A Proposal to Incorporate Digital Auscultation and Its Processing into an Existing Electronic Health Record

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Abstract: This paper aims to describe and discuss a proposal to incorporate digital auscultation and its processing into an existing EHR. The architecture was planned to be used in both primary and hospital care, and includes a digital stethoscope; an exam collection module; an integration module; an EHR web service; and an EHR. Special attention was given to standardize communications using HL7 and openEHR. The proposed implementation uses a commercial stethoscope, an android app to collect the data, a mirth integration engine that communicates using HL7 or openEHR through REST or SOAP calls. The signal processing of the sounds is also included. The auscultation sound files are made available to the EHR users. This solution will open the possibility to have richer patient records than can be very important for patient care, research and medical teaching. It also raises issues regarding ethical and legal concerns that must be considered in future research.

1 INTRODUCTION

The ageing population has increased steadily over the past few years. According to the World Health Organization, in almost all countries, the proportion of people aged over 60 years, is growing rapidly as a result of increased life expectancy and reduced fertility rates (WHO, 2014; WHO, 2011). This raises the concern to focused not only on the treatment of disease and monitoring, but also in its prevention and active ageing (Rechel et al., 2013; SCPSDC, 2013).

Health problems in the elderly are usually linked to accidents, development of non-communicable diseases, poverty, social isolation and exclusion, abuse, and mental health disorders. It is also recognized that the limitations characteristic of this population, may often prevent their access to health care, which makes it imperative to identify these patients for closer monitoring. Remote monitoring of this population earns great interest not only in preventing the disease, but also in promoting an active lifestyle, and the detection of possible complications (WHO, 2012; EuropeanCommission, 2013). An integrated health system brings many benefits from the point of view of patients and health professionals. From the side of the patient, these systems allow a myriad of opportunities, from monitoring of chronically ill patients, health promotion and self-care, improving their overall condition. From the perspective of health professionals, this new paradigm allows a direct costs decrease by reducing the number of hospitalizations, the risks associated with nosocomial infections, and overcrowding. These technologies allow the extension of health care to patients away from urban centers, ensuring greater equity in health care, and providing further support to the health professional through medical decision support systems and alarms (Ferreira et al., 2013; Pereira et al., 2013).

The ICT for Future Health project, led by the University of Porto, aims to address this emerging reality by incorporating three health data gathering modalities into a unified Electronic Health Record (EHR), deployed in the zone of influence of a primary care center in the northern region of Portugal (USF Nova Via) that covers a population of around 7000 isolated elderly inhabitants. These three modalities are: continuous self assessment of patients using wearable sensing, self assessment of patients within a health kiosk environment, and assessment of patients by clinicians either at home or in a primary care environment. In this paper we will address the integration of the later into the unified EHR of the ICT for Future

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Health project.

1.1 Heart Auscultation

Auscultation is a standard medical exam for heart pathology screening, and although it is the gold standard for heart condition monitoring, it is a difficult skill to master (Carapetis et al., 2008). Besides, there is not still a way of storing this important data for patient follow-up; the current practice does not take this into consideration, losing important information in case of disease detection/evolution. There is not yet a standard for heart sound collection and transmission that may allow different professionals to evaluate the same signal (general practitioner and cardiologist e.g.). The DigiScope data collection system presented in Figure 1 was designed to fill this gap, collecting an auscultation using an electronic stethoscope, along with patient clinical data and annotations (Pereira et al., 2013).

Figure 1: DigiScope collector (DSCollector), used for electronic auscultation, with an electronic stethoscope and a tablet.

1.2 Electronic Health Records & HL7

OpenEHR (openEHR, 2013) is a non-proprietary standard architecture for electronic health records. OpenEHR lets you capture and store clinical knowledge in a structured manner, independent of software, providing interoperability of health information systems, avoiding trapping data in proprietary systems and increasing support for distributed clinical work flows. OpenEHR allows the standardization of the Electronic Health Record (EHR) architecture following a multi-level modelling approach, which separates information from knowledge (Beale and Heard, 2008). The first level (the reference model - RM) specifies a generic model according to which data will be stored and communicated. The second level (the archetype model) defines constraints in the reference model that represent concepts in a specific domain. Trough the use of archetypes (structured concepts of clinical knowledge) and templates (combination of archetypes related to a particular clinical task), the semantic meaning and functionality is kept independent of the systems collecting or holding the data (e.g. clinical records, mobile systems). The archetypes can be developed in any language and later be translated to other languages (e.g., Portuguese, English, Chinese, Swedish) keeping their original meaning. In addition, terminologies can be associated within archetypes elements supporting their definition.

Health Level 7 (HL7) is a well established message-based standard developed by the American National Standards Institute (ANSI) accredited standards developing organization Health Level 7 Inc. It aims to develop coherent and extensible standards for the exchange, management and integration of electronic information in the clinical and administrative domain (Health Level Seven International, 2007). HL7 refers to the Application Level of the OSI seven layers model. This level describes how data are exchanged and the timing of the interchange as well as the handling of communication errors. According to Health Level Seven, HL7 version 2.5 is the most widely implemented standard for health care information worldwide.

HL7 contains many optional data segments which makes it very flexible but at the same time impossible to guarantee standard conformance of any vendors' implementation. This has the regrettable consequence that vendors might need more time to analyse and plan their interface to assure that the same optional features are used by both parties (Health Level Seven International, 2007). The vagueness in the standard, the lack of a consistent application data model, a formal methodology to model data artefacts and the lack of well defined application user roles were issues addressed in HL7 version 3.0. It uses an object-oriented development methodology based on a data model, the Reference Information Model (RIM), to create messages. RIM provides an explicit representation of semantic and lexical connection that exists between the information transferred in HL7 version 3.0 messages (Health Level Seven International, 2007).

1.3 Aim

Since auscultation is the first line of screening of cardiovascular pathologies, but it is still not part of the electronic health record, this paper aims to describe and discuss a proposal to incorporate digital auscultation and its processing into an existing electronic health record.

2 STORYBOARD

The new paradigms of societal change imposed to healthcare have taken monitoring and data storage to a new level of systems interoperability. To better illustrate this new scenario, we will describe a storyboard to facilitate understanding of our service application.

2.1 At Primary Care Unit

Mrs. Amelia is a 72 years old woman, living alone in a rural house far from the city centre. Mrs. Amelia is autonomous, although she presents a few chronic health conditions: type II diabetes, hypertension and dyslipidemia. Mrs. Amelia has regular appointments with her general practitioner (GP) in her primary care unit, to analyze and manage her health condition, and when necessary, adjust the medication. Her consultation includes several physical observations, as standard clinical practice routine, including a heart auscultation. Her GP auscultates her with an electronic stethoscope, connected to a tablet (DSCollector), that links this information to her electronic health record (EHR), storing each auscultation as an observation of the consultation, identified with her national health identification number.

The heart sound, or phonocardiogram (PCG) record, is stored with her clinical data and with the description of the findings of the auscultation redeemed by the GP. When the collected PCG is sent to the EHR in the server, it passes through a signal processing unit that automatically extracts several features from the auscultation useful for clinical evaluation (heart rate, S12 and S21 time intervals, presence of murmurs and its shape and intensity, extra heart sounds, or hyperphonesis e.g.). This information is then fed to a machine learning algorithm that incorporates PCG features with the patient clinical data, providing an advisory system for the GP in case of warning signs, that may lead to further evaluation from a Cardiology specialist. This way, there is a register of the evolution of the heart sound and a possible alarm in case of missed events by the GP. In her last appointment Mrs. Amelia condition was stable, and she returned to her home until the next appointment.

2.2 At Home to a Central Hospital

Last week, Mrs. Amelia had a small accident and fractured her left foot, leaving her with limited mobility. Since Mrs. Amelia lives in a small village, far from the city centre, she was unable to continue her regular appointments, and the health care was delivered to her directly at home by a nurse. Every time the nurse leaves the primary care unit, the tablet connects to the central server, and receives the data from the scheduled patients for home visit that day. Every patient scheduled for visit has his/her information on the tablet, and after observation, the collected data will be synchronized with the server to update in case of change, and save the auscultation as an observation on the EHR. If for some reason, the health care professional needs to visit a patient that is not considered in the schedule of that day, he/she may add a new patient, using the national health identification number; after collection, and when synchronizing with the central server, this may be introduced as a new patient, with the correspondent exam, or as an observation for an existing patient in the database, identified through the national health identification number.

Since Mrs. Amelia has a combination of chronic conditions, on each visit the health professional collects several physiological variables in a tablet, including her auscultation according to the clinical standards. The visiting nurse was trained to perform an auscultation, directly sent to Mrs. Amelias EHR at the central server, and later analyzed by her GP. The PCG collected during the last visit was processed at the server, detecting a systolic murmur in her PCG. This event generated an alarm to her GP, that listened to her auscultation, confirming the clinical finding. Mrs. Amelia GP shared the auscultation with the Cardiologist from the regional hospital, for a second opinion, who considered that Mrs. Amelia was indicated for further evaluation. Mrs. Amelia was immediately referred to a Cardiology consultation, where she continued to be accompanied.

Data collected in both scenarios includes the personal information (age, weight, height and gender), clinical data resulting from the examination (systolic and diastolic blood pressure, oximetry, and a text field for comments), and the auscultation file (audio files, one for each auscultation spot).

3 ARCHITECTURE

The proposed architecture (figure 2) is composed by 5 modules that are independent of each other. We have the digital stethoscope; the collection module; the integration module; the EHR web service; and finally the EHR.

In the digital stethoscope we use is the Littmann 3200 stethoscope without any modification, this choice was made taking in consideration the acceptance from the medical staff and usability purposes. The collection module is assured with the DSCollector application. An android application that will

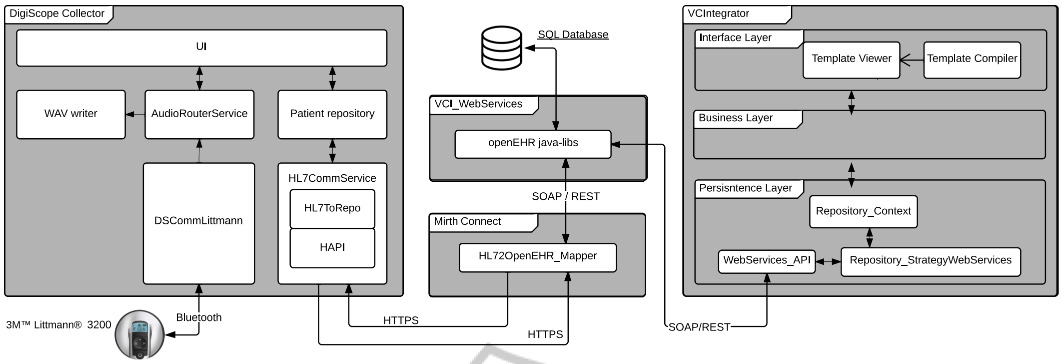


Figure 2: Architecture proposed with all the modules and information flows. The Littmann stethoscope sends the auscultation to the Digiscope Collector (collection module) via bluetooth. Then, this module communicates using HL7 messages with the Mirth Connect (integration module). Which in turn parses the messages, transforming them in the structure expected by the EHR web service. This flow allows that a patient record can be sent from the mobile application to the EHR repository.

assure the communication with the stethoscope (via bluetooth) and the storage of all the data collected during the appointment between the healthcare professional and the patient. This data is then compiled in standard HL7 messages that can be sent to the EHR modules (via HTTPS).

The integration module is our Mirth Connect that can receive any standard HL7 message, process it and translate it to the structure known by the EHR web service module. This module is also capable of doing the reverse communication flow, in our scenario the collection module can also request information about patients which requires being capable to receive HL7 queries and sent responses in accordance with the standard. The EHR web service module allows an external application or service to send EHR with a structure known to the EHR. This module can be seen as the door to the VCIntegrator module and that is why we need the integration module to transform the HL7 structure to this one operated in the VCIntegrator, this communication can be done with SOAP or REST.

Finally we have the EHR itself, which has its own structure based in OpenEHR and all the functionalities that are required in a systems like this. In this architecture, our EHR is handled by the VCIntegrator that is feed with patient records by our EHR web service, this communication can be done by SOAP or REST as well.

An important aspect to understand in the architecture is the main information flows between the modules. We have two information flows that we need to address: the retrieve of the patient list that the healthcare professional needs to visit; and the upload of the patients records to the EHR repository. As seen in the figure 2, the request of a patient list is made by an HL7 request from the DSCollector to the Mirth Connect, this one will parse the message and will do the same request to the EHR web service, that will retrieve the list from the VCIntegrator and send it back using the same route.

The other information flow is simpler, because there is no need to answer. The DSCollector will upload the patients records to the Mirth Connect, using HL7 messages, and this module will parse them and send them to the EHR web service in the expected structure.

4 IMPLEMENTATION

In this section we will address the HL7 messages that are required to communicate between the collection and integration modules and we will also explain how each module was implemented.

4.1 HL7 Communication Between Modules

The communication between the DSCollector and the VCIntegrator will be made by HL7 standard messages, and using the already approved IHE models. The IHE has already defined and validated two frameworks from where we can adapt. The Patient Demographics Query (PDQ) and the Patient Identifier Cross-Referencing (PIX), are two frameworks that handle patients list exchange between any systems (IHE, 2013). In figure 3) it is possible to see all the message handling between the collection and the integration modules.

Each interaction between the two modules requires an authentication of the user, and all the messages are exchanged under the security of this authentication. The first step of the protocol is to send a

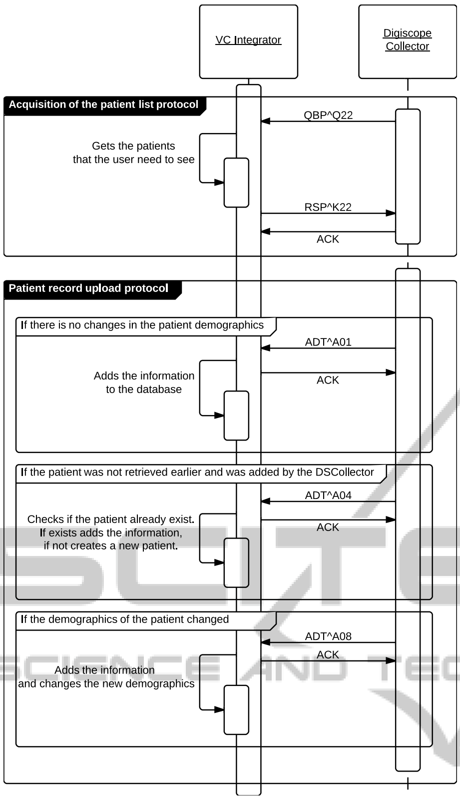


Figure 3: Communication protocol to exchange HL7 messages between the DSCollector and the VCIntegrator.

QBPˆQ22 to request all the demographics of the patients that the physician needs to see that day. In that message it is important to notice the specific method to request this list. Usually this message is used to request a list of patients based on a demographic field, but in this case, we send the identification of the physician that is requesting his schedule. This way we respect the standard, and the receiving application knows what to do (see field QPD.3.1 in the Message 1) and which physician list should he send (identification on the field QPD.3.2 in the Message 1).

Message 1: An example of a QBPˆQ22 message. This message is requesting the list of patients that the physician, identified in the filed QPD.3.2, needs to see during is work day.

```
MSH|^~\&|DSCOLLECTOR|DSCOLLECTOR|VCINTEGRATOR|VCINTEGRATOR
|201408310830||QBP^Q22|201408310830_5498465678|P|2.5
QPD|Q22^GetSchedule^HL7|201408310830_7489764|@PV1
.7.1^516886416
RCP|I|10^RD
```

With this message the VC Integrator should return a RSPˆK22, which is the standard response to the previous message. This message is fully compliant with the standard and should only return the demographics of the patients to visit in that day by the requesting physician (see Message 2). After this procedure the physician has all the information needed to go to the patients houses and proceed with the appointments.

Message 2: An example of a RSPˆK22 message with the demographics of the patients.

```
MSH|^~\&|VCINTEGRATOR|VCINTEGRATOR|DSCOLLECTOR|DSCOLLECTOR
|201408310832||RSP^K22|201408310832_6546871463|P|2.5
MSA|AA|201408310830_5498465678
QAK|201408310830_7489764|OK||2|2|0
QPD|Q22^GetSchedule^HL7|201408310830_7489764|@PV1
.7.1^516886416
PID|1||16546846||Gomes^Pedro||19900101|M|||Rua do Campo
Alegre^1021/1055^Porto^Porto^4169-007^Portugal
||+351123456789
PID|3||55587236||Frade^Samuel||19900101|M|||Rua Dr. Plcido
da Costa^s/n^Porto^Porto^4200-450^Portugal||+351123456789
```

In the end of the day, he needs to upload all the data collected from the appointments to the VC Integrator. In this procedure, the physician needs to authenticate himself in the VC Integrator and send all the patients observed as new admissions. If the patient demographics were retrieved earlier and no changes were made in the demographics, the DSCollector needs to send a simple admission (ADTˆA01 message in Message 3) with the clinical data gathered during the appointment. However, if any of the demographics has changed, the admission should imply that a change has been made (ADTˆA08 message, similar to Message 3). And the last scenario happens when, for any reason, the physician has an appointment with an unscheduled patient that was not retrieved earlier. In this case, we need to inform the receiving application that the patient that we are sending, does not have an identification known in the receiving database (ADTˆA04 message, similar to Message 3) and should be added as a new patient if not founded, or added as a normal admission if founded.

Message 3: An example of an ADTˆA01 message. This message is used to inform of an admission. The messages ADTˆA04 and ADTˆA08, also used in our protocol, are very similar to this one, they use the same tags and fields and only in the MSH header is possible to understand which kind of message is being sent.

```
MSH|^~\&|DSCOLLECTOR|DSCOLLECTOR|VCINTEGRATOR|VCINTEGRATOR
|201408311800||ADT^A01|201408311800_515674657|P|2.5
EVN|A01|201408311048
PID|16546846||16546846||Gomes^Pedro||19900101|M|||Rua do
Campo Alegre^1021/1055^Porto^Porto^4169-007^Portugal
||+351123456789
PV1||I|||||ID
^516886416|||||||||||||||||||||||||||||||||||||201408311048
OBX|1|ST|8302-2^Body height^LN||180|CM
OBX|2|ST|29463-7^Body weight^LN||80|KG
OBX|3|ST|8480-6^Systolic blood pressure^LN||120|MMHG
OBX|4|ST|8462-4^Diastolic blood pressure^LN||80|MMHG
OBX|5|ST|20564-1^Oxygen saturation^LN||98|%
```

```
OBX|6|ST|DS-OPENFIELD^OBS^DS||medicalObservation|txt
OBX|7|ST|DS-PCGAV^PCG_AORTIC^DS||file encoded in Base64|wav
OBX|8|ST|DS-PCGPV^PCG_PULMONARY^DS||file encoded in Base64|
wav
OBX|9|ST|DS-PCGTV^PCG_TRICUSPID^DS||file encoded in Base64|
wav
OBX|10|ST|DS-PCGMV^PCG_MITRAL^DS||file encoded in Base64|
wav
```

In this messages, the most important segment for our proposal is the OBX segment, because this is the segment that carries the clinical information collected during the appointment. In the Message 3, as example, we can see that the DSCollector sends ten observations collected during the appointment. Some of the fields are already common in this kind of procedure, such as height, weight or oxygen saturation and are sent using the LOINC coding system. We also have an open field where the physician can add information not accounted for, but the most relevant fields are the last four. In this OBX segments we are sending the phonocardiogram of the patient divided in the four major focal points, the aortic, pulmonary, tricuspid and mitral valve. This sounds are collected using the DSCollector (see section 4.3) and then encoded in Base64 to be sent inside this message, as commonly used in the email attachments.

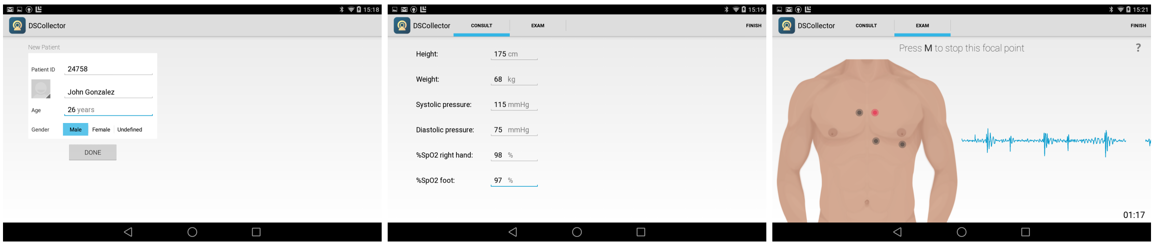
4.2 Mirth/VCIntegrator

VCIntegrator (VirtualCare, 2014) is an online electronic health record which implemented the openEHR standard, on which the health record forms are automatically generated based on openEHR templates and the data saved, following the openEHR specification. As long as the data is stored in this specified format it can be loaded into the associated form. The HL7 messages are received by a Mirth Connect citemirth server interface which has three channels configured: one channel to receive the collected raw data, another channel for signal processing and a channel intended for internal use that sends the data to VCIntegrator java backend webservices for storage. This way the channels can be easily arranged to several possible scenarios: either to ignore the signal processing and just store raw data, store both incoming data in parallel, or just forward the raw data to signal processing servers. The data sent via webservices can be visualized in VCIntegrator user inteface in the respective form and visual components. The extraction of the data from the HL7 messages into openEHR specification is done, at the moment, by mapping each of the HL7 data fields with the corresponding openEHR archetype data elements, each with a unique identifiable openEHR path. This is currently being done inside Mirth Connect using java, but further work should be put into a more automated solution. The webservice layer provides a solution for both SOAP and REST specifications. In order to be able to store the data, in either specifications, using the according client implementation, the client must first identify itself, then proceed with the patient EHR identification and set it as the current working EHR, identify the working openEHR Template and set the data to record (create Composition) and finally submit the Composition to the EHR. During these procedures the audit details are being generated and then saved together with the data. Creating the openEHR template for this work consisted in (1) identifying the clinical statements recorded by the DSCollector, (2) develop a structured representation of these statements, (3) search for existing archetypes in the openEHR Clinical Knowledge Manager (CKM) (openEHR community,) to represent the clinical statements, (4) create the template. Since the structured representation of the clinical statements and the archetypes were available, it was possible to create the template. The structured representation helped to create the framework of the template, where the archetypes were arranged. The development of the template was made on the Ocean Template Designer software that allows composing a set of archetypes into a template which is also available for free download on the Ocean Informatics website. The following openEHR arquetypes were obtained from the openEHR Clinical Knowledge Manager (CKM) and are used to represent the clinical data, as a template, collected by the DSCollector:

- openEHR-EHR-COMPOSITION.encounter.v1
- openEHR-EHR-CLUSTER.individual_personal.v1
- openEHR-EHR-CLUSTER.person_name.v1
- openEHR-EHR-OBSERVATION.blood_pressure.v1
- openEHR-EHR-OBSERVATION.body_weight.v1
- openEHR-EHR-OBSERVATION.height.v1
- openEHR-EHR-OBSERVATION.indirect_oximetry.v1
- openEHR-EHR-EVALUATION.clinical_synopsis.v1

4.3 DSCollector

The DSColector is an Android based application that allows healthcare professionals to collect clinical data, such as weight, height, blood pressure, etc; and the phonocardiogram from any patient anywhere. The most relevant feature of this application is the acquisition of the phonocardiogram in order to store it in the electronic health record of the patient. In order to do that, the DSCollector handles a bluetooth communication with an electronic stethoscope (in our case, the Littmann 3200), and using a simple protocol, stores



(a) (b) (c)

Figure 4: DSCollector screenshots of some of the acquisition stages during an appointment. 4(a) Patient creation layout. 4(b) Clinical information gathered from the patient. 4(c) Acquisition of the pulmonary valve sound.

4 different sounds from the patient, being them the 4 most common heart focal points (pulmonary valve, aortic valve, mitral valve and tricuspid valve).

As seen in figure 4 we can see the usual workflow of this application. The healthcare professional needs to first chose one electronic stethoscope to connect to, and he can then proceed with the appointment, this step is only required to do in the beginning of the application and not for every patient. After that he can chose to add a new patient or to create a new one, if he chose to create one, he is requested to enter the patient identification number (that should be unique under the national or private healthcare information system), name, age and gender. After the patient creation or after choosing an existence patient, the healthcare professional is requested to enter all the clinical data as he would retrieve in a standard appointment plus the auscultation.

In the figure 4(c) it possible to see how this procedure is done, the healthcare professional is requested to collect 4 individual sounds from the patient, being allowed to record more if required, from the same focal point.

All this data is then stored in the device and it will be ready to be sent to any system that can receive HL7 messages (see section 4.1). From all the data gathered with this device, only the sound files are not common data to be sent in an electronic health record, but as you can see in message 3 in the section 4.1, what we do is to encode the sound to Base64, as it is done with email messages, and send them inside the HL7 message. All the HL7 handling is made with the help of the HAPI parser an library for Java.

5 HEART SOUND SIGNAL PROCESSING

As described earlier, after data collection, clinical data are sent to the server for storage, and in parallel, several signal processing tasks will be performed over the collected PCG. The objective is to automatically extract relevant signal features, as soon as the PCG reaches the server, and produce a report with this information. This report will be later attached to the observation; if any alarming feature is detected, a warning may be sent to the clinician for earlier further evaluation of the patient. Several algorithms are already implemented for PCG analysis, and features extraction (Ferreira et al., 2013; Castro et al., 2013; Pedrosa et al., 2014; Oliveira et al., 2014; Castro et al., 2014): auscultation spot segmentation; heart sound envelope; heart cycle segmentation; signal quality; heart sounds amplitude and duration; murmur detection; S2 components' analysis.

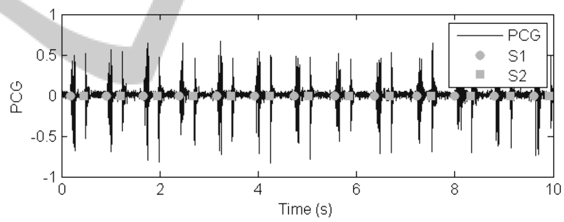


Figure 5: Example of a phonocardiogram collected in a real clinical environment with heart sounds detection and classification (heart rate, S12 and S21 time intervals estimation).

Figure 5 presents an example of an auscultation collected in a clinical scenario, with heart sounds detection, and features extraction.

Figure 6 shows a proposal for data presentation to the healthcare professional, with the results of the signal processing integrated in the EHR. A report with these features may be generated, as well as a graphical representation of the PCG, which may be very helpful for clinical assessment and is not available for standard acoustic auscultation.

6 DISCUSSION

In this paper we have proposed a framework for integrating the health data gathered by a clinician during a patient evaluation either at home or in a primary

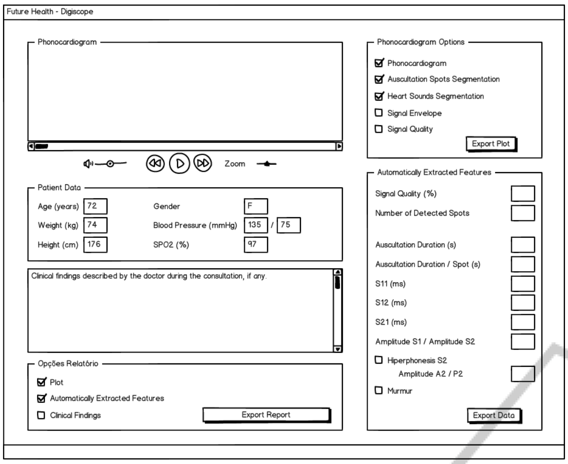


Figure 6: Proposal of data presentation to the healthcare professional including the signal processing results.

care environment. We have focused on the auscultation signal since it is by far the less explored in both literature and similar projects, given its challenging hardware and gathering protocol requirements.

A full solution is proposed that includes not only communication and storage protocols but also provides the framework with fundamental signal processing and data visualization capabilities.

As part of the workplan of the ICT for Future Health project, this framework will be implemented, deployed and evaluated at the USF Nova Via primary care center in Vila Nova de Gaia, Portugal, in early 2015.

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