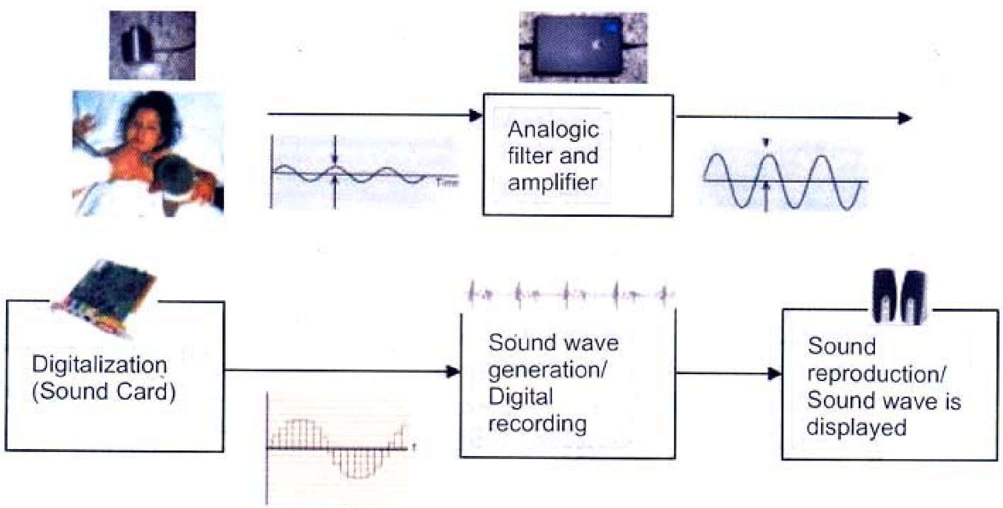

Fig. 3—Block diagram of the prototype's hardware and software

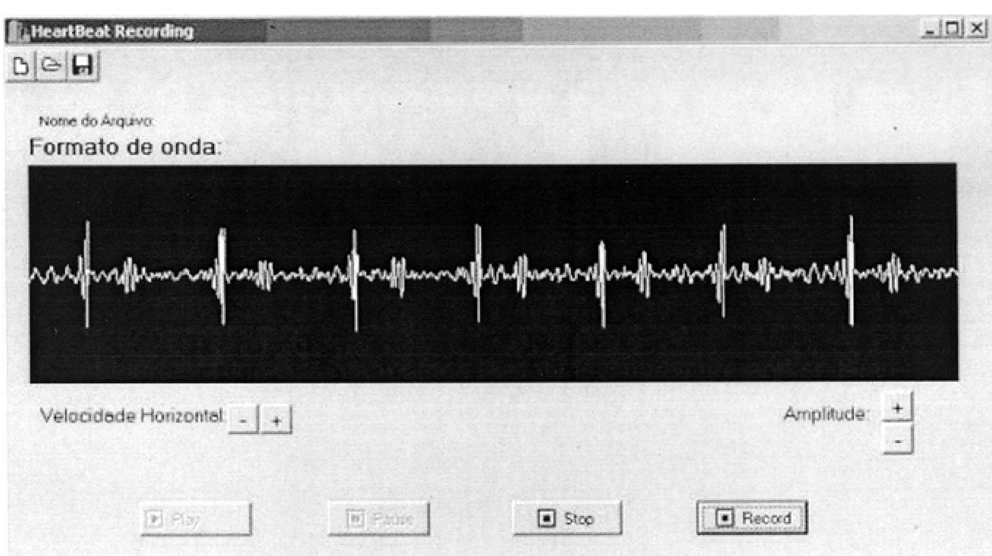

Fig. 4—Software screen with the graphics of a sound

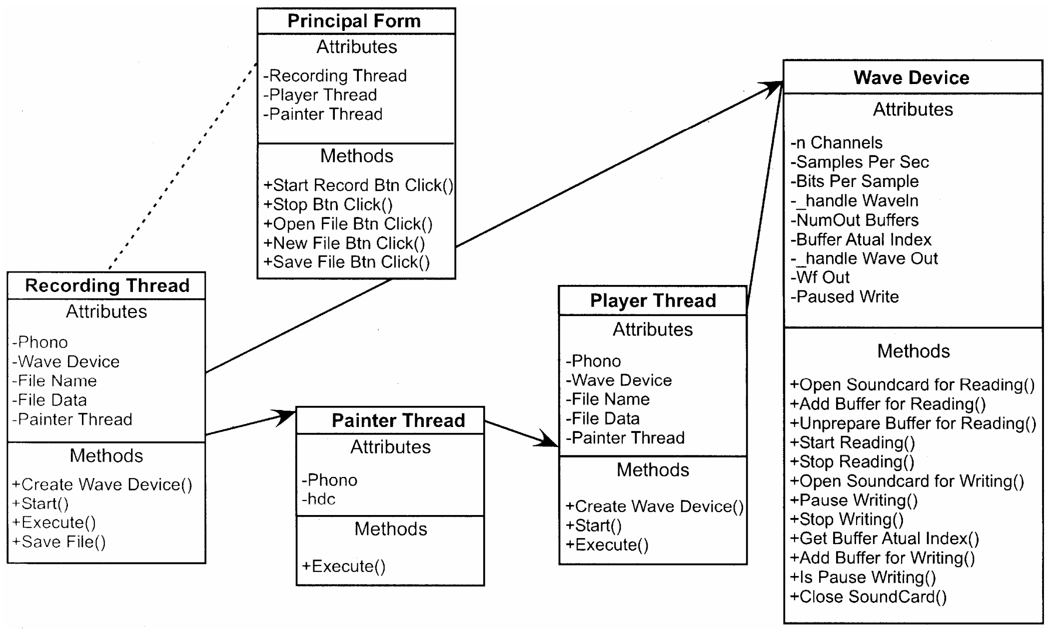

Fig. 5—UML diagram of the software's main classes

the program's structure is shown in Fig. 5. The class "PrincipalForm" is the class that has the graphical interface and manages the program behavior. The program sets a desired file name that captures the sound and display the sound waveform. There are some graphical adjustments that need to be done, such as: amplitude, vertical size, velocity and the horizontal spacing of the sound wave. Another use of the program is to play a previously captured sound and display its wave form as it is displayed.

Testing of the prototype—After assembling the prototype, it was tested in three different clinical scenarios within our Unit, and between the Unit and in two virtual out-patient clinics established with a public maternity hospital in our State, and a pediatric out-patient clinic in the neighbouring State of Paraíba. In all three locations, the infrastructure of a microcomputer IBM-PC with a soundcard was provided to plug into the tele-stethoscope. Figure 6 demonstrates schematically, the settings in which the tele-stethoscope has been used.

These two out-patient clinics are part of a partnership program with the Heart Circle of Pernambuco, a non-governmental organization that helps poor children with heart conditions in this part of the world. Patients attending one of the three places had their routine physical examination performed and then had their cardiac sounds recorded with the tele-stethoscope. During the out-patient clinic sessions, the

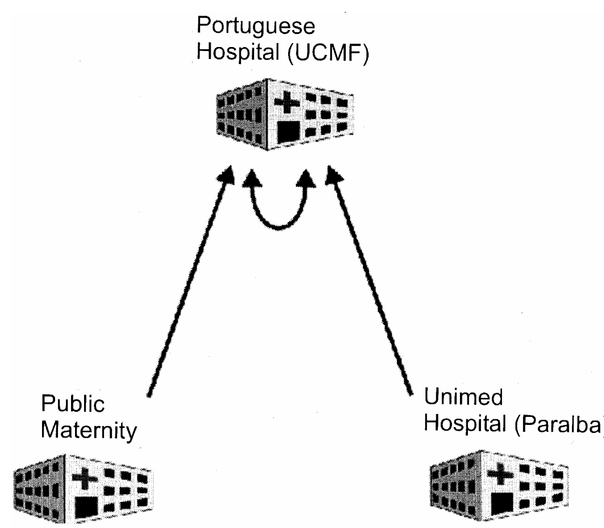

Fig. 6—Block diagram interlinking various centers for tele-stethoscope.

sounds were transmitted online through the internet for remote evaluation from the expert consultants by using the software skype[23]. One hundred auscultations were recorded during these tests, including all of the most common congenital heart lesions. They were reviewed and discussed on-line by a panel of experience cardiologists during the sessions. Although the sounds were considered "satisfactory" by the medical team for diagnostic purposes, they identified some qualitative differences in the electronically recorded auscultations, such as a higher pitch of the recorded sounds. Prospective clinical studies are now being conducted to further evaluate the interference of the electronic device in the physicians´ capability to diagnose different cardiac conditions.

Development of the homepage—The collected materials were catalogued and made available in the internet though the construction of a homepage which was linked to our academic page www.caduceusvirtual.com.br/auscultaped. This page has been developed using common web technologies such as javascript and HTML. It was supplied with information about the most common paediatric cardiac conditions and the sounds samples. The sounds are stored and downloaded on request. There is also an option to download the stethoscope's software so that the user can see the waveform of the sound as he/she hears it. The page is being constantly updated with new auscutations as new data is being acquired with the use of the tele-stethoscope in new clinical research projects.

Results

During the last two years, the tele-stethoscope was tried in different clinical scenarios and the initial data stored at a homepage in the internet. The system works with a microcomputer with multimedia, a commercial membrane that can mimick a phonocardiogram, through the use of a commercial software package, SoundForge from Sony with filters set at 100Hz. All other parts of the system, physical and logical, have been developed in our laboratory.

As a result of the tests, it was found that the best results were obtained as the hardware's low-pass filter was set to about 1.085 Hz. The final circuit of the amplifier was, at first, tested in the CircuitMaker software, where it was found that it has a sensitivity of 0.01mV/Pa in the input signal, higher sensitivity to the 5 mV/Pa of the transducer, in this case a microphone. The output voltage is about 1.3V. Common AA 1.5V batteries supply power to the circuit since it has a low consumption (13 mW).

For the capture, the adopted sample rate was 8.800 Hz. It was chosen in accordance with the range of sound's frequencies and the available soundcard sampling rates. There is an oversampling, allowing a further implementation of a digital filter. The 16 bits resolution was chosen because it best reproduces the auscultation.

The system's software allows for a real time feed-back on the quality of the capture sound. With the tele-stethoscope, we were able to record the cardiac sounds from hospitalized patients, from our own out-patient clinics and remote clinics at collaborative Institution of research partnership program.

Over 100 auscultations were performed to validate the prototype of the tele-stethoscope. These include the heart sounds from atrial septal defects, ventricular septal defects, atrioventricular septal defects, valvar lesions (pulmonary, aortic, tricuspid and mitral) and patent foramen ovale. In the initial usage of the tele-stethoscope in a clinical scenario, the quality of the auscultation was considered satisfactory in relation to the auscultation using acoustic stethoscopes. Some differences were perceived by the medical team with relation to the "pitch" of the tele-stetoscope but they did not seem to affect the physicians' ability to diagnose the heart condition. However prospective clinical studies are being conducted to further investigate its sensitivity and specificity in relation to conventional auscultation and other non-invasive methods to establish hemodynamics, such as echocardiography.

The Virtual Library of *Cardiac Auscultation (Biblioteca Virtual de Cardíaca)* homepage has been constructed and is available for assessment at www.caduceusvirtual.com.br/ausculta. It contains auscutations with their graphic displays from different pathologies of children, such as septal defect and valvar lesions. A brief explanation of the more common cardiac conditions is also available.

Discussion

The reliability of telemedicine examinations has been under scrutiny since the 1990´s and most studies show that it is a safe and low cost technology that adds to the appropriate management of patients. Its potentialities are far from being explored. In cardiology, the search for a monitoring device that could send information on a patient's clinical condition has long been sought. The idea of an integrated bio-monitor, that could intelligently acquire cardiac sounds, process these through a neural network and generate the diagnosis, has been proposed.

The auscultation or recording of the cardiac sounds is an important part of any telemedical application in cardiology. Various authors have addressed the importance of developing accurate systems to extract the cardiac sounds from the environment noises. Hahn[24] discusses these limitations and appeals to biomedical circuit designers to learn more about the acoustics of commonly used stethoscopes and to develop an appropriate group of circuits which would emulate them much like music synthesizers which can emulate almost any musical instrument.

We have developed an electronic tele-stethoscope, composed of software and hardware components for the windows platform, which, through a man-machine interface allows for its easy use. The system is low cost in relation to similar ones in the market and can be used both for long distance diagnosis and for the teaching of cardiology in teaching rounds or pediatric out-patient clinics. It could potentially be integrated to a monitoring device for home care usage.

The tele-stethoscope does not require a soundproof room which can be of value to the acquisition of the sounds data in different clinical settings. It also provides audio and graphic displays, like a phonocardiogram, which can be very helpful when interpreting the auscultatory findings, especially with elevated heart rates, which is the case in infancy.

Besides the traditional resources of the stethoscope, the project also permits the remote transmission of data on-line and off-line, via internet or telephone, for telemedicine services such as remote examination and second opinion to be performed within this easy and low cost setup.

The lack of specialized equipment and cardiac professionals in many areas of developing countries, such as Brazil, can be minimized with the adoption of solutions, such as this one. By improving the diagnostic abilities of an out-patient, non-specialized clinic, one could potentially reduce costs with transportation of patients from distant centres, thus bringing less discomfort to this population who often travel long hours under very difficult conditions.

Through a partnership program with the Heart Circle of Pernambuco, the prototype was used experimentally in a pediatric out-patient clinic set in João Pessoa, the capital city of the neighbour state of Paraíba, from where we often receive children to undergo cardiac surgery. Since the establishment of this virtual out-patient clinic, we have been "examining" the children on line in collaboration with local pediatricians, and this approach has helped their local management and reduced the number of visits to our Institution. A similar experience with a local public maternity which used to refer their neonates for second opinion was experienced. Their referral numbers have also been reduced since the establishment of the virtual out-patient clinics. Although the tele-stethoscope is not the only device used in these clinics, as we discuss the cases and review also eletrocardiograms, chest X rays and echocardiograms, the physicians involved in the clinics have also reported that "listening" to the patients' hearts at a distance has been an important part of the sessions, both for the diagnosis of the patient as well as for the teaching of their pediatric colleagues.

The initial results from the use of the tele-stethoscope have been satisfactory and encouraging. However, larger experiments are required to establish the system sensitivity and specificity for the diagnosis of congenital and acquired heart diseases in childhood.

The home page of the Library of Cardiac Auscultation is another important aspect of this project. It has been developed and is being constantly updated to provide pediatricians and medical students with a variety of examples of different cardiac sounds. A prospective study to assess the users' satisfaction with the information is also being conducted and may guide us to adjust its form and content to the best benefit those interested in learning pediatric auscultation.

Acknowledgement

We acknowledge the participation of the majority of cardiologists from our Unit in the use of the tele-stethoscope's prototype.

Dedication

To Prof. Fernando Rocha Carvalho (in memorium), great master of Cardiology and phonomechano-cardiography from the Federal University of Pernambuco, our teacher and mentor who inspired the development of this Project, which we kindly nicknamed "the little rock".

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