4ª ed

MIM

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

Daniel Cláudio Pereira

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2º CICLO DE ESTUDOS

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To all those who shared with me this project.

Abstract

Keywords: Decision Support Systems, Clinical; Heart Auscultation; Stethoscopes; Data Collection; User-Computer Interface

Introduction: 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.

Aim: Our main objective is creating a prototype that can gather a large annotated database for cardiology signal processing and machine learning. As such, accomplishing the overall goal of requires the accomplishment of the following objectives: (1)Define a database model for all the collected data, including not only audio data but also patient record information; (2)Devise effective data collection systems that do not hinder typical routine hospital work; (3)Study solutions for fast and simple annotation of the audio samples collected.

Methods: 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 and a data annotation model. A specific data model was created for the repository.

Results: The contribution of this work 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).

Sumário

Palavras-chave: Sistemas de apoio à decisão clínica; Auscultação cardíaca; Estetoscópios; Colecta de dados; interface homem-maquina.

Introdução: Os estetoscópios electrónicos são aparelhos médicos que podem colectar, armazenar e por vezes transmitir batimentos cardíacos de uma auscultação acústica num formato digital. Pode então ser reproduzido, enviado para um colega para uma segunda opinião, estudado ao pormenor depois de uma auscultação, usado para ensino ou, tal como encaramos isso, pode ser utilizado como uma ferramenta barata e poderosa para triagem de patologias cardíacas. Neste trabalho, apresentamos o desenho, desenvolvimento e implementação de um protótipo para colectar e anotar os batimentos cardíacos em ambientes hospitalares reais.

Objectivo: O nosso principal objectivo é criar um protótipo que possa reunir uma grande base de dados anotada para o processamento de sinal cardíaco e o *machine learning*. Como tal, cumprir o objectivo principal requer a realização dos seguintes objectivos: (1) Definir um modelo de base de dados para todos os dados colectados que incluirá, além dos dados de áudio, as informações do registo do paciente, (2) Conceber sistemas eficazes de colecta de dados que fazem não perturbem a rotina hospitalar; (3) Estudar soluções para a anotação rápida e simples das amostras de áudio colectadas.

Métodos: O protótipo apresentado gira em torno de um estetoscópio electrónico que pode transmitir o sinal de áudio colectado para um tablet PC. Interacção com este sistema é baseado em dois modelos: um modelo de colecta de dados e um modelo de anotação de dados. Um modelo de dados específico foi criado para o repositório.

Resultados: A contribuição deste trabalho é a apresentação do desenho, desenvolvimento e implementação de um protótipo para colectar e anotar os batimentos cardíacos em de ambientes hospitalares reais. Este protótipo está operacional e já foi implementado em dois hospitais (Centro Hospitalar do Alto Ave, Guimarães, Portugal, e Real Hospital Português, Recife, Brasil).

Prologue

*"When you open your mind to the impossible, sometimes you find the truth" (*Walter Bishop)

In 2009, when I joined the master's degree in medical informatics, I was a professor of computer science at a secondary school and had never been in contact with medical informatics. However, the master gave me to know the surrounding areas of medical informatics. When it came time to choose the theme of the thesis, I thought initially in an area linked to a medical emergency, but which was not possible to advance. I spoke with Professor Ricardo Correia and he proposed that I enter the Digiscope project, a project that had been presented during the master. After a first meeting with Professor Ricardo Correia Professor and Professor Miguel Coimbra (project leader), I decided to embark on this project. I joined the data collection team led by Professor Ricardo Correia, I had the responsibility to develop a prototype for the collection and annotation of heartbeat. I started my work in October 2010 on the premises of the CINTESIS, in the Medicine Faculty of the University of Porto, becoming a member of this service in June 2011. In parallel, I continued to teach computer science at a secondary school at night. I left this work in September 2011 when I started a research grant for this project.

Do to my academic training was focused on information systems, the whole process of design and application development allowed me to acquire new knowledge, particularly in the area of programming (including object-oriented programming and particularly Java) and realize the importance of usability in this area.

This project allowed me to learn not only from an IT point of view but also better understand the perceptive health professionals and their needs in this area.

Besides all the knowledge I gained with this project, I got a PhD grant from FCT to continue this project.

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Abbreviations and acronyms

CDSS – Clinical Decision Support System

UML – Unified Modeling Language

XML – Extensible Markup Language

API – Application Programming Interface

Figures list

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Thesis organization

This thesis is divided into six chapters, Introduction, State of art, DigiScope Collector system, System evaluation, Discussion and References.

The first chapter – Introduction, present a brief description of the importance of the stethoscope in medicine and how it is possible to increase their capacities using the audio processing. The DigiScope project is detailed; the objectives and the five functional tasks are described. And the expected results are presented. Finally, an approach to the main objective of this work and a description of the necessary tasks to achieve it are made.

The second chapter – State of the art, presents a large part of the bibliographic research performed prior to the development of the system. The three focus areas for the literature search are: electronic stethoscopes, clinical decision support system and processing signal.

The third chapter – DigiScope Collector system, describes the idealization process of the system, its features and how it should interact with the different users. This chapter presents also a comprehensive description of the system architecture as well as UML diagrams created during previous development. The conceptual model shows the functions and mechanism of interaction with the various users. The data model defined for these propose is also presented. Finally, the implementation shows an explanation for the prototype technology chose, a large description of the user interface, and for concluding, the encountered problems and possible solutions are explains.

The fourth chapter, System evaluation, is divided into three sections: Evaluation Methodology, Results and Interpretation/Discussion. For better understanding and organization of the thesis, we opted for this division of the chapter, the reader can well fit in the overall satisfaction, and the details of the methodology used to assess the implementation of the system, the results obtained with this assessment and thus better understand the interpretation of these results.

The fifth chapter - Discussion, presents the final conclusions the main results of this work, the limitations it presents, and simultaneously makes proposals for future work.

The sixth chapter - References, shows the references used in this work.

Scientifics and financial results

Publications in proceedings of scientific meetings

Daniel Pereira, Fabio Hedayioglu, Ricardo Correia, Tiago Silva, Inês Dutra, Filipa Almeida, Sandra Mattos, Miguel Coimbra, "DigiScope – Unobtrusive Collection and Annotating of Auscultations in Real Hospital Environments", 33rd Annual International IEEE EMBS Conference, 2011. (Appendix 1)

Fabio Hedayioglu, Felipe Mourato, Daniel Pereira, Miguel Coimbra, Sandra Mattos - "DigiScope: Uma ferramenta para coleta e anotação de auscultas em ambientes clínicos e hospitalares", XXI Congresso Pernambucano de Cardiologia, Agosto 2011, submitted.

Daniel Pereira, Fabio Hedayioglu, Ricardo Correia, Tiago Silva, Inês Dutra, Filipa Almeida, Sandra Mattos, Miguel Coimbra, "DigiScope – Unobtrusive Collection and Annotating of Auscultations in Real Hospital Environments", RecPad 2011, the 17th edition of the Portuguese Conference on Pattern Recognition.. (Appendix 2)

Pedro Ferreira, Daniel Pereira, Inês Dutra, Fabio Hedayioglu, Miguel Coimbra, "The DigiScope Auscultation Data: First Exploration", RecPad 2011, the 17th edition of the Portuguese Conference on Pattern Recognition. (Appendix 3)

Others publications

Press release entitled: "New sound synchronisation technology holds the key to earlier diagnosis of heart disease", EPSRC, 02 June 2011, available at: http://www.epsrc.ac.uk/newsevents/news/2011/Pages/earlierdiagnosisofheartdisease.aspx

Journal article entitled "Novo estetoscópio digital pode revolucionar diagnóstico cardíaco", CiênciaHoje, June 17, 2011, available at: http://www.cienciahoje.pt/index.php?oid=49658&op=all

Press release entitled: "Um estetoscópio que faz bem ao coração", noticias.up.pt, June 13, 2011, available at: http://noticias.up.pt/catalogo_noticias.php?ID=7804

Press release entitled: "New Sound Synchronization Technology Holds the Key to Earlier Diagnosis of Heart Disease", ScienceDaily, June 3, 2011, available at: http://www.sciencedaily.com/releases/2011/06/110602095414.htm?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed:%20sciencedaily%20%28ScienceDaily:%20Latest%20Science%20News%29

Press release entitled: "New Sound Synchronization Technology Holds The Key To Earlier Diagnosis Of Heart Disease", ScienceDaily, June 2, 2011, available at: http://www.redorbit.com/news/health/2058049/new_sound_synchronization_technology_holds_the_key_to_earlier_diagnosis/index.html

Press release entitled: "New technology holds the key to earlier diagnosis of heart disease", 2 June 2011, available at: http://www.qmul.ac.uk/media/news/items/se/49371.html

Presentation of the DigiScope project, 3rd Medical Informatics Symposium, October 29-30, 2010, Faculty of Sciences, University of Porto.

Presentation of the DigiScope project, BEST Days On Technology'11 simposium, April 11-13, 2011.

Presentation of the DigiScope project, 4th Medical Informatics Symposium, October 8, 2011, Faculty of Sciences, University of Porto.

1. Introduction

1.1. Introduction

Used by an experienced physician, a stethoscope provides important clinical information which can help a first assessment of a patient's health, thereby driving the need for more specific tests. This is particularly true for cardiology and pneumology, and why the stethoscope still holds a key position in modern medicine. However, listening to an auscultation is a difficult skill to master. The heart sounds are low frequency and the intervals between events are in the order of milliseconds, requiring a lot of training for the human ear to distinguish the differences between a normal and a pathological heart sound. The use of a digital stethoscope, adequate for training inexperienced physicians, or as a tool for worldwide screening of specifics cardiac diseases, are just some examples where advanced technology can be used to benefit society. It is based on this motivation that we define the main objective of the DigiScope project: developing a prototype of a digital stethoscope, capable of automatically extracting clinical features from the collected heart sounds, combine them with other available patient information, in order to provide a second medical opinion about specific cardiac pathologies.

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 (Durand and Pibarot 1995). Several electronically enhanced and digital stethoscopes have been developed and described in literature (Tavel, Brown et al. 1994; Brusco and Nazeran 2005; Hedayioglu, Mattos et al. 2007). 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 contribution of this thesis is the presentation and the evaluation 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 (Hedayioglu, Coimbra et al. 2009) 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 overall goal of creating a prototype that can gather a large annotated database for cardiology signal processing and machine learning requires the accomplishment of the following objectives:

- 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;
- Study solutions for fast and simple annotation of the audio samples collected;
- Extract information from complex heterogeneous Hospital information systems.

We will address the first three in this thesis.

1.2. DigiScope project

The DigiScope project (DIGItally enhanced stethoSCOPE for clinical usage) is a nationally funded project (FCT – Fundação para a Ciência e Tecnologia) that involves Portuguese academic (Instituto de Telecomunicações, CINTESIS/FMUP, INESC-Porto) and medical institutions (Centro Hospitalar Alto Ave, Guimarães) but also cooperating international academic (Queen Mary, University of London) and medical institutions (Real Hospital Português, Recife, Brazil) (See Figure 1). It started in February 2010 and has duration of 3 years. The principal objective of the DigiScope project is the creation of an advanced clinical tool, capable of recording, processing and analyzing heart sounds to aid physicians in screening different cardiac pathologies. Previous literature shows this objective cannot be accomplished from a purely technological perspective (Tavel, Brown et al. 1994; Durand and Pibarot 1995; Brusco and Nazeran 2005; Hedayioglu, Mattos et al. 2007; Hedayioglu, Coimbra et al. 2009). A close collaboration between physicians and medical signal processing scientists is vital so that the experience from the clinical examination of the patient can be used into building the new device. Otherwise we risk ending up with a very sophisticated tool with limited clinical application. Our experience with multi-disciplinary projects, especially between clinicians and computer scientists, helps us in devising a convincing research plan that not only stimulates the dialogue between researchers but also layers the objectives of each task, so that we guarantee that the project will accomplish its principal objective, even if some novel research ideas prove to be unsuccessful in practice.

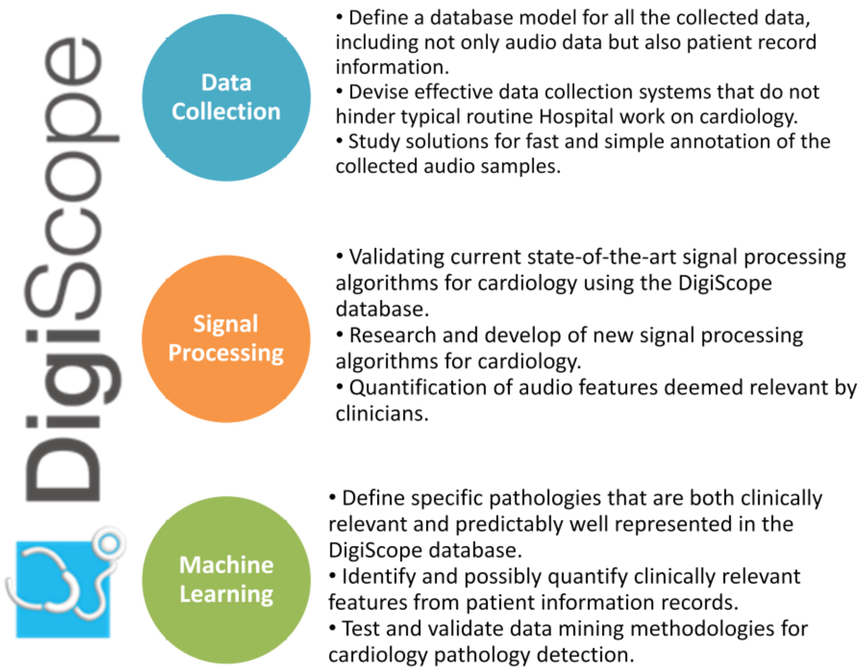


Figure 1 – The three areas of the DigiScope project and theirs tasks

The DigiScope project is structured into five functional tasks. Tasks 1 (Data Management) and 4 (Prototype) are essentially development tasks that will guarantee the viability of the final prototype. This thesis is essentially based on the work developed in these tasks. Tasks 2 (Audio Processing) and 3 (Data Mining) are the core research of the project. They are responsible for exploring novel ideas that will add new functionalities to the prototype. Task 5 (Clinical Validation) will make sure that the device is clinically useful and predict the conforming to the high clinical requirements of routine Hospital usage. All tasks constantly followed by clinical partners that provide consultation on the clinical usefulness of the targeted research objectives, and validate all resulting technology.

Figure 2 - DigiScope logo

Expected key results of the project are:

- Produce, deploy and evaluate a DigiScope prototype;
- Design, implement and populate a massive clinically annotated database for research on this topic;
- Publish all novel research in high-impact journals and conferences.

1.2.1. Audio Processing for Cardiology

The research has given a clear ideas regarding what has been accomplished in this topic so far. Based on this, three research lines have defined, that will be explored in this task:

- Field validation of the robustness of published Heart Sound Segmentation algorithms. Although these results seem quite impressive (Liang, Lukkarinen et al. 1997; Liang and Hartimo 1998; Omran and Tayel 2003), the interest is in testing them in a real environment where circumstances are much harder to control (resisting patients, noisy environments) and understanding if they are robust enough for clinical routine;
- Deeper exploration of Aortic Pulmonary Signal Decomposition. Based on current research, the interest is in improving the performance of these algorithms since they provide direct clinical features to a physician's examination. Furthermore, it’s expectable to validate the relationship between the second heart sound signal and its associated pulmonary blood pressure, hopefully creating robust ways to screen the generic population for pulmonary hyper-pressure;
- Extraction of relevant clinical features. By working directly with cardiologists, it is possible to gain a deeper understanding of what it is considered relevant in an examination. This will lead to the

definition of new challenges for signal processing. Examples are the presence of a third heart sound, or the instability of some heart sound features (e.g. volume, duration, etc.). Furthermore, that will interact directly with the pathology detection task, for providing statistical features that might be interesting for data mining algorithms.

1.2.2. Pathology Detection

Following previous successful work done on extracting relevant information for other medical data such as mammographies, the DigiScope project intends to continue exploring better ways of reducing false positives in pathology screening algorithms. In previous work, elements of the DigiScope team applied inductive logic programming and Bayesian networks (Davis, Burnside et al. 2005) to predict malignant findings in mammograms. The approach resulted in two interesting achievement: First, the language used by inductive logic programming and Bayesian networks was well understood by medical professionals, validating the possibility of generating rules that make sense for clinical specialists, and secondly, interesting results were published in regarding advances in classification methods and in medical analysis of mammographies (Burnside, Davis et al. 2005; Davis, Burnside et al. 2005; Davis, Burnside et al. 2007).

The DigiScope team aims to continue on this successful track by applying the same principles of this previous research to heart pathology detection. The methods will be based on what has already been used for detecting malignant findings in mammographies, and on the improvement of the classification algorithms in order to give better diagnosis and prediction models. An example is to investigate how to better combine different classification approaches as evaluation functions, in the same way it was done in SAYU (Davis, Burnside et al. 2005). Another possibility is to investigate how the integration of medical reports with data produced by the digital stethoscopes can help uncover new relevant knowledge. Another track to follow is based on the work started by Ong et al. (Ong, Dutra et al. 2005) on better connecting related objects and paths to improve the quality of extracted knowledge, and the work of Salvini et al. (Salvini, Aguilar et al. 2007) on improving quality and efficiency of the classification algorithms.

1.3. Objective

The principal objective of this thesis, it is the presentation of a working prototype of a system capable of recording and annotating heart sounds, and his implementation and evaluation. To accomplish this goal, we have split this problem into two distinct tasks:

- Data Collection and Management;
- Prototype design, development, deployment and evaluation.

As we have explained previously, research on audio processing for cardiology has shown that it is essential to collect large amounts of data from real clinical situations, all of which must be manually annotated 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 non-transparent audio data collection systems. Furthermore, we can think of several smaller specific problems such as how to correlate extracted audio samples with stethoscope body position or how can clinicians perform fast manual annotations of such samples. As such, accomplishing the objective of creating a very large clinically annotated database for cardiology signal processing has required the following sub-tasks:

- Define a database model for all the collected data, including not only audio data but also patient record information;
- Design and develop a technological solution to collect audio samples;
- Study solutions for fast and simple annotation of the collected audio samples.

After understanding how to collect and annotate data as transparently as possible, we need to build a DigiScope prototype that can integrate such knowledge with the automatic processing modules (Signal processing and Data mining) produced by the others members the DigiScope team. The accomplishment of this task has been divided in three parts:

- Study and implement an user-centered interaction system for the clinician, which is both simple and effective;

- Creation of the software platform of the prototype, which can integrates the processing modules (Signal processing and Data mining).

2. State of art

The DigiScope project proposes to collect patient data but this objective presuppose two fundamental tasks:

- Gathering clinical data directly from clinicians. That is considered one of the greatest challenges for the successful implementation of Electronic Health Records (EHR) (Dick, Steen et al. 1997).
- Auscultate. The auscultation is a fundamental type of data for medicine and there is a growing awareness that a technological leap that allows its integration with EHR is now possible (Tavel 2006).

In this state of art, we proposed to analyze the published literature about three fundamental topics:

- Electronic stethoscopes;
- Clinical Decision Support System (CDSS);
- Signal processing.

The first one, electronic stethoscopes, it is the most obvious, because it is the principal tool to auscultate and to record the heartbeat.

The second topic is the CDSS. We choose this one because the main objective of the DigiScope project it is to be a system that can help the physician to detect cardiac pathologies. In this topic, we approach also the machine learning because we consider them as part of the CDSS.

The last topic is the signal processing because it is a fundamental part of the project. Without the signal processing it is impossible to obtain results and consequently potential diagnosis suggestion.

2.1. Electronic Stethoscopes

The stethoscope has a special place in medicine, being closely bound up with the doctor´s image. Since the invention of the first stethoscope by the French physician René Laennec (Necker hospital, Paris) in 1816, auscultation via a stethoscope is widely used by physicians as a simple, non-invasive and patient-friendly diagnostic method of chest diseases, where the sounds heard are correlated with the underlying pulmonary pathology (Andres, Brandt et al. 2008). It is one of the most simple and practical diagnostic tools used in medicine (Tavel 2006). Actually, two different types of stethoscopes are available on the market: acoustic and electronic. The main advantages of acoustic stethoscopes are their robustness and ergonomic designs. However, they are not ideal because they attenuate sound transmission proportional to frequency, their frequency response shows maxima and minima at very specific frequencies due to tubular resonance effects, and differences in the transmission properties are observed between different models (Ertel, Lawrence et al. 1969; Kindig, Beeson et al. 1982; Charbonneau and Sudraud 1985; Abella, Formolo et al. 1992).

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 (Durand and Pibarot 1995). The US Military Aircraft Command recommended in 1966 that an electronic stethoscope be developed for use aboard aircraft because listening procedures were extremely difficult, if not impossible, with regular stethoscopes (Brogan, Collins et al. 1967).

We can thus think of digital stethoscopes as an evolution of the later, since we exploit the advantages of converting the audio signal to the digital domain, whether these are storage, transmission, analysis or simply visualization. Bredesen and Schmerle (Bredesen and Schmerler 1988) have patented an intelligent stethoscope designed for performing auscultation and for automatically diagnosing abnormalities by comparing digitized sounds to reference templates using a signature analysis technique. Several other electronic stethoscopes have been developed and described in literature (Tavel, Brown et al. 1994; Brusco and Nazeran 2005; Hedayioglu, Mattos et al. 2007).

There is, however, very little published data comparing conventional and electronic stethoscopes. An early study in 1998 comparing some of the more primitive electronic stethoscopes with standard devices, concluded that the acoustic stethoscopes were preferable, however, they proposed that an ideal device would feature a combination of both (Grenier, Gagnon et al. 1998). More recently, a Norwegian study randomized third year medical students to either a traditional or an electronic stethoscope (Welch Allyn see Figure 3)and found no difference in terms of diagnostic accuracy when assessed by a cardiac auscultation test (Hoyte, Jensen et al. 2005). A Danish study comparing a standard stethoscope with a 'cardiology' stethoscope also found no difference (Iversen, Sogaard Teisner et al. 2006). Experiences with electronic stethoscopes when teaching medical students has been a positive one based primarily on the ability to amplify sounds and reduce background noise. The ability to record the abnormal auscultatory findings and immediate facility to replay that sound has been particularly useful (Asghar, Alam et al. 2010).

Figure 3 - Welch Allyn Master Elite Electronic Stethoscope

Besides early attempts to use electronic stethoscopes for computer assisted decision, some studies have shown that the cardiac auscultation skills of undergraduate medical students were not negatively influenced by the use of an electronic sensor-based stethoscope (Hoyte, Jensen et al. 2005; Sverdrup, Jensen et al. 2010). This reinforces our belief that this learning could then benefit from a system that includes an electronic stethoscope, if an adequate interactive solution is researched, implemented and deployed (Hedayioglu, Coimbra et al. 2009).

We can conclude that there is scarce literature on this topic. The few comparative studies are few comprehensive, and show there are no diagnostic differences between acoustic and electronic stethoscopes. Here is an interesting opportunity to make a large comparison between acoustic and electronic stethoscopes, and publish a paper. Another interesting point is that studies show that there is no negative influence to the medical students and on the contrary that the electronic stethoscope can be a great learning tool. This is one of the tasks that we propose as future work. We can finally conclude that the electronic stethoscope offers possibilities such as recording, filtering, etc... that are not available to of traditional stethoscopes.

2.2. Clinical decision support system

Before analyzing the importance of clinical decision support system, it's essential to define what a Clinical Decision Support System (CDSS) is. Studying the literature we see that there are different definitions proposed by various authors.

Wyatt defines a CDSS as an active knowledge systems which uses two or more items of patient data to generate case-specific advice (Wyatt and Spiegelhalter 1992). A computer program that provides reminders, advice or interpretation specific to a given patient at a particular time (Wyatt 2000).

Any mechanical, paper, or electronic aid that collects or processes data from an individual patient to generate output that aids clinical decisions during the doctor-patient encounter. Examples include decision support systems, paper or computer reminders and checklists, which are potentially useful tools in public health informatics, as well as other branches of medical informatics (Wyatt and Liu 2002).

Osheroff suggest that a clinical decision support is defined as providing clinicians or patients with computer-generated clinical knowledge and patient-related information, intelligently filtered or presented at appropriate times, to enhance patient care (Osheroff, Pifer et al. 2005).

CDSS had a high point in the seventies with the first experiments using Bayesian techniques and rules chaining. The results were promising. But expert systems stagnated, continued only as an object of academic study, but without extensive practical use. One of the reasons given for this fact was the fear that the decision support software producers could be responsible for medical errors caused, even indirectly, by use, or misuse of systems. With the US tradition of insurance and significant compensation for medical errors, software vendors judged risky to take risks in this market. The subject seemed forgotten, but in recent years, interest in clinical support decision systems is being taken up by the path of integration with other tools of electronic medical records and greater coverage.

CDSS are increasingly important in primary care for the practice of evidence-based medicine and the development of shared general practitioner-patient decision making (Short, Frischer et al. 2004). But integrating computerized decision aids into routine care has been shown to be difficult (Eccles, McColl et al. 2002). A range of reasons have been identified. These include a reluctance by general practitioners to use systems because of limitations in their information technology skills and, consistent with previous research, difficulties in finding the time to use a support system in consultation (Sullivan and Mitchell 1995). Others factors include “a lack of agreed national standards, a failure of systems to examine the needs of users adequately, and the profusion of different systems that do not communicate with each other” (Delaney, Fitzmaurice et al. 1999). Research specifically into the adoption of prognostic models in practice has proposed a lack of clinical credibility and uncertainty concerning the evidence as potential reasons (Wyatt and Altman 1995). But, may be the most important factor is the time. First, if systems are to be used in a consultation, designers must ensure that the system is practical within limited time available to general practitioners. Any guidance or information must be accessible to the user quickly and clearly. Given the importance of time, practitioners are less likely to use a system if the process to access the information is complex or time consuming (Short, Frischer et al. 2004).

After defining the factors that hinder the growth of CDSS, let us see what the main functions that they should have are. Clinical decision support systems are typically designed to integrate a medical knowledge base, patient data and an inference engine to generate case specific advice. Four key functions of electronic clinical decision support systems are outlined in (Perreault and Metzger 1999):

- Administrative: Supporting clinical coding and documentation, authorization of procedures, and referrals;
- Managing clinical complexity and details: Keeping patients on research and chemotherapy protocols; tracking orders, referrals follow-up, and preventive care;
- Cost control: Monitoring medication orders; avoiding duplicate or unnecessary tests;
- Decision support: Supporting clinical diagnosis and treatment plan processes; and promoting use of best practices, condition-specific guidelines, and population-based management.

It is important to show some of the most respected of diagnosis systems:

DXplain: it's a decision support system which uses a set of clinical findings (signs, symptoms, laboratory data) to produce a ranked list of diagnoses which might explain (or be associated with) the clinical manifestations. DXplain provides justification for why each of these diseases might be considered, suggests what further clinical information would be useful to collect for each disease, and lists what clinical manifestations, if any, would be unusual or atypical for each of the specific diseases (Barnett, Cimino et al. 1987). DXplain includes 2,200 diseases and 5,000 symptoms in its knowledge base and was developed by Laboratory of Computer Science, Massachusetts General Hospital, and Harvard Medical School. Despite its usage in clinician training, similar to other clinical decision support systems, DXplain has not expanded beyond the research laboratory or medical training setting, due in part to a lack of support by clinicians in real-world settings (Coiera 2003).

QMR (Quick Medical Reference): A diagnostic decision-support system with a knowledge base of diseases, diagnoses, findings, disease associations and lab information. With information from the primary medical literature on almost 700 diseases and more than 5,000 symptoms, signs, and labs. Developed in 1980 by the University of Pittsburgh and First Databank, California. QMR was designed for 3 types of use:

- as an electronic textbook;
- as an intermediate level spreadsheet for the combination and exploration of simple diagnostic concepts;
- as an expert consultant program (Miller, Masarie et al. 1986).

Here are some of the most respected information systems laboratories:

PUFF system: automatic interpretation of pulmonary function testing (OpenClinical 1983).

GermWatcher: police hospital infections, comparing national and local criteria (Doherty, Noirot et al. 2006).

PEIRS (Pathology Expert Interpretative Reporting System): interpret 80 to 100 laboratory tests per day, with a diagnostic accuracy of approximately 95% (OpenClinical 1991).

The studies reveal that the CDSS has grown because it has been integrated with other tools. The doctors are still reluctant to adopt the CDSS because it often perturb their routine work and are unreliable. To develop a CDSS, we will have to include the following factors: fast, user-friendly, quick to learn, intelligent and reliable. More importantly, do not disturb the routine of the physician. Finally we can take another conclusion is that the CDSS is inseparable from machine learning.

2.3. Signal processing

Realization of the potential of computer-aided auscultation is supported by decades of research in heart sound analysis, clinical studies employing phonocardiography, and advances in signal processing methods applied to heart sounds.

A significant amount of literature discusses clinical phonocardiography, of which the early encyclopedic work of McKusick (McKusick 1958) serves as an outstanding example, and of which the works of Tavel (Tavel 1985), Leatham (Leatham 1975), and Harris (Harris, Sutton et al. 1976) are representative. These and numerous other studies have helped in identification of the spectral and temporal properties of heart sounds and murmurs, as well as their association with physiological events and diseases. Echocardiography has done much to illuminate and further clarify the process through which heart sounds and murmurs are generated, although problems remain to be solved and processes must be better understood.

Recent works in heart sound analysis have taken advantage of advanced digital signal processing methods to characterize heart sounds and murmurs (for reviews, see Durand (Durand and Pibarot 1995) Lin (Lin and Chen 1996) Obaidat (Obaidat 1993) and Rangayyan (Rangayyan and Lehner 1988)). Specifically, advanced time-frequency methods, especially wavelets, have been identified as having excellent properties for heart sound analysis (Khadra, Matalgah et al. 1991; Bulgrin and Rubal 1994) and have been applied to analysis of the first heart sound (Yoganathan, Gupta et al. 1976; Durand, Chen et al. 1997; Durand, Chen et al. 1997; Durand, Chen et al. 1997), the second heart sound (Yoganathan, Gupta et al. 1976; Xu, Durand et al. 2000), and murmurs (van Vollenhoven, van Rotterdam et al. 1969; Debiais, Durand et al. 1997; Debiais, Durand et al. 1997).

Advanced analysis of heart sounds and murmurs has provided a useful substrate for the design of algorithms for the automatic detection and identification of these sounds. Early approaches used linear classification methods (Iwata, Ogawa et al. 1979) and reported excellent clinical results in murmur detection (Rangaraj and Murthy 1979) and in distinguishing innocent from pathological murmurs (Ninova, Dascalov et al. 1978).

The signal processing is essential to obtain an efficient CDSS. There is significant amount of literature about this topic. Recent studies show significant results in the heartbeat characterization and murmurs detection. The investigation in this area will be fundamental to obtain good results with the DigiScope system. It will be essential to collect a maximum of auscultation to allow researchers to have a relevant database for the investigations in this area and also for the machine learning and CDSS.

3. DigiScope Collector system

3.1. Requirements

Actually, according to the literature search conducted in the first phase of this investigation there is no system to collect and annotate cardiac and pulmonary auscultation to that presented in this research.

We present the following storyboard:

Storyboard part 1

Miss Rosetta Stone came to a consultation with the cardiologist, Jean-François Champollion. The cardiologist used the DigiScope Collector to record all details of the consultation (including heartbeat). He measures the systemic pressure and using the Littmann 3200 stethoscope, the cardiologist auscultates the patient. With this system he can see in real time the heartbeat graph (Figure 4). The cardiologist introduces in the DigiScope Collector the systemic pressure of the patient.

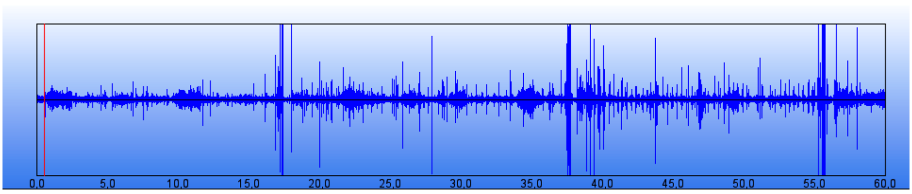


Figure 4 - Heartbeat graph from the auscultation screen of the DigiScope Collector

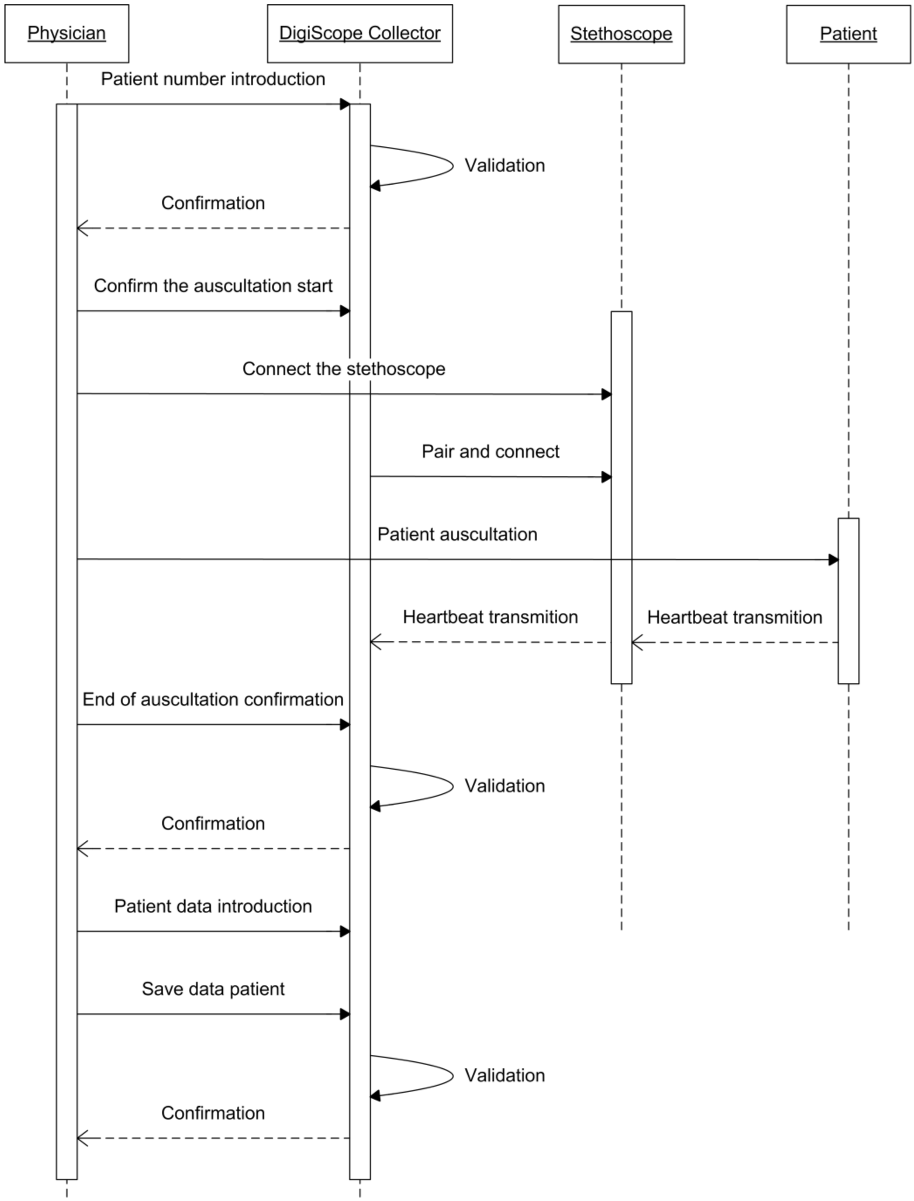


Figure 5 - UML Sequence diagram of a patient auscultation using the DigiScope Collector and the Littmann 3200 stethoscope, and the introduction of patient data.

The Figure 5 shows the sequence of actions of the part 1 of the storyboard:

- The cardiologist introduces the unique number of the patient, generally the internal process number of the hospital;
- The system validates the number. It verifies if the number already exists in the existing process. If the process number exists a pop-up appears to inform the cardiologist.
- The cardiologist press the button Begin to indicates to the system the begin of the auscultation. A popup asking to turn on the stethoscope and confirm if the Bluetooth is blinking. The cardiologist turn on the stethoscope and press the button OK.
- The system searches the stethoscope and when it founds, connects with it.
- A message appears on the stethoscope display asking to the cardiologist to press the M button of the stethoscope when he will begin the auscultation.
- When the cardiologist press the M button, the stethoscope begins the transmission of heartbeat signal and the cardiologist can see a graph of the signal on the screen of the computer (Figure 4).
- After the auscultation, two buttons appears: Add another auscultation and End auscultation. The cardiologist chooses to indicate the end of the auscultation.

The appendix 4 shows the part 1 of the storyboard illustrated with screenshots of the DigiScope Collector.

Storyboard part 2

Due to the high number of patients who have to attend, the cardiologist asks at his medical assistant to complete some basic data (birth, weight, height...) which can be found in the patient record.

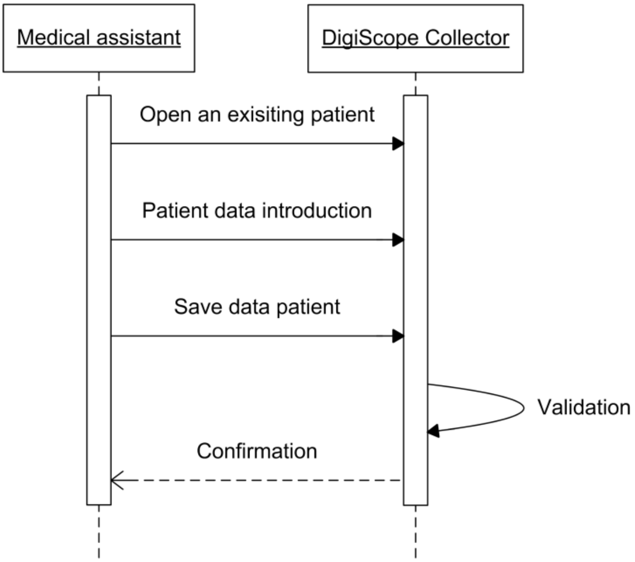


Figure 6 - UML Sequence diagram of the introduction of patient data in the DigiScope Collector

The Figure 6 shows the sequence of actions of the part 2 of the storyboard:

- The medical assistant in the initial menu, select he button Existing patient.
- A table appears with the patient already created. The medical assistant can see for each patient: number id, name, numbers of auscultation recorded and the state of the patient data form (empty, incomplete or complete). The medical assistant selects the name of Rosetta Stone.
- Using the internal information system of the hospital, the medical assistant introduces in the DigiScope Collector form the basic data (birth, weight, height...).

- Finally she presses Save button. The system validates the data in the fields and confirms the existence of any anomaly.

The appendix 5 shows the part 2 of the storyboard illustrated with screenshots of the DigiScope Collector.

Storyboard part 3

At the end of the day, the cardiologist decides to review the case of Miss Rosetta Stones to confirm the diagnosis. He access at the patient form in the DigiScope Collector and decides to hear again the heartbeat using the stethoscope playback function. He confirms the previous diagnosis and records in the form the cardiac pathology (Arterial hypertension).

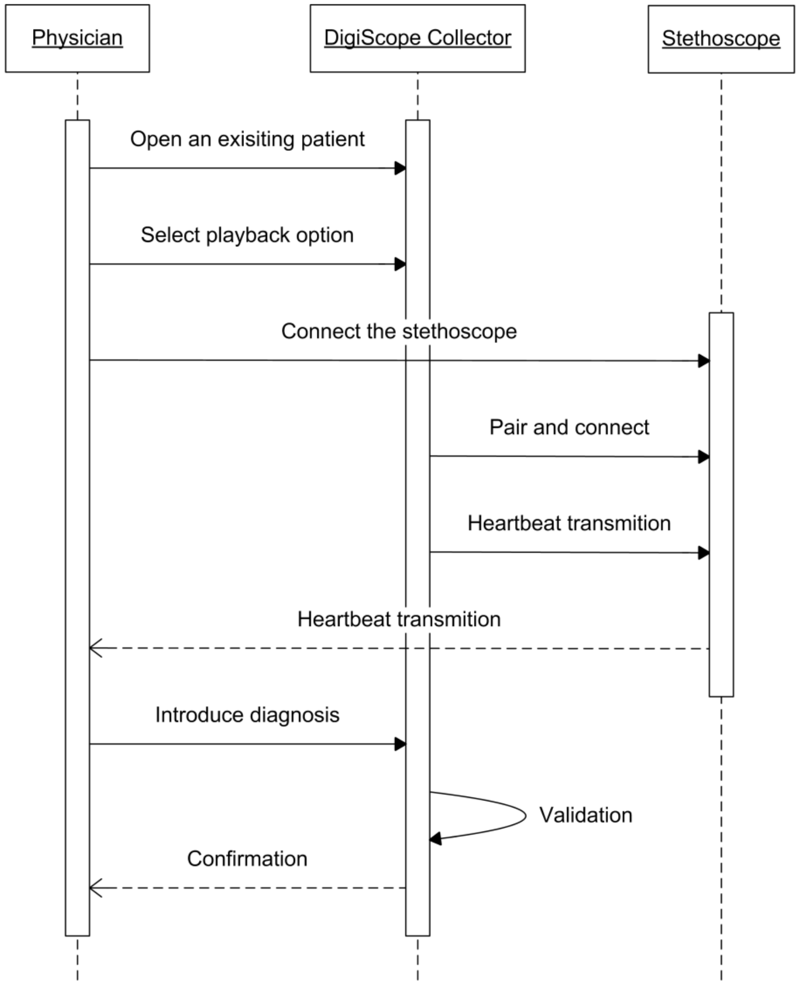


Figure 7 - UML Sequence diagram of the playback of an auscultation record with the DigiScope Collector and the Littmann 3200 stethoscope. And introduction of the diagnosis

The Figure 7 shows the sequence of actions of the part 3 of the storyboard:

- The medical assistant in the initial menu, select he button Existing patient.
- A table appears with the patient already created. The cardiologist can see for each patient: number id, name, numbers of

auscultation recorded and the state of the patient data form (empty, incomplete or complete). He presses the name of Rosetta Stone.

- The form appears with some data introduced. The cardiologist presses the Playback button.
- He is invited by the system to connect the stethoscope.
- After the connection between the stethoscope and the system, a message appears in the display of the stethoscope inviting the cardiologist to press the M button when he is ready to listen the heartbeat recorded.
- After the playback, the cardiologist presses the form button to introduce the diagnosis.
- Finally he presses the Save button.

The appendix 6 shows the part 3 of the storyboard illustrated with screenshots of the DigiScope Collector.

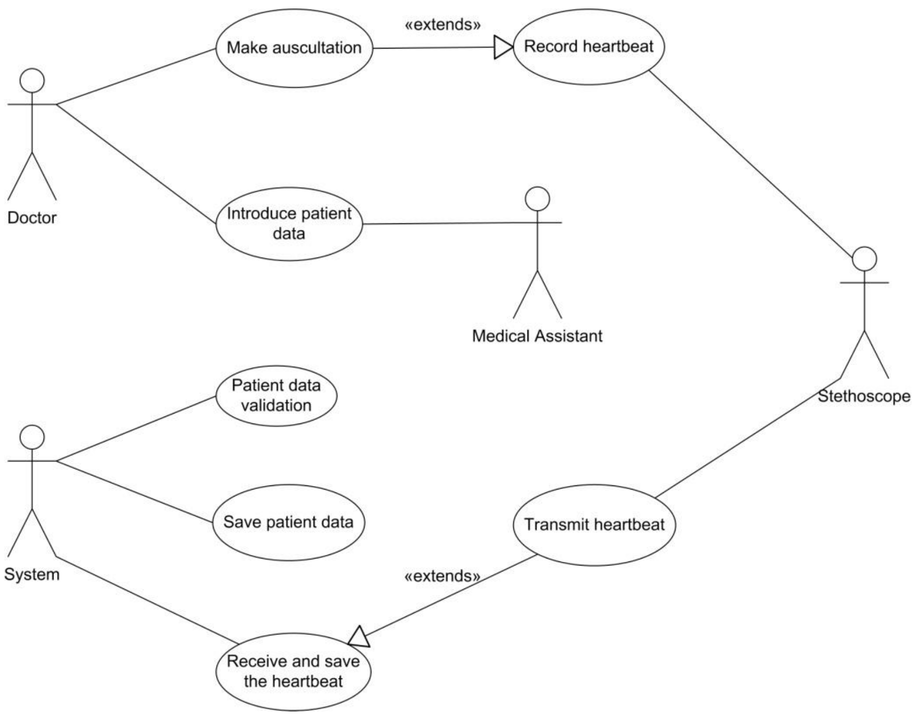


Figure 8 - UML Use case diagram for the storyboard

3.2. System architecture

3.2.1. System model

Figure 9 shows the main components of our system and their respective interactions. The system has four main components:

- Data Collection;
- Signal Processing;
- Machine Learning;
- Data Repository.

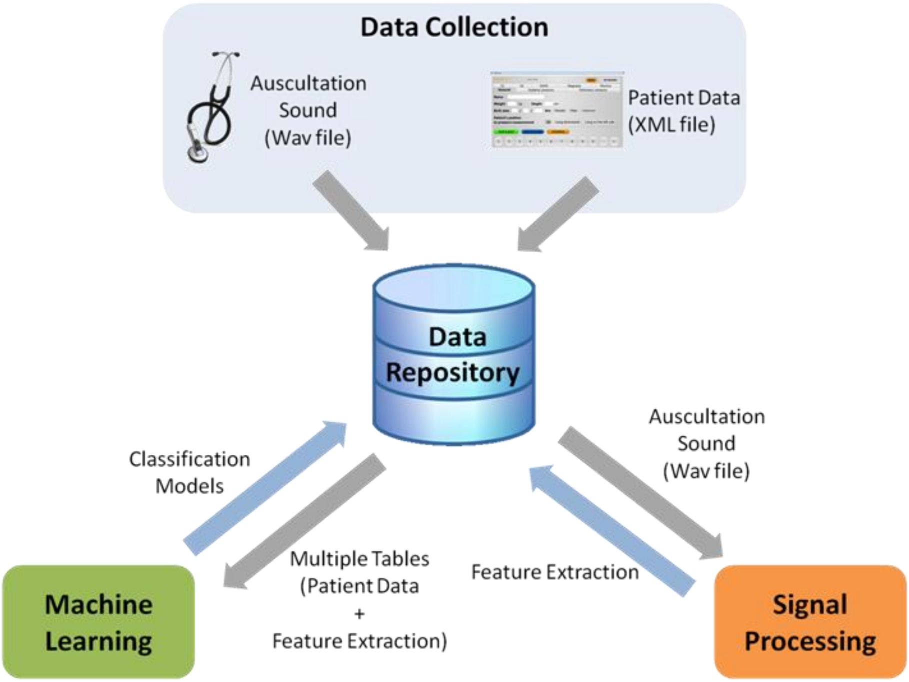


Figure 9 - The DigiScope system model

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 (Norman 2007):

- 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 (Centro Hospitalar do Alto Ave, Guimarães, Portugal, and Real Hospital Português, Recife, Brazil). 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.

Figure 10 - Images of the examination room at Centro Hospitalar do Alto Ave

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 to deploy the future DigiScope system for clinical decision support. 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.

3.2.2. Conceptual model

Two functional conceptual models were produced for the DigiScope Collector and can be observed in Figure 11 and Figure 12. 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. 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 (Bluetooth). 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 or a medical assistant.

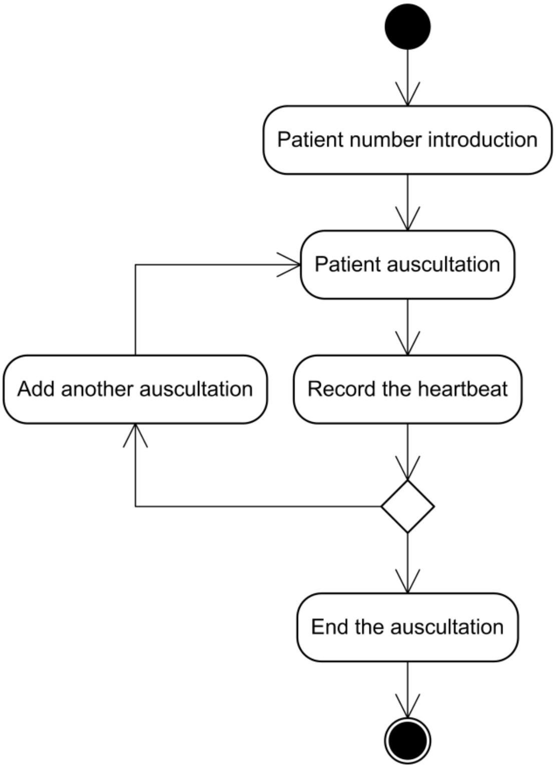


Figure 11 - UML Activity diagram of the data collection model

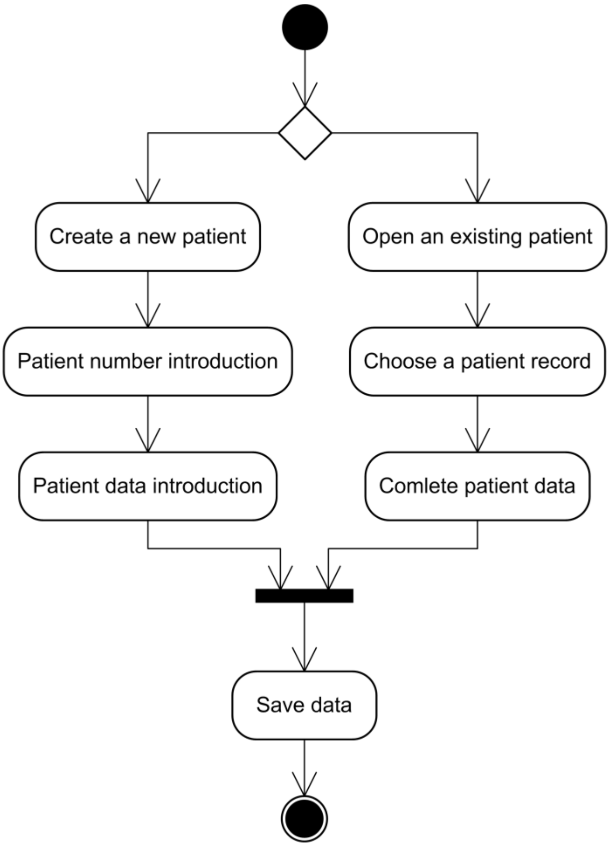


Figure 12 - UML Activity diagram of the data annotation model

3.2.3. Data model

Given the significant amount of data that can be captured each day by this 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 (Radiology 2007)). We then define what patient metadata is interesting for pathology screening, and is viable to be annotated in this context. Contributions to this definition also came from the HL7 standard (Health Level Seven 2011) and openEHR publicly available archetypes (Foundation 2011).

We had the possibility to choose between saving the data in a database or in a XML file. Choosing a database provides a more traditional, fast to query and easy way to store data. XML is easier to use, offers an unparalleled portability and allows to read the file without any specific application. Bearing in mind that we anticipate the evolution of the system is easier using XML A new version of the DigiScope Collector can read older version of the XML, two XML versions can coexist. The choice of XML seemed to us the most pertinent.

Figure 13 shows the XML file created from the data patient entered on the form. It is strutured as follows:

- The red tags represent the form tabs;
- The blue tags correspond to each field or button of the form.;
- The values of the fields (elements) appears in black.

And respect theses rules:

- If a field is not filled or a button is not selected, the tag appears like that: *<Telesystolic />;*
- If a field or a button of the form can not be filled or selected, the tag appears with a NA (Not Available): *<Protodiastolic>**NA**</Protodiastolic>*.

All units of measurement were added to the name of the corresponding field in the XML tag, for example: *<Weight-**kg**>90</Weight-**kg**>*. For each auscultation episode a XML is created with the correspondent patient id. The XML file is stored in a folder named with the patient id. As for each patient there is only one XML file, this file is equaly named with the patient id.

```xml
<?xml version="1.0" encoding="UTF-8"?>
<Patient id="12345">
 <General>
  <Name>John Doe</Name>
  <Weight-kg>90</Weight-kg>
  <Height-cm>200</Height-cm>
  <Day>12</Day>
  <Month>10</Month>
  <Year>1979</Year>
  <Sex>Male</Sex>
  <PressurePosition>Sit</PressurePosition>
  <AuscultationPosition>Sit</AuscultationPosition>
 </General>
 <SystemicPressure>
  <SystemicPressureMethod>Manometry</SystemicPressureMethod>
  <SystolicSystemicPressure-mmHg>145</SystolicSystemicPressure-mmHg>
  <DiastolicSystemicPressure-mmHg>60</DiastolicSystemicPressure-mmHg>
 </SystemicPressure>
 <PulmonaryPressure>
  <PulmonaryPressureMethod>Echocardiogram</PulmonaryPressureMethod>
  <SystolicPulmonaryPressure-mmHg>20</SystolicPulmonaryPressure-mmHg>
  <DiastolicPulmonaryPressure-mmHg>8</DiastolicPulmonaryPressure-mmHg>
  <CatheterismSimultaneousMeasurement> NA</CatheterismSimultaneousMeasurement>
  <EchocardiograSameConsultation>NA</EchocardiograSameConsultation>
 </PulmonaryPressure>
 <Murmur>
  <Cycle>Systolic</Cycle>
  <Protosystolic />
  <Mesosystolic>Yes</Mesosystolic>
  <Telesystolic />
  <Holosystolic />
  <Protodiastolic>NA</Protodiastolic>
  <Mesodiastolic>NA</Mesodiastolic>
  <Telediastolic>NA</Telediastolic>
  <Holodiastolic>NA</Holodiastolic>
  <Grading>3</Grading>
 </Murmur>
 <S1>
  <S1Status>Normal</S1Status>
 </S1>
 <S2>
  <S2Status>Normal</S2Status>
  <IfAbnormal>NA</IfAbnormal>
  <PulmonaryComponent>Normal</PulmonaryComponent>
 </S2>
 <S3>
  <S3Exist>No</S3Exist>
 </S3>
 <S4>
  <S4Exist>No</S4Exist>
 </S4>
 <Diagnosis>
  <CardiacPathology>Yes</CardiacPathology>
  <PulmonaryHypertension />
  <ArterialHypertension>Yes</ArterialHypertension>
  <ValvularAorticDisease>Yes</ValvularAorticDisease>
  <IntraventricularCommunication />
  <OtherCardiacPathology />
 </Diagnosis>
 <FormStatus>
  <StatusForm>Complete</StatusForm>
 </FormStatus>
</Patient>
```


Figure 13 - XML of the patient data form

However, being aware that for the next version of the system it will be necessary to use a server to keep the data. It becomes essential to use a database to the server. In Figure 14, we propose a database model. 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 (Ghamrawi and McCallum 2005)).
- Relations between medication and patient health status.

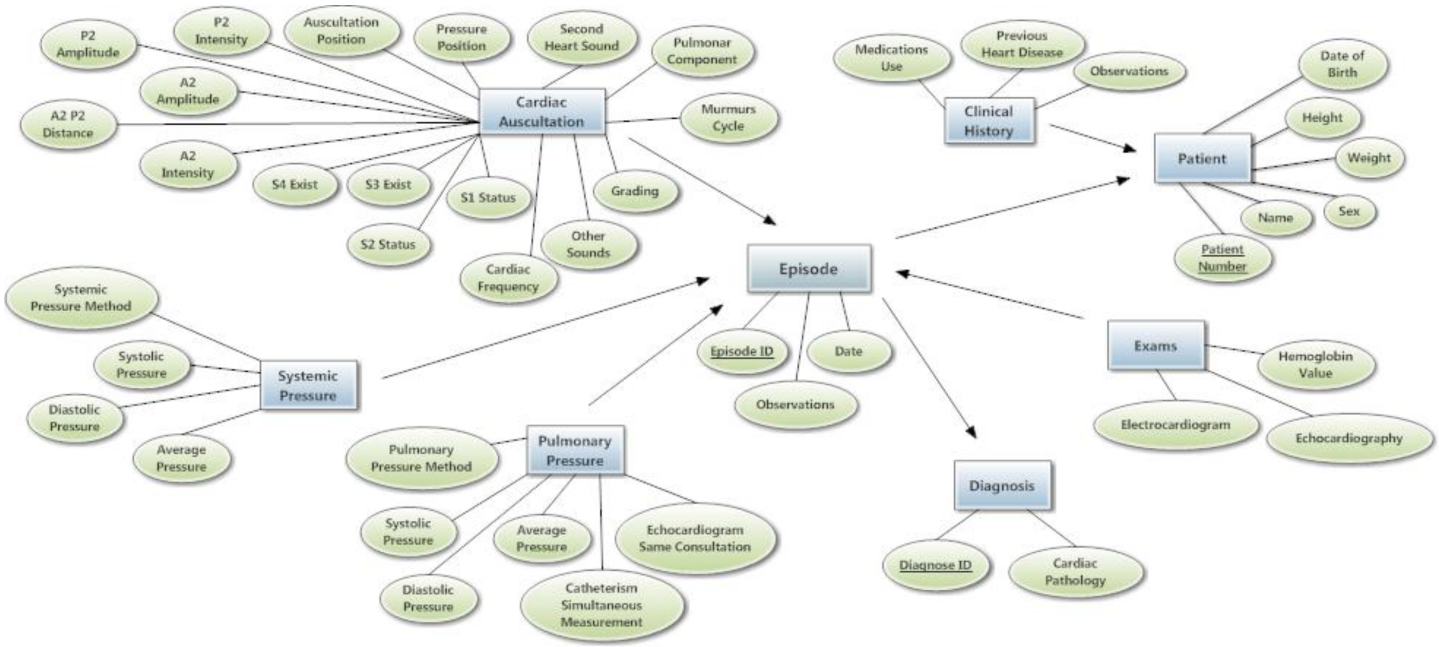


Figure 14 - Preview of the data model for the DigiScope server

3.3. Implementation

3.3.1. Prototype technology

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 (2010). 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 3.2.1 (minimize disruption). Figure 16 shows an image of the final version of the hardware prototype.

Figure 15 – Littmann 3200 stethoscope

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).

Figure 16 - Image of the DigiScope Collector hardware prototype

As can be seen in Figure 17, the heart sounds are recorded in WAV format, and the patient data (see section 3.2.3) is saved in a XML format (Figure 13). The data are kept in a folder for each patient. At the end of each day, all the data is sent to a database on a secure server. The application was developed using Netbeans IDE 6.9.1 (Oracle 2010) on a Java platform version 6. The Bluecove API (2008) was used to establish the communication between the system and the stethoscope.

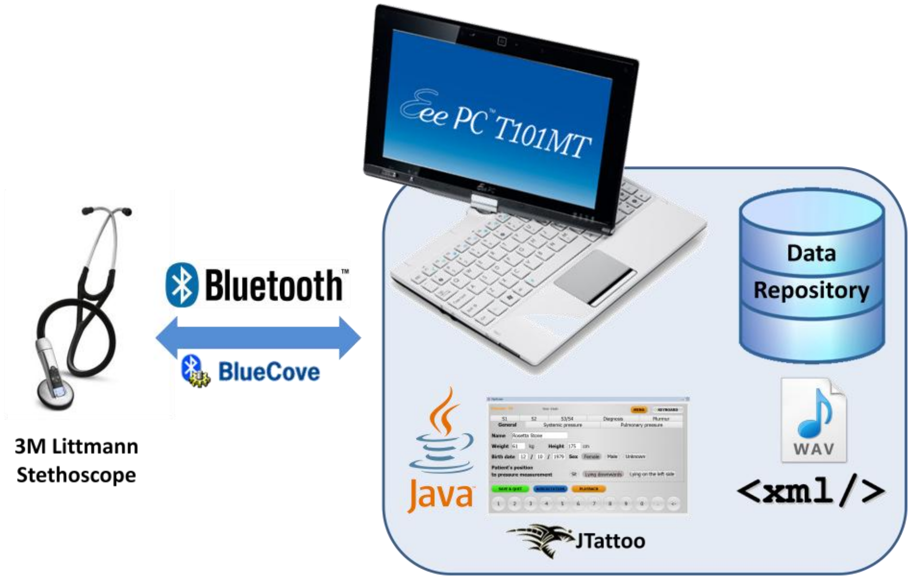


Figure 17 - The DigiScope Collector technologies

3.3.2. User interface

As motivated previously, our conceptual design is focused on the three generic usability requirements (Wyatt and Wright 1998) described in Section 3.2.2. 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 (Figure 11). During this phase, the proposed system suggests only two options (Figure 18), which can be selected using large buttons placed in the center of the screen, thus heavily constraining the user to simplify his understanding and reduce possible errors. The secondary options are proposed with smaller buttons and placed in the top of the screen.

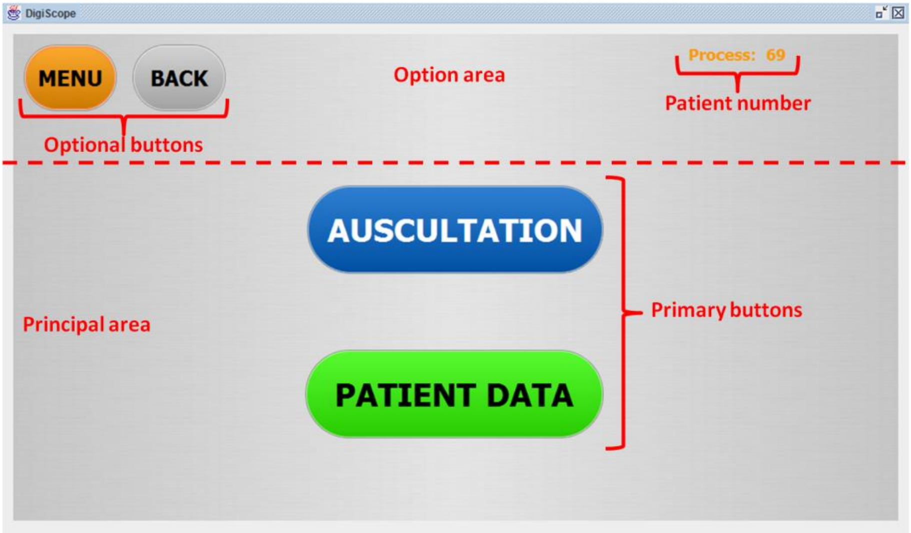
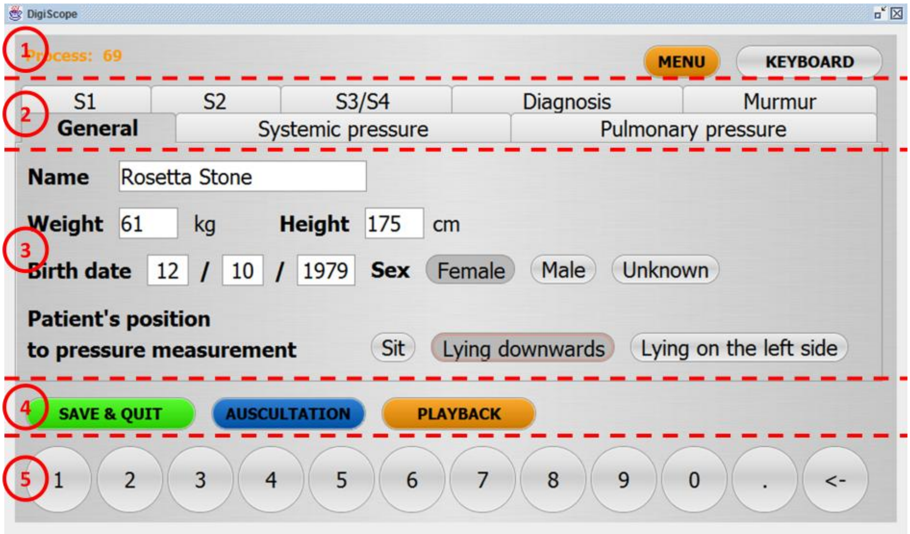


Figure 18 - Screenshot showing the menu after the process number introduction

In a second phase (Figure 12), 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, and Diagnosis. 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 (Figure 19 and Figure 20), typing errors are inevitable, we have used toggle 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. When the button "Save & Quit" is pressed, the fields are validated, that limit the numbers of errors. If an error is detected, for example an invalid date or letters in a numeric field, the tab where is localized the error is selected and the label field where is the error appears in red.

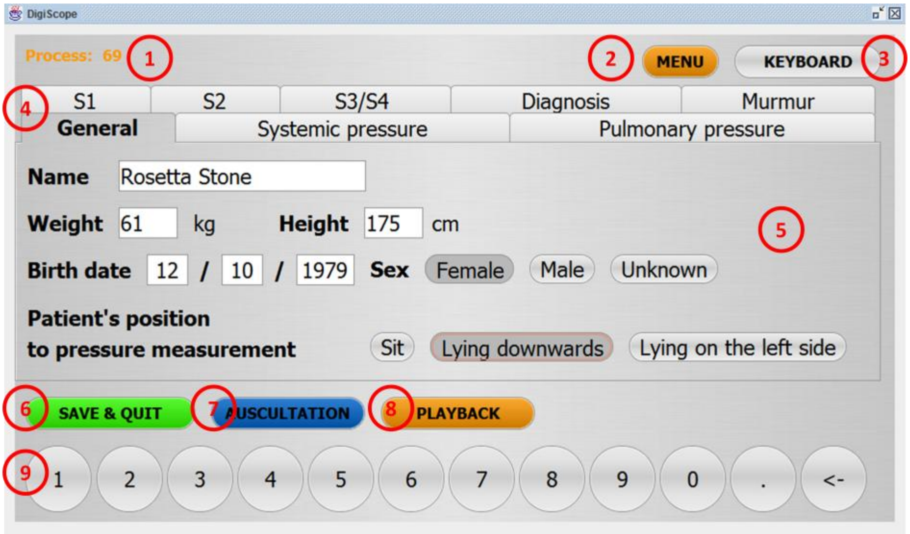
From the main menu, the physician can access a table which lists all patients who have already been introduced in the application. In this table he can see:

the patient number, name, date of release, the state of the form (blank, incomplete or complete) and how many hearings have already been added.



1 – Information & optional buttons
2 – Tabs for browsing
3 – Introduction area
4 – Main buttons
5 – Numeric keyboard

Figure 19 - The five areas of the patient data form



1 – Process of the patient
2 – Back to the main menu
3 – Open a virtual keyboard
4 – Forms tabs
5 – Patient data fields
6 – Save and back to the main menu
7 – Add an auscultation
8 – Listen saved auscultation
9 – Virtual numeric keyboard

Figure 20 - The buttons of the patient data form

3.3.3. Problems

During the development of the application we found several problems, from the connectivity to the design through programming.

Initially the main problem was to understand the various medical routines and found technological solutions and a design that capture the data without disturbing these routines. The chosen technology is described and explained in the section 3.3.1. For the design, we chose to propose two functional modes (See sections 3.2.2 – Conceptual model and 4.3.2 – User interface). Regarding the design, the major challenge was to create a user friendly form with almost 40 fields.

The other major problem was the communication between the Littmann Model 3200, the Asus Eee PC and the application. First, we encounter difficulty to found the communication protocol. The second surge during our tests at the hospital, the Bluetooth communication is very sensitive. When the doctor was placed between the stethoscope and the computer, the communication is broken. We had put an external Bluetooth adapter (Class 1 - 100 mW/20 dBm) to increase the signal power, but without success. Actually we continue working to solve this problem.

Finally, we found another problem, the distance. The Portuguese hospital was at 50 km from our lab, but the other hospital was in Brazil, most than 8500 km and 4 times zones. We had to adapt our schedules and find tools to work remotely, for that we choose TeamViewer (2011).

4. System evaluation

4.1. Methods

We have adopted two methods to evaluate the system:

- Observational study
- The Questionnaire for User Interaction Satisfaction (QUIS)

Observational study

For the observational study, we had created a questionnaire (see Appendix 7) to collect the data. The observational study took place at the Centro Hospitalar do Alto Ave in Guimarães in an exam room. We have seen 20 cardiology consultations spread over three days. 13 consultations were performed by the cardiologist Filipa Almeida and the others 7 by the cardiologist Marina Fernandes. To respect the privacy of patients, we chose to only observe consultations of male patients.

Questionnaire

To understand usability it is important to not only measure user performance (effectiveness and efficiency) but also satisfaction. The utilization of an established questionnaire gives more reliable and repeatable results than ad hoc questionnaires. A large number of questionnaires have been developed to assess the user's subjective satisfaction of the system and related issues. However, few have focused exclusively on user evaluations of the interface (Chin, Diehl et al. 1988). We can highlight the three most important:

- System Usability Scale (SUS) is a 10-item questionnaire, developed by John Brooke, that gives an overview of satisfaction with software;
- Software Usability Measurement Inventory (SUMI) is a 50 item questionnaire that measures five aspects of user satisfaction (Likability, Efficiency, Helpfulness, Control and Learnability), and scores them against expected industry norms.
- Questionnaire for User Interaction Satisfaction (QUIS), developed by the University of Maryland, is similar to SUMI, but measures attitude towards eleven interface factors (screen factors, terminology and system feedback, learning factors, system capabilities, technical manuals, on-line tutorials, multimedia, voice recognition, virtual environments, internet access, and software installation).

We chose QUIS because it is the most complete and oriented to the user interface satisifaction. Inicialy the QUIS is composed by twelve independents parts, but we select only the relevant parts of questionnaire for this evaluation (see Appendix 8):

- System Experience
- Past Experience
- Overall User Reactions
- Screen
- Terminology and System Information
- Learning
- System Capabilities

The fifth last parts are not relevant for the moment for our evaluation:

- Technical Manuals and On-line help
- On-line Tutorials
- Multimedia
- Teleconferencing
- Software Installation

We had an incial part at the questionnaire called User definition, to understand the technbological profile of our users.

While working with teams in Brazil, we decided to put the questionnaire online in order to facilitate the sending of the same and the collect of the data. We use the MedQuest (Gomes 2010), a tool for web questionnaires in the health area. The questionnaire was sent to only 5 persons (3 cardiologists, 1 medicine student and 1 medical secretary). It was decided to opt for this low number because they are the only people who regularly work with the system.

Unfortunately at this moment, we have not received all the answers to the questionnaire which made it impossible to have results for this thesis.

4.2. Results

The following results are common to the 20 patients:

- Patient's position to auscultation: Sit
- Patient's position to pressure measurement: Sit
- Number of times the tension was measured: 1
- Patient with disease: Yes
- First visit: No
- The patient was created during the consultation: Yes
- The form was completed immediately following the hearing: No
- The form was completed: Partially
- Doctor position: Standing
- System localization: Desk

Table 1 – Results of the observational study: Patient age and duration of the consultation, application utilization, pressure measurement and auscultation.

		Duration (mm:ss)			
Patient ID	**Age (Year)**	**Consultation**	**Application utilization**	**Pressure measurement**	**Auscultation**
1	45	14:46	01:35	00:50	00:47
2	43	08:50	01:30	00:47	00:51
3	47	16:15	01:21	00:50	00:45
4	65	14:30	01:35	00:50	00:55
5	62	24:00	01:25	00:56	00:54
6	78	14:00	01:34	00:53	00:56
7	40	10:10	01:23	00:52	00:55
8	38	12:35	01:22	00:48	00:54
9	41	20:08	01:30	00:49	00:56
10	46	11:10	01:27	00:53	00:51
11	55	14:00	01:29	00:54	00:53
12	67	14:23	01:34	00:52	00:53
13	56	17:55	01:32	00:56	00:56
14	49	13:54	01:29	00:49	00:55
15	50	15:05	01:35	00:48	00:54
16	54	10:20	01:44	00:53	00:57
17	67	12:10	01:39	00:48	00:53
18	68	14:50	01:34	00:55	00:55
19	62	13:40	01:26	00:56	00:57
20	59	12:25	01:45	00:58	00:58
Mean	54,6	14:16	01:31	00:52	00:54
Median	54,5	14:00	01:30	00:52	00:55
Maximum	78	24:00	01:45	00:58	00:58
Minimum	38	08:50	01:21	00:47	00:45

In all cases, the physician measures the systemic pressure and only after auscultates the patient.

Others results:

The examination room was brightly lit leading to very existence of reflections on the screen of the system. Another important point is the sound stage. The windows facing the street were always open which increased the noise (ambulances, cars, etc.). Another source of noise came from the next room and hallway.

The doctor always used, for the measurement of systemic pressure and lung auscultation, her stethoscope classic, a Littmann Master Classic II.

4.3. Interpretation/Discussion

After analyzing the previous results, we suggest:

- Allowing at the physician to insert the systemic pressure value in the auscultation screen;
- In all cases, the duration of auscultation is less than 60 seconds, a mean of 54 seconds. And by default, the DigiScope Collector record during 60 seconds. It will important to resolve a technical problem and allow at the physician to define the duration of the auscultation, a good solution will be using the stethoscope M button to inform the system of the start and the end of the auscultation.
- Remove the noise environment of the recording heartbeat will be a fundamental task for the signal processing team.
- It would be important to accustom the doctor to the electronic stethoscope using it in his every day.

5. Discussion

5.1. Conclusion

In this work, we proposed as main objective the creation of a prototype that can gather a large annotated database for cardiology signal processing and machine learning working prototype of a system capable of recording and annotating heart sounds. We can conclude the goal was accomplished. The results show that the DigiScope Collector, although at an advanced stage of development and was implemented in two hospitals, needs some improvements and corrections.

Although the evaluation to be a little advanced state, it was possible to detect some weaknesses that can and should be corrected. One of the critical points is without doubt the connectivity problems found. The other point is to increase the portability of the system is fundamental to collect in the emergency room.

The development and the evaluation of the DigiScope Collector will continue to confirm these preliminary results and improve them.

However we can conclude this work is well under way and has begun to yield results. It was possible to collect 200 pediatric auscultations with this prototype in the Real Hospital Português (Recife – Brazil), and 25% of them are fully annotated and we expected to double this last number very quickly. Also the Centro Hospilar do Alto Ave is beginning the collect of auscultation.

5.2. Future work

A technological solution for digital auscultation has been developed and deployed within the DigiScope project. However, this solution was designed for data collection and technology validation, therefore, as future work, we propose to develop the following tasks:

- Further the evaluation of the system. Continuing the observational studies. Collect papers and conducting its analysis. Finally, examine the logs.
- Evolve the current DigiScope Collector prototype to a CDSS;
- Design and develop an interactive solution using digital stethoscopes for medical student training;
- Explore the potential of voice as a new interaction paradigm for DigiScope.

The DigiScope Collector was only the first step of the DigiScope project.

6. References

. "Littmann Electronic 3200 Stethoscope Review." Retrieved March 2011, 2011, from http://solutions.3m.com/wps/portal/3M/en_US/Littmann_3100_3200/stethoscope/?#Model3200.

(2008). "BlueCove." Retrieved March 2011, 2011.

(2010). "Electronic Stethoscope Market Survey 2010." Retrieved March 2011, 2011, from http://www.telehealthtac.org/toolkits/electronic-stethoscopes.

(2011). "TeamViewer." Retrieved September 2011, 2011, from http://www.teamviewer.com/pt/index.aspx.

Abella, M., J. Formolo, et al. (1992). "Comparison of the acoustic properties of six popular stethoscopes." J Acoust Soc Am **91**(4 Pt 1): 2224-2228.

Andres, E., C. Brandt, et al. (2008). "[From the interest of sounds characterization to the auscultatory school creation]." Presse Med **37**(6 Pt 1): 925-927.

Asghar, O., U. Alam, et al. (2010). "Cardiac auscultation: the past, present and future." The British Journal of Cardiology **17**(6).

Barnett, G. O., J. J. Cimino, et al. (1987). "DXplain. An evolving diagnostic decision-support system." JAMA **258**(1): 67-74.

Bredesen, M. S. and E. D. Schmerler (1988). Intelligent Stethoscope, Bloodline Technology. **5010889**.

Brogan, F. A., F. G. Collins, et al. (1967). "An experimental electronic stethoscope for aircraft use. A preliminary report. SAM-TR-67-39." Tech Rep SAM-TR: 1-8.

Brusco, M. and H. Nazeran (2005). "Development of an Intelligent PDA-based Wearable Digital Phonocardiograph." Conf Proc IEEE Eng Med Biol Soc **4**: 3506-3509.

Bulgrin, J. and B. Rubal (1994). "Time-frequency analysis of heart sounds." Scientific Computing and Automation: 15-21.

Burnside, E. S., J. Davis, et al. (2005). "Knowledge discovery from structured mammography reports using inductive logic programming." AMIA Annu Symp Proc: 96-100.

Charbonneau, G. and M. Sudraud (1985). "[Measurement of the frequency response of several stethoscopes in common use. Consequences for cardiac and pulmonary auscultation]." Bull Eur Physiopathol Respir **21**(1): 49-54.

Chin, J. P., V. A. Diehl, et al. (1988). Development of an instrument measuring user satisfaction of the human-computer interface. Proceedings of the SIGCHI conference on Human factors in computing systems. Washington, D.C., United States, ACM**:** 213-218.

Coiera, E. (2003). The Guide to Health Informatics. London, Arnold.

Davis, J., E. Burnside, et al. (2007). Learning a New View of a Database: With an Application in Mammography. Introduction to Statistical Relational Learning. L. G. B. Taskar, MIT Press.

Davis, J., E. Burnside, et al. (2005). "An integrated approach to learning Bayesian networks of rules." Machine Learning: Ecml 2005, Proceedings **3720**: 84-95.

Debiais, F., L. G. Durand, et al. (1997). "Time-frequency analysis of heart murmurs. Part II: Optimisation of time-frequency representations and performance evaluation." Medical & Biological Engineering & Computing **35**(5): 480-485.

Debiais, F., L. G. Durand, et al. (1997). "Time-frequency analysis of heart murmurs. Part I: Parametric modelling and numerical simulations." Medical & Biological Engineering & Computing **35**(5): 474-479.

Delaney, B. C., D. A. Fitzmaurice, et al. (1999). "Can computerised derision support systems deliver improved duality in primary care?" British Medical Journal **319**(7220): 1281-U1211.

Dick, R. S., E. B. Steen, et al. (1997). The Computer-Based Patient Record: An Essential Technology for Health Care, Revised Edition, National Academy Press.

Doherty, J., L. A. Noirot, et al. (2006). "Implementing GermWatcher, an enterprise infection control application." AMIA Annu Symp Proc: 209-213.

Durand, L. G., D. Chen, et al. (1997). "Time-frequency analysis of the first heart sound. Part 2: An appropriate time-frequency representation technique." Medical & Biological Engineering & Computing **35**(4): 311-317.

Durand, L. G., D. Chen, et al. (1997). "Time-frequency analysis of the first heart sound. Part 1: Simulation and analysis." Medical & Biological Engineering & Computing **35**(4): 306-310.

Durand, L. G., D. Chen, et al. (1997). "Time-frequency analysis of the first heart sound: Part 3: Application to dogs with varying cardiac contractility and to patients with mitral mechanical prosthetic heart valves." Medical & Biological Engineering & Computing **35**(5): 455-461.

Durand, L. G. and P. Pibarot (1995). "Digital signal processing of the phonocardiogram: review of the most recent advancements." Crit Rev Biomed Eng **23**(3-4): 163-219.

Eccles, M., E. McColl, et al. (2002). "Effect of computerised evidence based guidelines on management of asthma and angina in adults in primary care: cluster randomised controlled trial." BMJ **325**(7370): 941.

Ertel, P. Y., M. Lawrence, et al. (1969). "How to test stethoscopes." Med Res Eng **8**(1): 7-17.

Foundation, o. (2011). openEHR.

Ghamrawi, N. and A. McCallum (2005). Collective multi-label classification. Proceedings of the 14th ACM international conference on Information and knowledge management. Bremen, Germany, ACM**:** 195-200.

Gomes, J. A. J. (2010). Medquest - Uma ferramenta web para questionários na área da saúde. Faculty of Medicine. Porto, University of Porto.

Grenier, M. C., K. Gagnon, et al. (1998). "Clinical comparison of acoustic and electronic stethoscopes and design of a new electronic stethoscope." Am J Cardiol **81**(5): 653-656.

Harris, A., G. Sutton, et al. (1976). Physiological and Clinical Aspects of Cardiac Auscultation. Philadelphia, JB Lippincott.

Health Level Seven, I. (2011). HL7.

Hedayioglu, F. D., M. T. Coimbra, et al. (2009). "A Survey of Audio Processing Algorithms for Digital Stethoscopes." Healthinf 2009: Proceedings of the International Conference on Health Informatics: 425-429.

Hedayioglu, F. L., S. S. Mattos, et al. (2007). "Development of a tele-stethoscope and its application in pediatric cardiology." Indian J Exp Biol **45**(1): 86-92.

Hoyte, H., T. Jensen, et al. (2005). "Cardiac auscultation training of medical students: a comparison of electronic sensor-based and acoustic stethoscopes." BMC Med Educ **5**(1): 14.

Iversen, K., A. Sogaard Teisner, et al. (2006). "Effect of teaching and type of stethoscope on cardiac auscultatory performance." Am Heart J **152**(1): 85 e81-87.

Iwata, A., N. Ogawa, et al. (1979). "Automatic classification of phonocardiogram. Processed by linear predictive analysis." Japanese Journal of Medical Electronics and Biological Engineering **17**: 185-192.

Khadra, L., M. Matalgah, et al. (1991). "The Wavelet Transform and Its Applications to Phonocardiogram Signal Analysis." Medical Informatics **16**(3): 271-277.

Kindig, J. R., T. P. Beeson, et al. (1982). "Acoustical performance of the stethoscope: a comparative analysis." Am Heart J **104**(2 Pt 1): 269-275.

Leatham, A. (1975). Auscultation of the Heart and Phonocardiography. Edinburgh, Churchill Livingstone.

Liang, H., S. Lukkarinen, et al. (1997). "Heart sound segmentation algorithm based on heart sound envelogram." Computers in Cardiology 1997, Vol 24 **24**: 105-108.

Liang, H. Y. and I. Hartimo (1998). "A feature extraction algorithm based on wavelet packet decomposition for heart sound signals." Proceedings of the Ieee-Sp International Symposium on Time-Frequency and Time-Scale Analysis: 93-96.

Lin, Z. Y. and J. D. Chen (1996). "Advances in time-frequency analysis of biomedical signals." Critical Reviews in Biomedical Engineering **24**(1): 1-72.

McKusick, V. A. (1958). Cardiovascular sound in health and disease. Baltimore, Williams & Wilkins.

Miller, R., F. E. Masarie, et al. (1986). "Quick medical reference (QMR) for diagnostic assistance." MD Comput **3**(5): 34-48.

Ninova, P. P., I. K. Dascalov, et al. (1978). "Automated Phonocardiographic Screening for Heart-Disease in Children." Cardiology **63**(1): 5-13.

Norman, D. (2007). The Design of Everyday Things. New York, Doubleday Business.

Obaidat, M. S. (1993). "Phonocardiogram Signal Analysis - Techniques and Performance Comparison." Journal of Medical Engineering & Technology **17**(6): 221-227.

Omran, S. and M. Tayel (2003). "A heart sound segmentation and feature extraction algorithm using wavelets." Proceedings of the 46th IEEE International Midwest Symposium on Circuits & Systems, Vols 1-3: 392-395.

Ong, I. M., I. D. Dutra, et al. (2005). "Mode directed path finding." Machine Learning: Ecml 2005, Proceedings **3720**: 673-681.

OpenClinical. (1983). "PUFF system." Retrieved September, 2011, from http://www.openclinical.org/aisp_puff.html.

OpenClinical. (1991). "PEIRS - Pathology Expert Interpretative Reporting System." Retrieved September, 2011, from http://www.openclinical.org/aisp_peirs.html.

Oracle. (2010). "NetBeans IDE 6.9.1 Release Information." Retrieved June 2011, 2011, from http://netbeans.org/community/releases/69/.

Osheroff, J. A., E. A. Pifer, et al. (2005). Improving Outcomes with Clinical Decision Support: An Implementer's Guide. Chicago, Healthcare Information and Management Systems Society.

Perreault and Metzger (1999). "A pragmatic framework for understanding clinical decision support." Journal of Healthcare Information Management.

Radiology, A. C. o. (2007). Breast Imaging-Reporting and Data System.

Rangaraj, M. R. and I. S. Murthy (1979). "Quantitative analysis of the phonocardiogram for dectection of murmurs." J Biomed Eng **1**(4): 247-252.

Rangayyan, R. M. and R. J. Lehner (1988). "Phonocardiogram Signal Analysis - a Review." Crc Critical Reviews in Biomedical Engineering **15**(3): 211-236.

Salvini, R., E. Aguilar, et al. (2007). Skimmed Classifiers. International Conference on Inductive Logic Programming.

Short, D., M. Frischer, et al. (2004). "Barriers to the adoption of computerised decision support systems in general practice consultations: a qualitative study of GPs' perspectives." International Journal of Medical Informatics **73**(4): 357-362.

Sullivan, F. and E. Mitchell (1995). "Has general practitioner computing made a difference to patient care? A systematic review of published reports." BMJ **311**(7009): 848-852.

Sverdrup, O., T. Jensen, et al. (2010). "Training auscultatory skills: computer simulated heart sounds or additional bedside training? A randomized trial on third-year medical students." BMC Med Educ **10**: 3.

Tavel, M. E. (1985). Clinical Phonocardiography and External Pulse Recording, Mosby.

Tavel, M. E. (2006). "Cardiac auscultation: a glorious past--and it does have a future!" Circulation **113**(9): 1255-1259.

Tavel, M. E., D. D. Brown, et al. (1994). "Enhanced auscultation with a new graphic display system." Arch Intern Med **154**(8): 893-898.

van Vollenhoven, E., A. van Rotterdam, et al. (1969). "Frequency analysis of heart murmurs." Med Biol Eng **7**(2): 227-232.

Wyatt, J. and D. Spiegelhalter (1992). "Field Trials of Medical Decision-Aids - Potential Problems and Solutions." Fifteenth Annual Symposium on Computer Applications in Medical Care: 3-7.

Wyatt, J. C. (2000). "Decision support systems." J R Soc Med **93**(12): 629-633.

Wyatt, J. C. and D. G. Altman (1995). "Prognostic Models - Clinically Useful or Quickly Forgotten - Commentary." British Medical Journal **311**(7019): 1539-1541.

Wyatt, J. C. and J. L. Liu (2002). "Basic concepts in medical informatics." J Epidemiol Community Health **56**(11): 808-812.

Wyatt, J. C. and P. Wright (1998). "Design should help use of patients' data." Lancet **352**(9137): 1375-1378.

Xu, J., L. G. Durand, et al. (2000). "Nonlinear transient chirp signal modeling of the aortic and pulmonary components of the second heart sound." IEEE Trans Biomed Eng **47**(10): 1328-1335.

Yoganathan, A. P., R. Gupta, et al. (1976). "Use of the fast Fourier transform in the frequency analysis of the second heart sound in normal man." Med Biol Eng **14**(4): 455-460.

Yoganathan, A. P., R. Gupta, et al. (1976). "Use of the fast Fourier transform for frequency analysis of the first heart sound in normal man." Med Biol Eng **14**(1): 69-73.

Appendix

Appendix 1 – Paper entitled "DigiScope – Unobtrusive Collection and Annotating of Auscultations in Real Hospital Environments", presented at the 33rd Annual International IEEE EMBS Conference, at Boston (USA) in 2011

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..

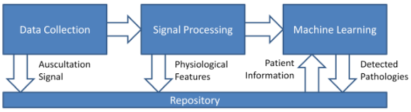

Fig.1: The DigiScope System Model

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

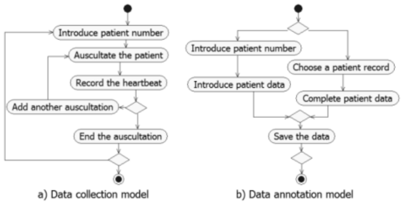

Fig. 2: Functional conceptual models of the DigiScope data collection system.

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).

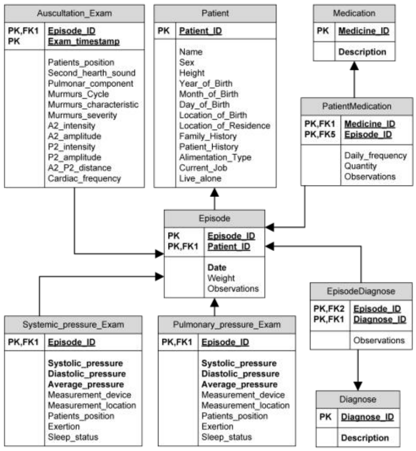

Figure 4: Digiscope data model

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.

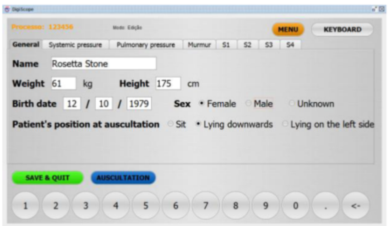

Fig. 6: Screenshot showing the first tab of the patient data form.

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.

References

[1] L. G. Durand and P. Pibarot, "Digital signal processing of the phonocardiogram: review of the most recent advancements," Crit Rev Biomed Eng, vol. 23, pp. 163-219, 1995.

[2] M. Brusco and H. Nazeran, "Development of an Intelligent PDA-based Wearable Digital Phonocardiograph," Conf Proc IEEE Eng Med Biol Soc, vol. 4, pp. 3506-9, 2005.

[3] F. L. Hedayioglu, et al., "Development of a tele-stethoscope and its application in pediatric cardiology," Indian J Exp Biol, vol. 45, pp. 86-92, Jan 2007.

[4] M. E. Tavel, et al., "Enhanced auscultation with a new graphic display system," Arch Intern Med, vol. 154, pp. 893-8, Apr 25 1994.

[5] F. Hedayioglu, et al., "A Survey of Audio Processing Algorithms for Digital Stethoscopes," presented at the Proc. of HealthInf, Porto, Portugal, 2009.

[6] D. A. Norman, The Design of Everyday Things: MIT Press, 2002.

[7] T. T. A. Center. Electronic Stethoscope Market Survey 2010. Available: www.telehealthtac.org, visited March 2011

[8] L. E. S. R. Site. Littmann Electronic 3200 Stethoscope Review. Available: http://littmannelectronicstethoscopes.com, visited March 2011

[9] BlueCove. BlueCove JSR-82 project. Available: http://bluecove.org/, visited March 2011

[10] A. C. o. Radiology, "Breast Imaging Reporting and Data System (BIRADSTM)," ed, 1998.

[11] H. L. S. I.-. HL7, "HL7 - Cardiology," ed, 2011.

[12] CKM. OpenEHR Clinical Knowledge Manager. Available: www.openehr.org/knowledge, visited April 2011

[13] N. Ghamrawi and A. McCallum, "Collective multi-label classification," presented at the Proceedings of the 14th ACM international conference on Information and knowledge management, Bremen, Germany, 2005.

[14] J. C. Wyatt and P. Wright, "Design should help use of patients' data," Lancet, vol. 352, pp. 1375-8, Oct 24 1998.

Appendix 2 – Paper entitled "DigiScope – Unobtrusive Collection and Annotating of Auscultations in Real Hospital Environments", presented at the the 17th edition of the Portuguese Conference on Pattern Recognition (RecPad), at Porto (Portugal) in 2011

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

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Abstract

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.

1 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 [3]. Several electronically enhanced and digital stethoscopes have been developed and described in literature [1] [4] [6]. 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.

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.

2 Conceptual design

2.1 System model

The system has four main components: (1) Data Collection, (2) Signal Processing, (3) Machine Learning and (4) Data Repository.

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 [5]:

- 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.

2.2 Conceptual model

Two functional conceptual models were produced for the DigiScope system: one for data collection and the other for data annotation. In the data collection 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 patientâĂŹs data, or this can be also done by a nurse.

2.3 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 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. Fig. 1 shows an image of the final version of the hardware prototype.

Figure 1: The DigiScope prototype

3 Data model

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 [2]).
- Relations between exams of the same patient and other patients.
- Relations between medication and patient health status.

4 System image

As motivated previously, our conceptual design is focused on the three generic usability requirements. 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. During this phase (Fig. 2), 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

Figure 2: Screenshots showing the initial menu and the menu after the recording of auscultation

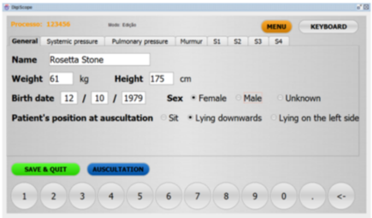

Figure 3: Screenshot showing the first tab of the patient data form

second phase, 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. 3), 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.

5 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 centred 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.

References

[1] M. Brusco and H. Nazeran. Development of an Intelligent PDA-based Wearable Digital Phonocardiograph. *Conf Proc IEEE Eng Med Biol Soc*, 4:3506–3509, 2005.

[2] T. T. A. Center. Electronic stethoscope market survey 2010, March 2011. URL `www.telehealthtac.org`.

[3] L. G. Durand and P. Pibarot. Digital signal processing of the phonocardiogram: review of the most recent advancements. *Crit Rev Biomed Eng*, 23:163–219, 1995.

[4] F. L. Hedayioglu et al. Development of a tele-stethoscope and its application in pediatric cardiology. *Indian J Exp Biol*, 45:86–92, Jan 2007.

[5] D. A. Norman. *The Design of Everyday Things*. MIT Press, 2002.

[6] M. E. Tavel, D. D. Brown, and D. Shander. Enhanced auscultation with a new graphic display system. *Arch. Intern. Med.*, 154:893–898, Apr 1994.

Appendix 3 – Appendix 2 – Paper entitled "The DigiScope Auscultation Data: First Explorations", presented at the the 17th edition of the Portuguese Conference on Pattern Recognition (RecPad), at Porto (Portugal) in 2011

The DigiScope Auscultation Data: First Explorations

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Abstract

The DigiScope project aims at developing a digitally enhanced stethoscope capable of using state of the art technology in order to help physicians in their daily medical routine. One of the main tasks of DigiScope is to build a repository of auscultations (sound and medical related data). In this work, we present a preliminary analysis and study of the first auscultations performed on children of a Brazilian hospital.

1 Introduction

In the ears of an experienced physician, a stethoscope yields important clinical information that can help an initial assessment of a patient's clinical condition and guide the subsequent need for more specialized exams. This is particularly true in chest Medicine, i.e. Cardiology and Pneumology, which is the reason why the stethoscope still maintains a key position in Medicine in the modern era. Auscultation, however, is a hard skill to master. The heart sounds are of low frequency and the intervals between events are in the order of milliseconds, requiring significant practice for a human ear to distinguish the subtle changes between a normal and a pathological heart sound.

The use of a digitally enhanced stethoscope, adequate for training physicians to improve their basic skills in diagnosing and treating heart conditions, or as a stronger tool for world-wide screening of specific heart pathologies are some examples of how state of the art technology can be used horizontally to benefit people at different economical, political or geographical levels. DigiScope [9] is one of the enhanced stethoscopes that aims at using state of the art technology in order to help physicians in their daily medical routine. DigiScope is a prototype of a digitally enhanced stethoscope, capable of automatically extracting clinical features from the collected data, as well as providing a clinical second opinion on specific heart pathologies. Several other electronically enhanced and digital stethoscopes have been developed and described in the literature [1, 6, 10], including models such as the iStethoscope Pro (application developed for the iPhone) or products such as the stethoscope developed by Zargis Medical Corp. Although all provide some degree of interesting ideas for digitally enhanced stethoscopes, most focus on the technological development of the apparatus itself. Our published review [3] argues that the key to robust solutions lies in a stronger interaction with the clinical community, both for understanding the needs of cardiologists and for robust clinical validation of not only the methods but also the final prototype.

One of the aims of the DigiScope project is to build a repository of high-quality data (sound and clinical information) that can be used to extract useful relations between patient data and cardiac pathologies. In order to achieve this objective, the DigiScope project is divided in three main tasks: (1) data collection; (2) signal processing and (3) machine learning. An application was developed and is being used in 2 hospitals, one in Portugal and another one in Brazil [9]. The data collected in Portugal is from adults while the data collected from Brazil is from children. In this work, we concentrate on the data analysis of the Brazilian children data. We discuss about the data model used by the DigiScope application, give some statistics about the data being collected in Brazil, and discuss about preliminary results we have on the correlation between the data attributes.

2 The DigiScope Data Model

Given the significant amount of data that can be captured each day by a prototype such as DigiScope, 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 BI-RADS - Breast Imaging Reporting and Data System - lexicon [8]). We then defined what patient metadata is interesting for pathology screening, and is feasible to be annotated in this context. Contributions to this definition also came from the HL7 standard [7] and openEHR publicly available archetypes [2].

A strong emphasis was given to collecting data that could 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 [4]).
- Relations between exams of the same patient and other patients.
- Relations between medication and patient health status.

The resulting data model (not shown here for lack of space) 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).

3 Preliminary Data and Analysis

The DigiScope application has been used for 3 months at the 2 hospitals. During this period, June to September 2011, around 200 patients (children) were auscultated at the Real Hospital Português, in Pernambuco, Brasil. We have 200 wave sound files with the auscultations, and xml files containing the clinical data collected and annotated by the physicians. We worked only with the annotated nominal data available at the xml files. From these files we have 49 with complete or almost complete annotation. For each patient, we have 40 attributes.

From the 40 attributes we used 8, which had distinct values and did not have a very high rate of missing values. These attributes are marked in bold.

Table 1 shows statistics on the final data, with the 8 attributes used.

Attribute	# Missing	Possible Values
Weight-kg	2	6-97
Height-cm	3	53-183
Date of birth (year)	4	1995-2011
Sex	1	18(F), 30(M)
SystolicSystemicPressure-mmHg	17	90-145, avg=102
DiastolicSystemicPressure-mmHg	17	50-90, avg=61.8
Cycle	8	37(1), 3(2), 1(4)
CardiacPathology	8	5(1), 36(2)

Table 1: Attributes used in a preliminary study

The nominal attributes Cycle and CardiacPathology are reported with the format "Count(Value)". For example, 37(1) for Cycle means that no murmur was recorded to 37 of the patients while 3 had a systolic murmur cycle and 1 had a continuous murmur cycle.

4 Methodology and Preliminary Results

The first experiment we performed was to try to find relations among the attributes using association rules and a ranking algorithm. The second experiment was focused on learning a classifier to predict CardiacPathology from the other attributes. In this second experiment, we performed two kinds of learning: (1) training a classifier with all 8 attributes and 49 cases, and (2) training a classifier without the attribute Cycle (that could influence the CardiacPathology). In both experiments with classification, we used the attribute CardiacPathology as class variable (5 patients had a pathology in our study, as shown in Table 2.

All experiments were performed using the WEKA tool [5] with the explorer and the experimenter modules. Statistical significance tests were applied to the results, with p=0.05.

4.1 Relations among attributes

When trying to find relations among attributes (association rules), the HotSpot algorithm correlated the CardiacPathology attribute (class variable) with the Date of Birth, Height and Weight. This finding needs to be further investigated and validated by the physicians. In a similar fashion, when trying to evidence the best attributes to predict the class variable (supervised feature ranking), the BestFirst algorithm reported Sex and SystolicSystemicPressure-mmHg. All of these experiments were performed without the attribute Cycle.

4.2 Classification: Predicting CardiacPathology

Results for the classification task were obtained using the classifiers ZeroR (reference), J48 (a decision tree), SMO (a Support Vector Machine), Naive Bayes and DTNB. J48 and SMO generated classifiers statistically significant better than ZeroR to predict CardiacPathology, with accuracy of 95.2% (ZeroR had accuracy of 88%), when using the attribute Cycle, with sensitivity = 60% and specificity = 100%. Interestingly, when we remove the attributes related to systemic pressure, the results do not change, which means that the attribute Cycle could be sufficient to predict if a patient has a pathology.

Without using the attribute Cycle, no classifier could reach an accuracy statistically different from the ZeroR algorithm, with p=0.05. In other words, without the attribute Cycle, any classifier will just "guess" the majority class to all instances. This may indicate two possibilities: (a) in the absence of more informative attributes, the attribute Cycle is definitive to classify a CardiacPathology, and (b) in the absence of the attribute Cycle, other attributes may be needed to improve the accuracy above the baseline classifier.

The J48 algorithm showed the top attribute to be SystolicSystemicPressure-mmHg, exactly as the selection of the best attribute had indicated. When we performed the same experiment with the Cycle attribute, this was naturally used as the best attribute to distinguish the abnormal from the normal instances.

The Cycle attribute is related to murmurs. A murmur occurs if the patient has any kind of abnormality with the opening or closing of the cardiac valves. These preliminary results seem to indicate that cardiac pathologies are very closely related to the murmur cycle.

Most of the attribute values are normally annotated by a doctor, but in some cases, no annotation is performed (for example, in a very busy day of work). For those cases, it would be interesting to automatically annotate the missing data, for example, by processing the sound signals. Automatically extraction of systemic pressure is a very difficult task for signal processing algorithms while cycle detection (or murmur detection) is relatively simple. This work contributes by indicating that if the cycle attribute is present, the systemic pressure has no relevance. Therefore, the whole system can still benefit from data that is collected under stress.

5 Conclusions and Future Work

In this work, we performed the first exploration of auscultation data in the context of the DigiScope project. The DigiScope project has already produced at least 200 auscultations, from which 49 are used in this study. We performed a preliminary study and analysis of this data, and concluded that Height, Weight, Sex and SystolicSystemicPressure-mmHg are attributes that are somehow related to CardiacPathology (positive or negative), when the attribute Cycle (related to murmurs) is absent. If the attribute Cycle is present, we can produce classifiers that reach 95% accuracy contrasting to the 88% achieved by a classifier that chooses the majority class (p=0.05). Moreover, if the attribute class is present, but we remove the systemic pressure attributes, the classifier's performance does not change, which means that Cycle is closely related to cardiac pathologies. This is a good indication, because, in a busy day of work, a doctor may not annotate any data related to systemic pressure or cycle. As Cycle can be automatically extracted from the sound signal, we can still use the classifier to predict pathology.

These are preliminary results that still need to be validated by the cardiologists. Nevertheless, this preliminary study already uncovered several issues that need to be addressed by the doctors and when developing a new version of the DigiScope software.

References

[1] M. Brusco and H. Nazeran. Development of an intelligent pda-based wearable digital phonocardiograph. In *Proceedings of the 2005 IEEE Engineering in Medicine and Biology 27th Annual Conference*, 2005.

[2] CKM. Openehr clinical knowledge manager, April . URL `http://www.openehr.org/knowledge`. visited April 2011.

[3] Fábio de Lima Hedayioglu, Miguel Tavares Coimbra, and Sandra da Silva Mattos. A survey of audio processing algorithms for digital stethoscopes. In *HEALTHINF*, pages 425–429, 2009.

[4] Nadia Ghamrawi and Andrew McCallum. Collective multi-label classification. In *Proceedings of the 14th ACM international conference on Information and knowledge management*, CIKM '05, pages 195–200, New York, NY, USA, 2005. ACM. ISBN 1-59593-140-6. doi: http://doi.acm.org/10.1145/1099554.1099591. URL `http://doi.acm.org/10.1145/1099554.1099591`.

[5] Mark Hall, Eibe Frank, Geoffrey Holmes, Bernhard Pfahringer, Peter Reutemann, and Ian H. Witten. The weka data mining software: An update. *SIGKDD Explorations*, 11:263–286, 2009.

[6] F. L. Hedayioglu, S. S. Mattos, L. Moser, and M. E. de Lima. Development of a tele-stethoscope and its application in pediatric cardiology. *Indian Journal of Experimental Biology*, 45, 2007.

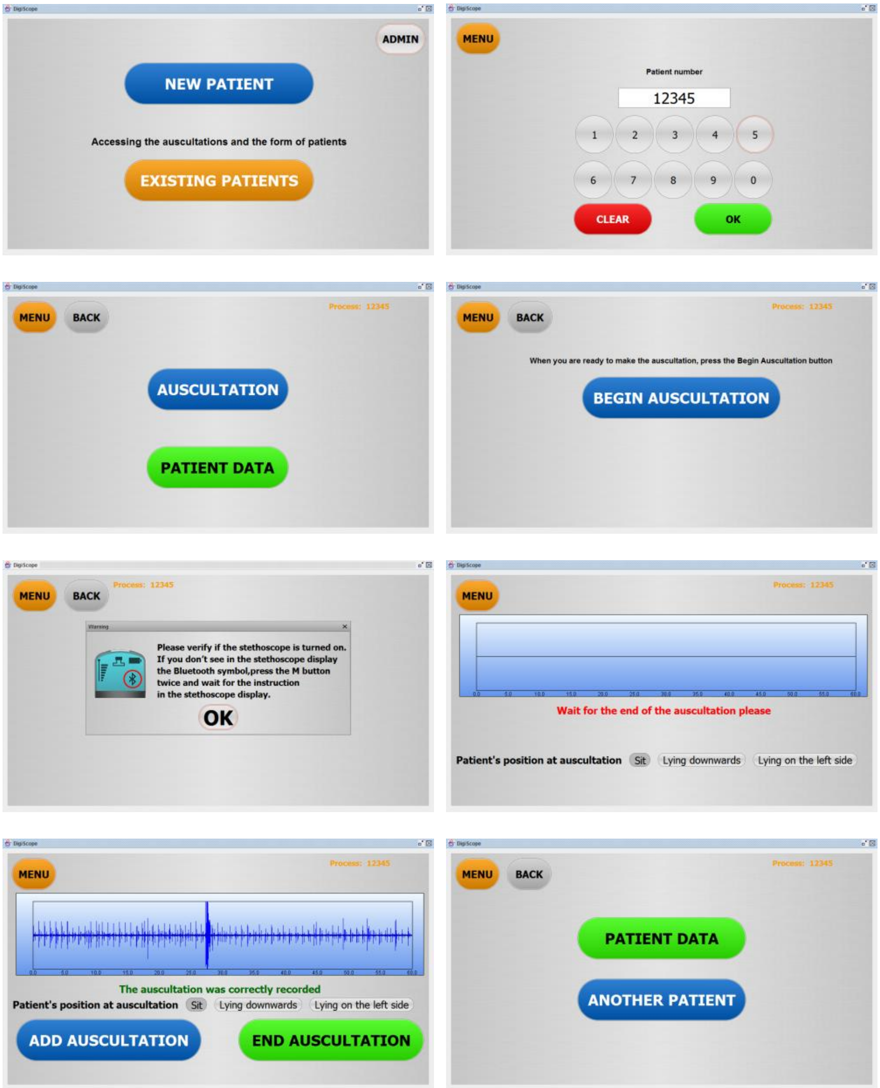
[7] H. L. S. I HL7. Hl7 - cardiology, 2011.

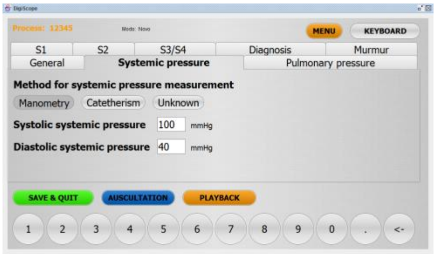
[8] A. C. o. Radiology. Breast imaging reporting and data system (biradstm), 1998.

[9] Daniel Pereira, Fabio Hedayioglu, Ricardo Correia, Tiago Silva, I. Dutra, Sandra Mattos, Filipa Almeida, and Miguel Coimbra. Digiscope - unobtrusive collection and annotating of auscultations in real hospital environments. In *Proceedimgs of the 33rd IEEE International Conference on Engineering in Medicine and Biology*. IEEE, 2011.

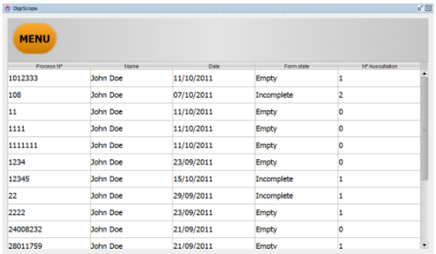
[10] M. E. Tavel, D. D. Brown, and D. Shander. Enhanced auscultation with a new graphic display system. *Arch. Intern. Med.*, 154:893, 1994.

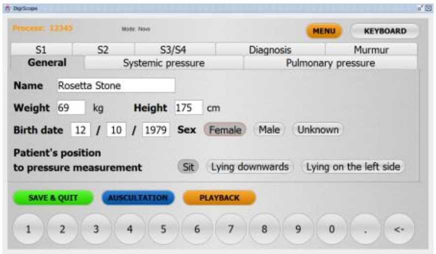
Appendix 4 – Screenshots of DigiScope Collector representing the storyboard part 1



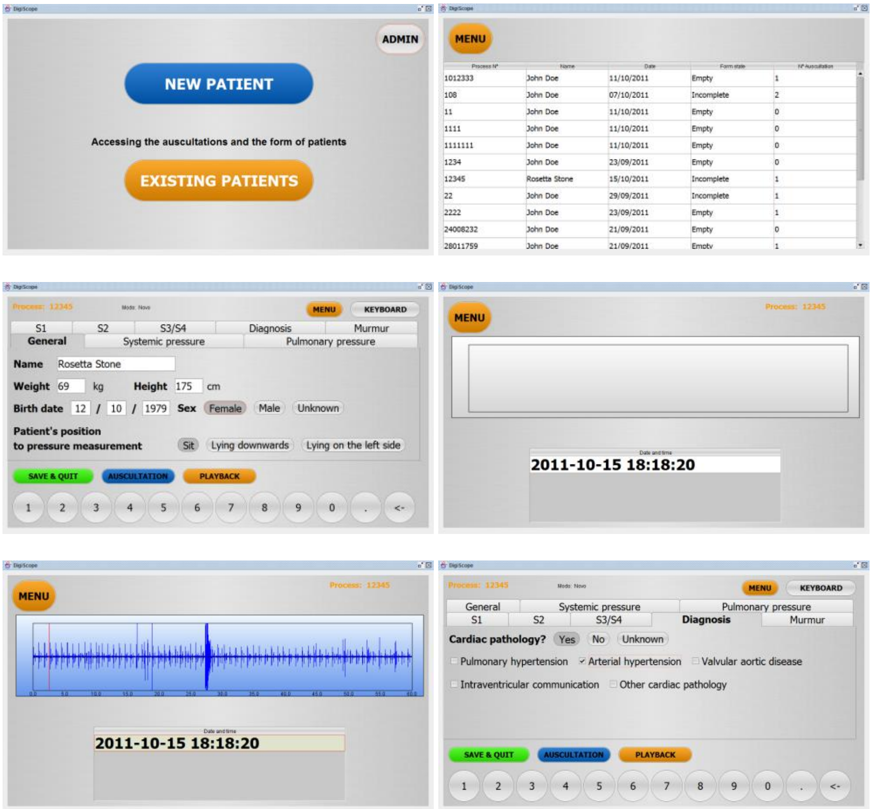

DigiScope
Process: 12345
Modo: Novo
MENU
KEYBOARD
S1
S2
S3/S4
Diagnosis
Murmur
General
Systemic pressure
Pulmonary pressure
Method for systemic pressure measurement
Manometry
Catetherism
Unknown
Systolic systemic pressure
100
mmHg
Diastolic systemic pressure
40
mmHg
SAVE & QUIT
AUSCULTATION
PLAYBACK
1 2 3 4 5 6 7 8 9 0 . <-

Appendix 5 – Screenshots of DigiScope Collector representing the storyboard part 2





Appendix 6 – Screenshots of DigiScope Collector representing the storyboard part 3



Appendix 7 – Observational study form

DigiScope

DigiScope Collector - Observational study

Local: __________ Date: __/__/____

PATIENT DATA

Patient sex: ❒Female ❒Male ❒Don't know

Age: _______

Patient's position to auscultation: _________________

Patient's position to pressure measurement: _____________________

Number of times the tension was measured: ____

Patient with disease: ❒Yes ❒No ❒ Don't know

If yes, what: ____

First visit: ❒Yes ❒No ❒ Don't know

LOCAL

❒Office ❒Exam room ❒Room Other: ____________________

Time: ____h____

Luminosity: _____________________

DURING THE AUSCULTATION

Scheme:

DigiScope

Location of the doctor regarding the patient: ____________________________________

Location of the physician regarding the system: ____________________________________

Location system for the patient: ____________________________________

Doctor position: ❒Sitting ❒Standing ❒Other: ____________

System localization: ❒Desk ❒Carinho ❒Bed ❒Other: ____________

TIMER

Start of consultation: ____________

Start using the application: ____________

Start of the pressure measurement: ____________

End of the pressure measurement: ____________

Start of auscultation: ____________

End of auscultation: ____________

End use of application: ____________

End of consultation: ____________

Order:

___ History ___ Clinical exam ___ Complementary exams

SYSTEM

The patient was created during the consultation: ❒Yes ❒No ❒Don't know

The form was completed immediately following the hearing: ❒Yes ❒No ❒ Don't know

The form was completed: ❒Fully ❒Partially ❒ Don't know ❒NA

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DIFICULTIES

With the system:

____
____
____
____

With the stethoscope:

____
____
____
____

Others:

____
____
____
____

OBSERVATIONS

____
____
____
____
____
____

Appendix 8 – Questionnaire for User Interaction Satisfaction

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Age: ______

Gender: ____ **male**

____ **female**

PART 0 - User definition

0.1 With what operating system(s) do you work regularly?

__ Windows XP
__ Windows Vista
__ Windows 7
__ Windows, but I don't know the version
__ OS X (Macintosh)
__ Linux
__ Other(s)
__ Don't know

0.2 What operating system(s) is/are installed on your phone(s)?

__ Windows for mobile
__ iOS (iPhone)
__ Symbian (Nokia)
__ RIM (BlackBerry)
__ Android
__ Bada (Samsung)
__ Other
__ Don't know

0.3 Do you have or regularly use a tablet (touch screen without keyboard like an iPad)?

__ Yes __ No __ Don't know

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If you answered yes at the question 0.3, what operating system(s) is/are instaled?

__ Windows

__ iOS (iPad)

__ Android

__ Other(s)

__ Don't know

__ NA

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PART 1: System Experience

1.1 How long have you worked on this system?

__ less than 1 hour

__ 1 hour to less than 1 day

__ 1 day to less than 1 week

__ 1 week to less than 1 month

__ 1 month to less than 6 months

__ 6 months to less than 1 year

__ 1 year to less than 2 years

__ 2 years to less than 3 years

__ 3 years or more

1.2 On the average, how much time do you spend per week on this system?

__ less than one hour

__ one to less than 4 hours

__ 4 to less than 10 hours

__ over 10 hours

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PART 2: Past Experience

2.1 How many operating systems have you worked with?

__ none	__ 3-4
__ 1	__ 5-6
__ 2	__ more than 6

2.2 Of the following devices, software, and systems, check those that you have personally used and are familiar with:

__ computer terminal	__ joy stick	__ computer games
__ personal computer	__ pen based computing	__ voice recognition
__ lap top computer	__ graphics tablet	__ video editing systems
__ color monitor	__ head mounted display	__ CAD computer aided design
__ touch screen	__ modems	__ rapid prototyping systems
__ floppy drive	__ scanners	__ e-mail
__ CD-ROM drive	__ word processor	__ internet
__ keyboard	__ graphics software	
__ mouse	__ spreadsheet software	
__ track ball	__ database software	

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PART 3: Overall User Reactions

Please circle the numbers which most appropriately reflect your impressions about using this computer system.
Not Applicable = NA.

3.1 Overall reactions to the system:	terrible	wonderful	
	1 2 3 4 5 6 7 8 9		NA
3.2	frustrating	satisfying	
	1 2 3 4 5 6 7 8 9		NA
3.3	dull	stimulating	
	1 2 3 4 5 6 7 8 9		NA
3.4	difficult	easy	
	1 2 3 4 5 6 7 8 9		NA
3.5	inadequate power	adequate power	
	1 2 3 4 5 6 7 8 9		NA
3.6	rigid	flexible	
	1 2 3 4 5 6 7 8 9		NA

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PART 4: Screen

4.1 Characters on the computer screen	hard to read	easy to read	
	1 2 3 4 5 6 7 8 9		NA
4.1.1 Image of characters	fuzzy	sharp	
	1 2 3 4 5 6 7 8 9		NA
4.1.2 Character shapes (fonts)	barely legible	very legible	
	1 2 3 4 5 6 7 8 9		NA
4.2 Highlighting on the screen	unhelpful	helpful	
	1 2 3 4 5 6 7 8 9		NA
4.2.1 Use of reverse video	unhelpful	helpful	
	1 2 3 4 5 6 7 8 9		NA
4.2.2 Use of blinking	unhelpful	helpful	
	1 2 3 4 5 6 7 8 9		NA
4.2.3 Use of bolding	unhelpful	helpful	
	1 2 3 4 5 6 7 8 9		NA
4.3 Screen layouts were helpful	never	always	
	1 2 3 4 5 6 7 8 9		NA
4.3.1 Amount of information that can be displayed on screen	inadequate	adequate	
	1 2 3 4 5 6 7 8 9		NA
4.3.2 Arrangement of information on screen	illogical	logical	
	1 2 3 4 5 6 7 8 9		NA
4.4 Sequence of screens	confusing	clear	
	1 2 3 4 5 6 7 8 9		NA
4.4.1 Next screen in a sequence	unpredictable	predictable	
	1 2 3 4 5 6 7 8 9		NA
4.4.2 Going back to the previous screen	impossible	easy	
	1 2 3 4 5 6 7 8 9		NA
4.4.3 Progression of work related tasks	confusing	clearly marked	
	1 2 3 4 5 6 7 8 9		NA

Please write your comments about the screens here:

____

____

____

____

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PART 5: Terminology and System Information

5.1 Use of terminology throughout system	inconsistent	consistent	
	1 2 3 4 5 6 7 8 9		NA
5.1.2 Work related terminology	inconsistent	consistent	
	1 2 3 4 5 6 7 8 9		NA
5.1.3 Computer terminology	inconsistent	consistent	
	1 2 3 4 5 6 7 8 9		NA
5.2 Terminology relates well to the work you are doing?	always	never	
	1 2 3 4 5 6 7 8 9		NA
5.2.1 Computer terminology is used	too frequently	appropriately	
	1 2 3 4 5 6 7 8 9		NA
5.2.2 Terminology on the screen	ambiguous	precise	
	1 2 3 4 5 6 7 8 9		NA
5.3 Messages which appear on screen	inconsistent	consistent	
	1 2 3 4 5 6 7 8 9		NA
5.3.1 Position of instructions on the screen	inconsistent	Consistent	
	1 2 3 4 5 6 7 8 9		NA
5.4 Messages which appear on screen	confusing	clear	
	1 2 3 4 5 6 7 8 9		NA
5.4.1 Instructions for commands or functions	confusing	clear	
	1 2 3 4 5 6 7 8 9		NA
5.4.2 Instructions for correcting errors	confusing	clear	
	1 2 3 4 5 6 7 8 9		NA
5.5 Computer keeps you informed about what it is doing	never	always	
	1 2 3 4 5 6 7 8 9		NA
5.5.1 Animated cursors keep you informed	never	always	
	1 2 3 4 5 6 7 8 9		NA
5.5. 2 Performing an operation leads to a predictable result	never	always	
	1 2 3 4 5 6 7 8 9		NA
5.5.3 Controlling amount of feedback	impossible	easy	
	1 2 3 4 5 6 7 8 9		NA
5.5.4 Length of delay between operation	unacceptable	acceptable	

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		1 2 3 4 5 6 7 8 9	NA
5.6 Error messages	unhelpful helpful	1 2 3 4 5 6 7 8 9	NA
5.6.1 Error messages clarify the problem	never always	1 2 3 4 5 6 7 8 9	NA
5.6.2 Phrasing of error messages	unpleasant pleasant	1 2 3 4 5 6 7 8 9	NA

Please write your comments about terminology and system information here:

____

____

____

____

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PART 6: Learning

6.1 Learning to operate the system	difficult	easy	
	1 2 3 4 5 6 7 8 9		NA
6.1.1 Getting started	difficult	easy	
	1 2 3 4 5 6 7 8 9		NA
6.1.2 Learning advanced features	difficult	easy	
	1 2 3 4 5 6 7 8 9		NA
6.1.3 Time to learn to use the system	slow	fast	
	1 2 3 4 5 6 7 8 9		NA
6.2 Exploration of features by trial and error	discouraging	encouraging	
	1 2 3 4 5 6 7 8 9		NA
6.2.1 Exploration of features	risky	safe	
	1 2 3 4 5 6 7 8 9		NA
6.2.2 Discovering new features	difficult	easy	
	1 2 3 4 5 6 7 8 9		NA
6.3 Remembering names and use of commands	difficult	easy	
	1 2 3 4 5 6 7 8 9		NA
6.3.1 Remembering specific rules about entering commands	difficult	easy	
	1 2 3 4 5 6 7 8 9		NA
6.4 Tasks can be performed in a straight-forward manner	never	always	
	1 2 3 4 5 6 7 8 9		NA
6.4.1 Number of steps per task	too many	just right	
	1 2 3 4 5 6 7 8 9		NA
6.4.2 Steps to complete a task follow a logical sequence	never	always	
	1 2 3 4 5 6 7 8 9		NA
6.4.3 Feedback on the completion of of steps	unclear	clear	
	1 2 3 4 5 6 7 8 9		NA

Please write your comments about learning here:

____

____

____

____

QUIS 7.0 DigiScope

PART 7: System Capabilities

7.1 System speed	too slow / fast enough	1 2 3 4 5 6 7 8 9	NA
7.1.1 Response time for most operations	too slow / fast enough	1 2 3 4 5 6 7 8 9	NA
7.1.2 Rate information is displayed	too slow / fast enough	1 2 3 4 5 6 7 8 9	NA
7.2 The system is reliable	never / always	1 2 3 4 5 6 7 8 9	NA
7.2.1 Operations are	undependable / dependable	1 2 3 4 5 6 7 8 9	NA
7.2.2 System failures occur	frequently / seldom	1 2 3 4 5 6 7 8 9	NA
7.2.3 System warns you about potential problems	never / always	1 2 3 4 5 6 7 8 9	NA
7.3 System tends to be	noisy / quiet	1 2 3 4 5 6 7 8 9	NA
7.3.1 Mechanical devices such as fans, disks, and printers	noisy / quiet	1 2 3 4 5 6 7 8 9	NA
7.3.2 Computer generated sounds are	annoying / pleasant	1 2 3 4 5 6 7 8 9	NA
7.4 Correcting your mistakes	difficult / easy	1 2 3 4 5 6 7 8 9	NA
7.4.1 Correcting typos	complex / simple	1 2 3 4 5 6 7 8 9	NA
7.4.2 Ability to undo operations	inadequate / adequate	1 2 3 4 5 6 7 8 9	NA
7.5 Ease of operation depends on your level of experience	never / always	1 2 3 4 5 6 7 8 9	NA
7.5.1 You can accomplish tasks knowing only a few commands	with difficulty / easily	1 2 3 4 5 6 7 8 9	NA
7.5.2 You can use features/shortcuts	with difficulty / easily	1 2 3 4 5 6 7 8 9	NA

QUIS 7.0

Please write your comments about system capabilities here:

___

___

___