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DigiScope – Unobtrusive Collection and Annotating of Auscultations in Real Hospital Environments

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***Abstract*—Digital stethoscopes are medical devices that can collect, store and sometimes transmit acoustic auscultation signals in a digital format. These can then be replayed, sent to a colleague for a second opinion, studied in detail after an auscultation, used for training or, as we envision it, can be used as a cheap powerful tool for screening cardiac pathologies. In this work, we present the design, development and deployment of a prototype for collecting and annotating auscultation signals within real hospital environments. Our main objective is not only pave the way for future unobtrusive systems for cardiac pathology screening, but more immediately we aim to create a repository of annotated auscultation signals for biomedical signal processing and machine learning research. The presented prototype revolves around a digital stethoscope that can stream the collected audio signal to a nearby tablet PC. Interaction with this system is based on two models: a data collection model adequate for the uncontrolled hospital environments of both emergency room and primary care, and a data annotation model for offline metadata input. A specific data model was created for the repository. The prototype has been deployed and is currently being tested in two Hospitals, one in Portugal and one in Brazil.**

I. Introduction

TRADITIONAL stethoscopes depend solely on acoustics to amplify and transmit the heart sounds to the physician. The concept of electronic stethoscope arrived when electronic components were first used to amplify, filter and transmit the sound [1]. Several electronically enhanced and digital stethoscopes have been developed and described in literature [2-4]. Introducing a digital stethoscope in clinical practice can bring several advantages, all focused on its capability of recording and possibly transmitting heart sounds. Access to such sounds allows several tasks such as sending the sound to a colleague for a second opinion, using recorded sounds as a teaching tool or, more ambitiously, learning patterns of normal or abnormal heart beats so such systems can be used as a cheap powerful tool for cardiac pathology screening. The DigiScope project ultimately aims to build a system that is capable of collecting heart sounds in real environments, extracting relevant physiological information from these signals, and combining it with patient information using machine learning methodologies, hoping to demonstrate that it is possible to use systems within hospitals based on digital stethoscopes that can function as a cheap first level of screening of cardiac pathologies. The contribution of this paper is the presentation of the design, development and deployment of a prototype for collecting and annotating auscultation signals within real hospital environments. This prototype is operational and has been deployed in two hospitals (Centro Hospitalar do Alto Ave, Guimarães, Portugal, and Real Hospital Português, Recife, Brazil), with sounds being collected mostly in a primary care environment.

Previous research on audio processing for cardiology [5] has shown that it is vital to collect large amounts of data from real clinical situations, all of which must be manually registered by cardiology specialists. Such a simple task becomes quite complex when confronted with the reality of current Hospitals where information systems are complex and highly heterogeneous, or where clinicians have very busy schedules and cannot be hindered by obtrusive audio data collection systems. As such, accomplishing the objective of creating a prototype that can gather a large annotated database for cardiology signal processing and machine learning requires the following tasks:

- Define a database model for all the collected data, including not only audio data but also patient record information.
- Devise effective data collection systems that do not hinder typical routine Hospital work on cardiology.
- Study solutions for fast and simple registering of the audio samples collected.
- Extract information from complex heterogeneous Hospital information systems.

We will address the first three tasks in this paper, which is organized as follows. Section II describes the system model with its components and interactions. Section III presents our conceptual data model. In Section IV we draw conclusions and present perspectives for future work.

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II. CONCEPTUAL DESIGN

A. System Model

Fig. 1 shows the main components of our system and their interactions. The system has four main components: (1) Data Collection, (2) Signal Processing, (3) Machine Learning and (4) Data Repository.

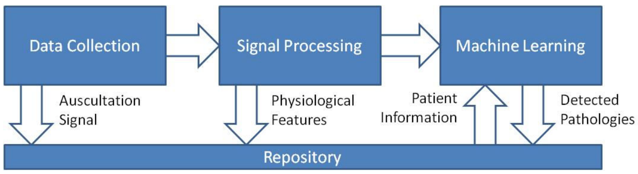

Fig.1: The DigiScope System Model

The proposed system was designed to be implemented in hospitals and help physicians incorporate it in their routine work with minimal disruption. Some generic usability requirements were established [6]:

- Minimize disruption - The system should be easy to use and the equipment should adapt well to the normal routine work of the physician with minimum interference. It should also accommodate different ways to perform data collection, namely allowing the collection of patient data after each auscultation or after a set of auscultations.
- Minimize errors - The flow of interactions should be adequately constrained in order to minimize the number of errors done by the physician and its associated reduction in data quality.
- Easy to learn - The interface should be intuitive and guide the physician through the use of the application, reducing the adaptation time and difficulty to the system. This is essential for increasing the number of physicians that are willing to adopt and test this new technology.

User studies were performed in the two cooperating Hospitals. The objectives were:

- Learn and model the auscultation procedure typically applied in hospitals.
- Identify hospital environments where such a system is both adequate and useful.
- Define a set of clinically useful and viable to annotate metadata to be associated with each auscultation.

Contextual studies methodologies were used, which mainly involved a combination of observation sessions and semi-structured interviews. As a result, two hospital environments were selected, namely the Emergency Room and Primary Care. The reasons for this choice are that the typical physician present is not a cardiologist (and can thus benefit from a system that can provide a first level of screening of cardiac pathologies), auscultation is performed in nearly every situation (it simply implies changing from a normal stethoscope to a digital one), there is a strong influx of new patients (maximizing the potential benefits of the screening process), and it is simple to deploy a tablet-type PC within enough communication range to receive the signals transmitted by a digital stethoscope. An environment that was discarded although an initual intuition might say otherwise was the Cardiology service. The main reason for this is that there is convincing evidence that it is theoretically possible to screen pathologies using signal processing and machine learning methodologies, namely the ones that cardiologists can identify but other physicians can't. We can argue that there are enough differences in the signal itself that allow for this distinct performance. We can't, however, say the same for pathologies that even cardiologists can't identify using auscultation alone.

B. Conceptual Model

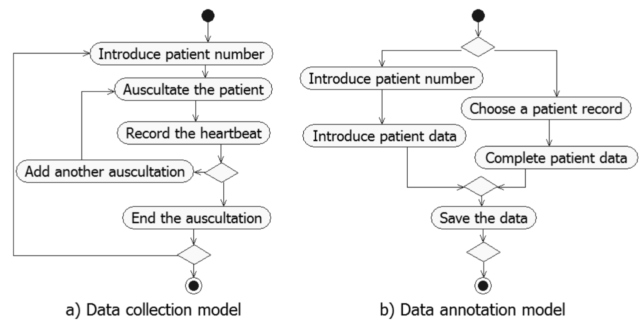

Fig. 2: Functional conceptual models of the DigiScope data collection system.

Two functional conceptual models were produced for the DigiScope system and can be observed in Fig. 2. User studies have shown us that the interaction mechanism must be very simple in order to be used within an Emergency Room. Very rarely the physician will have time to do anything besides its conventional auscultation, so we only require the bare minimum as additional effort (introducing a patient number, which can be performed by a nurse). In this model, after starting the application, the physician simply needs to introduce a new patient (a number is exclusively assigned to each one). After that, the physician can start the auscultation using the digital stethoscope. This device is connected to a computer or computing base through wireless connection. The heart sounds are then transmitted by streaming. The physician has the possibility to add more than one heartbeat record for each patient, using a simple button press in the stethoscope itself. After the auscultation is finished, the physician can start a session for a new patient or move to the annotation procedure, defined by the annotation conceptual model. Here, the physician can complete the patient's data, or this can be also done by a nurse.

C. Prototype Technology

The computer chosen is an Asus Eee PC with touch screen T101MT. This choice is motivated not only by the simplicity of a touch-based solution, but mainly by the fact that it has a rotating screen, effectively allowing the physician to work in the two modes defined by the conceptual models. In the collection mode the tablet PC form is used (physician standing up, prototype on his hand), while the annotation mode allows the use of the keyboard (physician sitting at a desk, faster and more conformable typing).

The electronic stethoscope chosen is a Littmann Model 3200. This stethoscope has three frequency response modes such as bell, diaphragm, and external range. The bell mode amplifies from 20 to 1000Hz, the diaphragm mode: amplifies from 20 to 2000Hz and the extended range mode amplifies sounds from 20 to 2000Hz. It can amplify the heart and lung sounds up to 24 times [7, 8]. The LCD screen allows some information to be shown to the physician. This model can transmit signals wirelessly using Bluetooth technology. In fact, this was the only widespread commercial stethoscope that we could find with this transmission capability. Other available options did not have the traditional shape of conventional stethoscopes, which was considered essential for the first usability requirement defined in Section 2.A (minimize disruption). Fig.4 shows an image of the final version of the hardware prototype.

Fig. 3: The DigiScope prototype

Heart sounds are recorded in WAV format, and the patient data (detailed in Section III) is saved in a XML format. At the end of each day, all the data is sent to a database on a secure server. The application was developed in Java. The Bluecove API [9] was used to establish the communication between the system and the stethoscope.

III. DATA MODEL

Given the significant amount of data that can be captured each day by such a prototype, it is important to define exactly what information to store and in which format. In the medical area, it is common to use specific terminologies when describing a certain sub-specialty (for example, in the area of breast cancer, the terminology is based on the BIRADS – Breast Imaging Reporting and Data System – lexicon [10]). The third objective of the user studies described in Section II.A (define what patient metadata is interesting for pathology screening, and is viable to be annotated in this context) led to the definition of the DigiScope data model. Contributions to this definition also came from the HL7 standard [11] and *open*EHR publicly available archetypes [12]. A strong emphasis was given to collecting data that might be helpful in the near future for machine learning research on cardiac pathology detection. We defined our data model with attributes that could be relevant to uncover new knowledge about:

- The history of exams of patients (one patient can have several episodes of auscultation). This information can be useful to learn temporal diseases relations.
- Differences between normal and abnormal cases (several attributes, in particular, the characteristic of the second heart sound (S2) can be very important do distinguish between normal and abnormal findings)
- Multiple diseases for the same patient (multi-labeling [13]).
- Relations between exams of the same patient and other patients.
- Relations between medication and patient health status.

The resulting data model can be seen in Figure 4. It not only defines several attributes that are annotated by physicians (e.g. patient information) but contemplates other attributes that we expect will be a product of the signal processing task (e.g. A2_intensity).

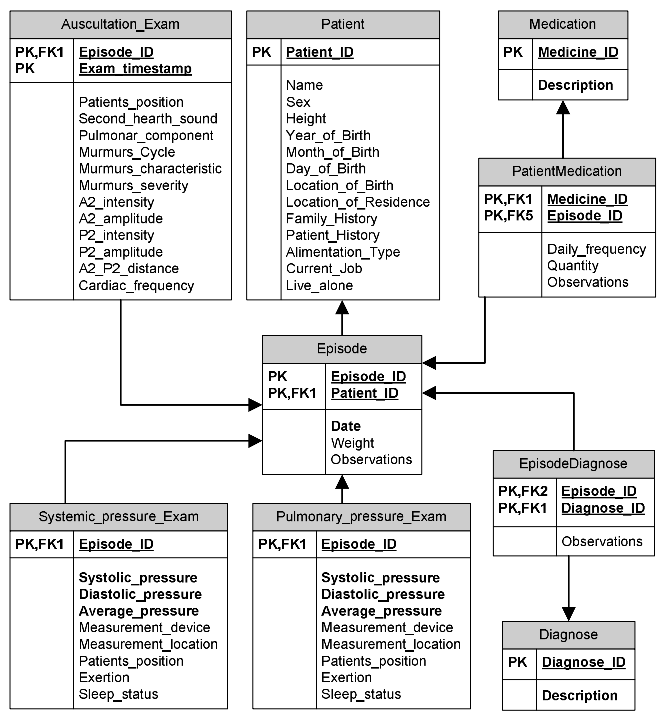

Figure 4: Digiscope data model

IV. SYSTEM IMAGE

As motivated previously, our conceptual design is focused on the three generic usability requirements described in Section II.A [14]. The physician uses the system in two distinct phases. First, when he is standing and executes the patient auscultation, he will use the electronic stethoscope and the computer in touch mode (Fig.2.a, Data collection model). During this phase (Fig. 6), the proposed system suggests only two options, which can be selected using large buttons, thus heavily constraining the user to simplify his understanding and reduce possible errors.

In a second phase (Fig.2.a, Data annotation model), the physician is sitting and can complete patient data. This does not need to be done immediately after the auscultation and can also be partially performed by a nurse. The data form is clearly more complex than in the previous model, benefiting from the undivided attention of the user. Data fields are split in tabs: general, systemic pressure, pulmonary pressure, murmurs, S1, S2, S3 and S4. Some of these data fields can actually be completed before the auscultation itself. As essential function was thus the ability to only provide partial information, which can be completed at a later stage. During this phase (Fig. 7), typing errors are inevitable. We have used radio buttons whenever possible to minimize them. For all the text fields, except the patient name, physicians can use a numeric virtual keyboard. For the patient name, an alphanumeric virtual keyboard is displayed, although this is clearly a sub-optimal choice, which is hidden whenever it is not needed. From the main menu, the physician can access a table which lists all patients who have already been introduced in the application. In this table he can see: the patient number, name, date of release, the state of the form (blank, incomplete or complete) and how many hearings have already been added.

Fig. 5: Screenshots showing the initial menu and the menu after the recording of auscultation.

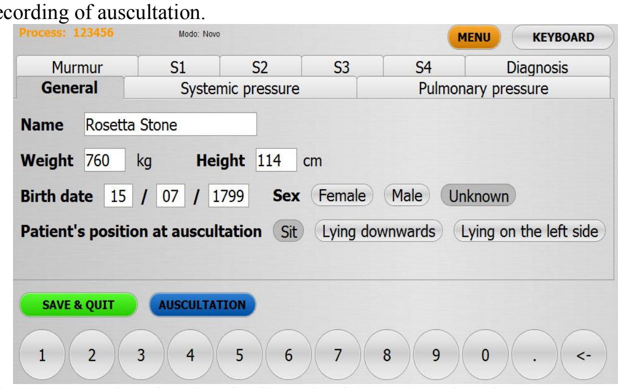

Fig. 6: Screenshot showing the first tab of the patient data form.

V. Discussion and Conclusions

In this work, we presented a working prototype of a system capable of recording and annotating heart sounds.

Contextual design methodologies were used to address the three key usability requirements that have been identified for this type of systems: minimize disruption, minimize errors, easy to learn. The prototype is centered about a digital stethoscope that transmits signals to a tablet PC, which can function in two modes of operations: collection mode and annotation mode.

The system has been successfully deployed in April 2011 on two Hospitals, and early results show that physicians were able to use it effectively with minimal training, on a Primary Care context. The more demanding Emergency Room context will be addressed in a second deployment stage, which is targeted for June 2011.

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