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A portable graphical representation tool for phonocardiograms

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Abstract— **This paper describes a prototype software application to display graphical and editable representations of patient data for use in electronic medical records (EMRs). The application dynamically generates graphics of cardiac and other patient data, and displays or saves them both in graphic and in text formats. The presentation of heart and other data in a consistent, clinically familiar, graphical format is designed to reduce the time necessary for anyone to review and understand this important information. Results of preliminary testing on actual case data are encouraging.**

I. INTRODUCTION

Our primary goals are to design an interface that provides a familiar and intuitive visualization of heart auscultation data, and design applications for input, output, and storage of that data. The system should accept several input formats, and produce clinically useful output including a snapshot of the entire cardiac examination graphically and in text formats.

Heart murmurs are very commonly detected in infants and children, with some estimates being well over 75%[1]. Very few of these children, less than 1%, are born with congenital heart disease. Heart auscultation, the interpretation of heart sounds by a physician, can determine which children require a formal cardiac evaluation. While both innocent and disease-produced heart sounds/murmurs can be accurately differentiated 90-95% of the time by pediatric cardiologists during a physical exam alone, research has demonstrated poor auscultation skills among general practitioners[2], [3]. We aim to create an application that can dynamically generate representations of this data in formats useful for cardiologists as well as primary care providers. The application should be portable so that it can be readily integrated into existing electronic medical records (EMRs).

Heart sound recordings or Phonocardiograms (PCGs) have been acquired and analyzed for decades[4], [5], [6], [7], [8], [9]. However, the incorporation of PCG data into EMRs is still not routine as it is for other data, for example EKGs. This paper describes physician-friendly graphical and text formats for PCG results that can be saved in an EMR along with the signals themselves. Expert cardiologists can describe and easily save their interpretation in a structured text/graphical format. These descriptions are useful for immediate clinical review of cases, are readily available to primary care workers and other experts without needing to interpret the sounds themselves, and can be a target format for the results of signal processing programs.

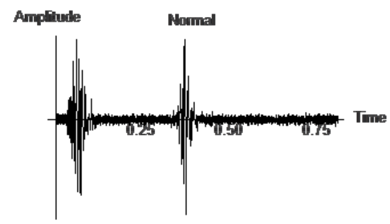

Fig. 1. The signal from a normal heart over one cycle. The peaks show the first and second heart sounds, respectively.

The rest of this paper is organized as follows. The next section provides background on the problem, the data acquired via heart auscultation. The next section describes the design and implementation of our system. The fourth section presents results, which are followed by a summary and future work sections.

II. BACKGROUND

Correctly interpreting raw, unprocessed images of PCG signals, such as shown in Figure 1 is difficult if not impossible for primary health care providers. These signals are too messy and complex to interpret while at the same time lacking key visual evidence of elements such as the splitting of second heart sound. The raw signal does not highlight the characteristics of the sound audible to humans, such as an amplification of higher pitched sounds compared to low pitched sounds.

Some expert cardiologists learn to interpret these images[4], [10] while others prefer to listen to the sounds themselves[11]. Patients are in one of several positions for cardiac auscultation, include sitting, lying down (supine) and left lateral recumbent. Four locations on the chest are routinely examined by auscultation and are shown as four large circles in Figure 2.

The *cardiac cycle* refers to the events related to the flow of blood that occurs from the beginning of one heartbeat to the beginning of the next [12]. Every 'beat' of the heart involves three major stages: atrial contraction (systole), ventricular systole and complete cardiac contraction (diastole).

Four classes of sound components may be audible in each heart cycle. The primary components are called heart sounds 1, 2, 3 and 4, abbreviated S_1, S_2, S_3, and S_4. These sounds are of short duration. S_1 and S_2 are heard in normal patients. S_1 is associated with the closing of the

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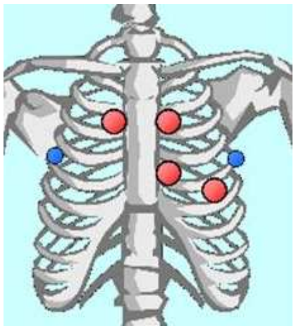

Fig. 2. The four sites commonly used for auscultation. From left to right and top to bottom in the figure, Aortic, Pulmonic, Left lateral sternal border, and Apex.

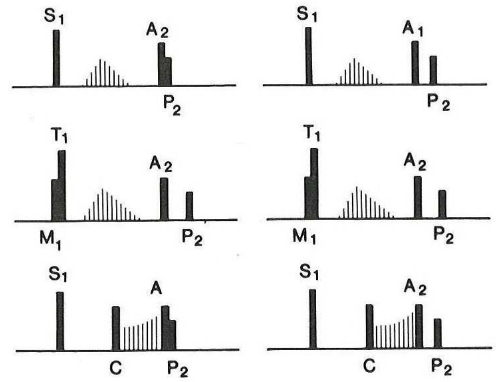

Fig. 3. Examples of heart sounds and murmurs from the American Medical Association[12]. Expiration is shown on the left. From top to bottom, an innocent murmur, Atrial Septal Defect, and Mitral Valve Prolapse.

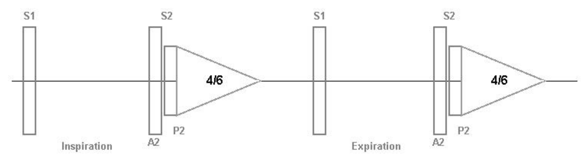

Fig. 4. A graphical represention of a grade 4/6 early diastolic murmur. Also shown are the first and second heart sounds, including both components of the second sound.

Mitral and Tricuspid valves and marks the onset of systole. The aortic and pulmonic valves create S_2, which marks the end of systole. The first of two tall peaks in Figures 1 and 3 indicate S_1 while the second peaks represents S_2. The individual components of S_2 are called A_2 and P_2, for the Aortic and Pulmonic valve components, respectively. If the separation between the components of S_2 is audible, the sound is called *split* or *splitting*. In a normal patient, the width of the split increases during inspiration, and during expiration it is audible as only a single sound to the human ear. S_3 is due to rapid ventricular filling during early diastole. Its presence is most often abnormal. S_4 is due to late diastolic filling following atrial contraction and is always abnormal.

The second most common class of sounds is murmurs, which have a longer duration than the sounds. Some are present in systole (between S_1 and S_2), some during diastole (between S_2 and the following S_1), and some can be heard throughout the cardiac cycle (called continuous).

Clicks and snaps are the remaining classes of sounds that may be audible. Snaps are rare, however clicks may be present in 2-3% of the population.

Medical students are taught that heartsounds contain distinct elements, which simplifies the diagnostic process. The American Heart Association uses a simpler graphical representation of heart sounds, including changes produced during inspiration and expiration, as shown in Figure 3 [12]. These images are markedly different from a raw signal, as shown in Figure 1. Note that the AHA graphic shows only the half of the signal above the X axis.

Heart sounds S_1, S_2, S_3 and S_4 are represented with vertical bars and the intensity or loudness of the sounds is represented by the height of the bars. The width between S_1 and S_2 indicates the relative time between S_1 and S_2. Murmurs are represented by diamond or rectangular shapes.

An example of our graphical representation, shown in Figure 4, displays both the parts above and below the center axis, as they appear in the raw signal. This user interface is designed to provide a familiar and intuitive visualization of heart sounds and murmurs for cardiologist and primary care physicians.

Related work on graphical representations of heart sounds has been published by Modegi [13] and Tovar-Corona et al. [14], [15]. Modegi uses a graphical MIDI (music) representation of heart sounds that contains different sized triangles and is closer in complexity to the raw signal (Figure 1) than the AHA examples in Figure 3. Tovar-Corona et al. use time-frequency representations of heart sounds. These contain ovals and swirls and are similar in appearance to elevation lines in topographical maps. Neither of these representations is MD friendly.

Anonymous data was obtained from the Pacific Asynchronous Telehealth/Global Electronic Children's Hospital (PATH/GECHO) system. The data includes patient histories, routine test and physical exam data, high-quality digital PCGs, and echocardiographic data. The data was collected on a Data Collection Form approved by the IRBs (Institutional Review Board for the Protection of Human Subjects) of the hospital and the university. The data was entered into an Excel spreadsheet with approximately 100 columns of data for each patient visit.

III. System Design and Implementation

We used a PC running Windows XP with Java version 1.5. Java was chosen as the implementation language for the Graphical User Interface (GUI) due to its portability across platforms and the ease of integration with other code. The system contains three large sections: input, data processing and output.

We used the *loosely coupled* software engineering model to design the classes. As a result, each class runs in a separate process and can communicate and interact effectively with other modules at runtime. The loosely coupled model greatly improved the flexibility of our system. The GUI interface was

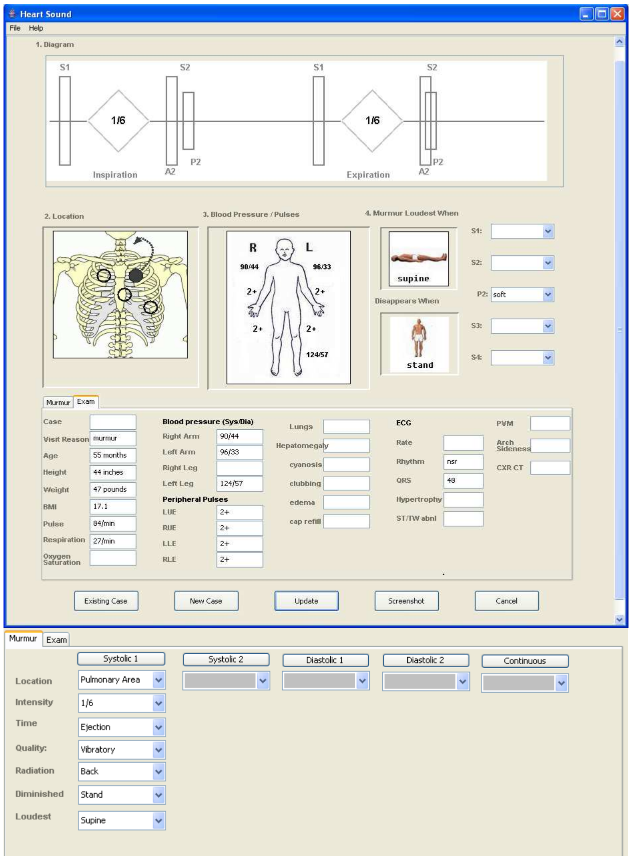

Fig. 5. Top: An image of the full-screen display of a patient's data with the exam tab information displayed. Bottom: the text that appears if the Murmur tab is selected.

implemented using the Java Swing library and the images were created based on the Java 2D API. The system was first built in the Jbuilder IDE and later developed and tested in the Eclipse IDE. Next we describe the data processing in the system.

Data processing occurs in five modules: File Format Conversion, XML (extensible markup language) parsing, Murmur Type Classification, Image Creation and EMR Output Generation. The common internal data representation format of the system is XML, meaning that all data is converted into this format. A user may enter information by changing the text fields shown in Figure 5 or read in data from a text file in XML or Lisp format. The Parser Module then parses and stores the data for use in other modules.

The Murmur Type Classifier Module determines the type of murmur (systolic, diastolic or continuous) and its characteristics, such as intensity, radiation, quality, etc. The murmur data then goes to the Image Creation Module, which determines the shape of the images created.

Finally, all the data is used to generate an EMR output format. Three output formats are currently supported: XML, Lisp, and JPEG. Since the internal representation data format is XML, an XML file is generated and saved for each case.

Figure 5 contains the images created by our system for one visit of a patient. The upper 75% of the figure contains two rows of graphics and one row of columns of text. Selecting the Murmur or Exam *tab* (shown just below the chest figure), determines what data is displayed in the bottom third of the screen. When the Exam tab is selected, the patient's height, weight and other exam data is displayed (shown in the third row of the figure). When the Murmur tab is selected, details of the auscultation data replacie the exam information. The data on the murmur tab for this patient is shown in the bottom quarter (row of columns) in Figure 5.

An example of the information available about heart sounds and murmurs is shown next, in structured text format (Lisp).

```
(heart
  (s2
    (p2 soft))
  (systolic_murmur
    (location
      (aortic_area
        (heard_best under_right_clavicle)))
    (loudness 4)
    (time regurgitant)
    (quality harsh)
    (radiation carotids)
    (disappears_when no_difference)
    (loudest_when no_difference)))
```

The graphical user interface (GUI) performs both input and output functions. It accepts data from a user as well as creates and displays images to describe the data. The display is similar to those used in medical textbooks such as [16], [17], [18]. Using the GUI, users are able to

1) select from a menu and read in an existing case file with case data.
2) create, enter and edit information in a case.
3) display patient data in text and graphical formats.
4) change the display colors of murmurs and heart sounds in the murmur image.
5) print a screen-shot of the current case data.
6) save the data to a file or files such that it may be read in to the system at a later time.

IV. Results

Our system creates three large images of auscultation data, as shown in the top two rows of Figure 5. The top image shows the timing of S_1 to S_4, murmurs, clicks and snaps within the cardiac cycle during both inspiration (on the left) and expiration (on the right). A chest image showing the position and radiation of any murmurs appears in the second row as well as image of the outline of a body with blood pressure and pulse data displayed. To the right of these images in the second row are two small images created to indicate if the position of the patient (standing or lying down) increases or decreases the volume of the murmur, respectively. An image representing *no difference* is used for cases where position does not affect the murmur's volume.

Creating the image of timing characteristics of heart sounds and murmurs uses information in the structured text (Lisp or XML) format as shown above. Multiple murmurs, if present, are each drawn in the same image.

The second image generation class creates the figure of a chest that appears on the left in the second line of Figure 5. In addition to the four auscultation site locations mentioned earlier, this image marks the site on the chest where the

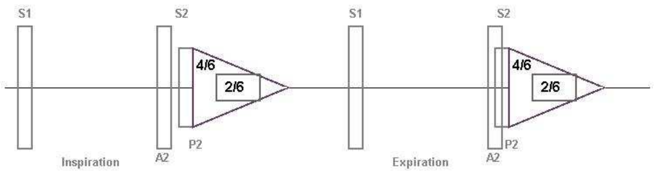

Fig. 6. A case with two diastolic murmurs. The large triangle represents a grade 4/6 early diastolic murmur that tapers off in volume. The inner rectangle represents a grade 2/6 mid-diastolic murmur. Heart sounds 1 and 2 are also shown.

heart murmur sounds the loudest as well as an arrow from there indicating the direction of murmur radiation, if any. The radiation areas are the axilla, back, or carotid arteries. This method uses the murmur loudest and radiation sections of the structured text description above.

The third image generated shows the blood pressure data around the outline of a body. Systolic and diastolic pressures for left and right arms and legs are displayed next to the corresponding appendage. Peripheral pulses are also displayed.

Green, et al.[19] developed and evaluated a method for recording veterinary heart murmur findings in SNOMED-CT. Our structured format contain the same semantic information they use as well as additional information about sounds and positions. We plan to create an additional translator to read and produce compatible SNOMED-CT descriptions in our system once a format is adopted. One particularly difficult part of representing auscultation results is that patients may have more than one murmur. For example, two systolic murmurs, two diastolic murmurs (an example is shown in Fig 6, a continuous murmur with a systolic or diastolic murmur, or one systolic and one diastolic murmur. Thus the characteristics of each murmur must be *connected with the particular murmur*, and not confused with characteristics from any other murmurs that may be present.

V. Summary

We created a portable prototype system that accepts input in multiple formats, creates a portable graphical representation of heart auscultation and other data, and exports the data graphically or as formatted text. Image generation is implemented in Java, which makes it portable and straightforward to integrate with other programs. The structured and graphical representations produced by our system are also portable within multiple EMRs as text and jpeg files. We are testing and evaluating the incorporation of these representations into an existing telemedicine system. Our system is designed to be MD friendly, using representations similar to those used in cardiology references. We hope that our interface design and images created by our system will become a valuable part of medical records used by primary healthcare workers, cardiologists and medical students.

VI. Future Work

Translation to and from SNOMED format is under development, increasing its usability and portability. Signal processing methods are planned that would produce a format readable by our system, thus automating the input of data to generate graphical and text descriptions. Decision-support programs for heart disease diagnosis and cardiology referral are planned.

Acknowledgments

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