A Technical Platform for Remote Monitoring of Biosignals in Real Time

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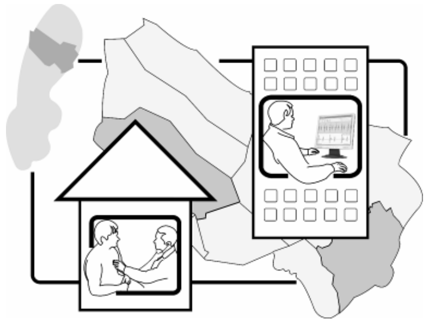
***Abstract*— The percentage of elderly in the European population is steadily increasing and this presents new challenges for the health care. Improved home health care has the potential to reduce costs and workload if patients can be successfully treated without having to travel and stay at the hospital. We have been working with technology and concept for remote monitoring of physiological parameters. During user studies we found a need which lead to a technical platform for monitoring and a database where the measurements are stored. A laptop computer with sensors is used to measure e.g. heart- and pulmonary sounds and ECG. The signals are sent over the network in real time to health professionals that can monitor, diagnose and provide their assessment. This work procedure was evaluated by paediatric cardiologists to examine children with suspected physiological murmurs. It has also been used by district nurses to consult a doctor when following up hypertensive patients. The need to perform some examinations remotely is even more immediate in the countryside where there are few doctors – patients have the right to receive the same qualitative care no matter where they reside. Future work will further evaluate this concept and the benefits of distributed care.**

I. Introduction

The percentage of elderly in the European population is steadily increasing and this presents new challenges for the healthcare. In 1975, 12.7 % of the population was over 65 years of age, in the year 2000 it had risen to 15.7 % and estimations show that in the year 2025 it will be 22.7 %. Today, as much as 70 % of the healthcare costs originate from this part of the population resulting in a large need for complements within the healthcare which allows the care taker to relieve the healthcare from this burden. Home healthcare and electronic venues are prioritized areas both nationally as well as within the European Union [1].

The need to perform examinations remotely is as much a matter of quality as it is a matter of improving the efficiency of health care. Quality is to offer the best available health care anywhere the patient lives. Quality is also when the health care reach those patients that are not strong enough to make the journey to the hospital. Supported by an expert the treatment and medication will be more precise and signs of illness can be found in an early stage. Technological advances in mobile broadband, miniaturization of computers and improved security solutions have made the technology mature enough for telemedicine to be utilized to its full extent. Today many discover the possibilities of telemedicine – both the Swedish government and in the European Union focus on IT in health care and electronic venues. In the county of Västerbotten there are many good examples of successful projects in telemedicine. Many of them have left the project stage and are scaling up to an increased number of users. Videoconferencing is particularly well deployed and is frequently used as a channel of communication between health care personal and also between patients and the doctor. The meeting and conversation between doctor and patient is always important. Remote monitoring is a complement for this situation which give a better medical basis for decision.



We believe that a national medical call centre could support home health care professionals all over the country with guidance and medical assessments based on monitored data, videoconference and medical images and the patient journal. The public authorities in Sweden have declared a national strategy for how the future of health care information and communication technology must evolve. The message is clear - the health care systems need to be standardized and integrated so that the patients health care record and health care services become a national resource. The patient and relatives will access information about disease and treatment thru a personal web portal where all the relevant patient information is collected. In this environment, the idea of a call center makes a lot of sense [2].

We have developed a generic platform for remote monitoring that have been used by user groups with different kinds of monitoring needs. It is a system of PC software, computers, sensors and headphones that remotely connects the health care staff to the specialist doctor so that unnecessary travel can be avoided.

II. System Design

The remote monitoring platform was developed during a two year project that progressed in three major phases. First we conducted user studies of different user groups working in different areas of health care. We identified their problems and needs. Remote monitoring and collaboration was part of the solution why we in the next phase began to develop a platform supporting them in this. Finally we developed a storage system that enables the person that register physiological measurements, the operator, to store measurements so that the specialist can assess them later if real-time is not an option. Visual Studio 2005 was used for building the software.

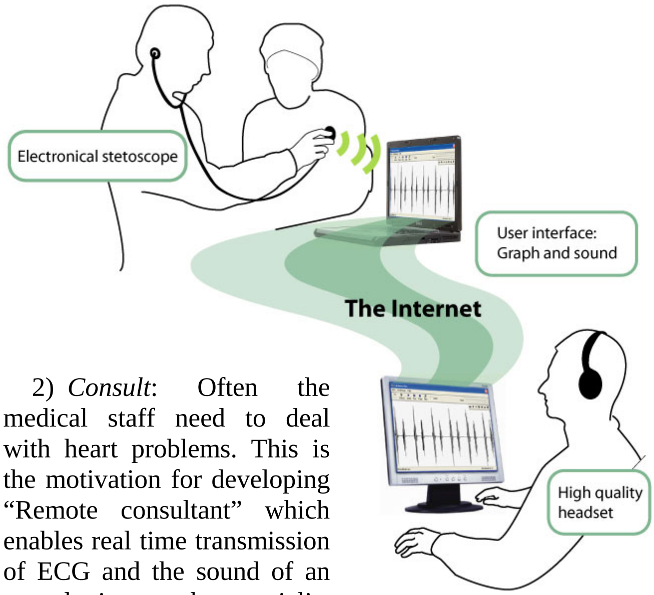
A. *Healthcare workflow*

The workflow when using remote monitoring in home health care was based on a methodology that evolved during the user studies and testing. The protocol listed below describes how one of the applications ("Remote Consultant") we build using the monitoring platform was used.

1) *Register physiological parameter*: The care provider visit the patient at home. A laptop is part of the equipment used to read the patient journal, search for information and at occasion, consult a specialist. Everything is up and running immediately; both applications and the mobile connection.

In some cases the care provider visiting the patient cannot form an opinion of the medical problem and what actions need to be taken and therefore choose to contact a specialist. Over the videoconference or telephone they will discuss the patient and how to proceed with treatment and possibly some medication.

By registering different physiological parameters a better understanding is gained of the condition of the patient. This system can measure heart and pulmonary sounds and ECG. It can be customized to measure practically any signal.



2) *Consult*: Often the medical staff need to deal with heart problems. This is the motivation for developing "Remote consultant" which enables real time transmission of ECG and the sound of an auscultation to the specialist as it is measured from the patient. The specialist can guide the measurement and the patient gets a medical opinion right away.

The software makes it really easy to contact the specialist. The user interface clearly show whether you are available for consultation and a click on your coworkers name in the address book is all it takes to connect and the consultation is initiated. You can consult several specialists at the same time to get a second opinion, or for other reasons such as education of new doctors.

To communicate with each other before, during and after the consultation there are functions to send text messages and also telephony to talk.

3) *Analyse*: The specialist can be a part of the examination and receive the signals as they are measured or they can be analyzed afterwards by opening the saved observations. Both ways have their pros and cons in different situations and for different care providers.

The sound of the heart and lungs is naturally reproduced in special high quality headphones and the sound is handled without compression at any stage. A graph shows the sound curve and the user can choose to listen to a specific episode or the whole registration. Phonocardiography analysis can be activated as tool to analyze for example murmurs.

When the assessment is done the specialist write it down in a form that is connected to the observation. This can be read by other medical personal – a simple referral system.

B. *Remote monitoring architecture*

To support the different types of communication and measuring needs that were identified during user studies and detailed in section *A. Healthcare workflow* we created a platform. This platform is made up of computing devices, medical sensors, a wireless acquisition system and a software architecture for remote monitoring. The reason we built our own remote monitoring software architecture was to be able to control every aspect of it, and at the same time minimize dependencies on products and technologies that would limit our choices of interaction model and user experience. We can make it work exactly as it need to work. The software was build bottom up by the pieces we needed and that are now to be explained.

1) Peer-to-peer messaging. For the messaging between the operator node and the receiving nodes we used a peer-to-peer distributed model. The nodes sent messages directly to each other which reduced latency, as opposed to routing messages thru a server. Microsoft .Net Remoting was used for sending textual messages but also for sending commands and metadata between the nodes. Remote commands were used to synchronize the state machines in all the nodes. E.g. when the operator started registering a measurement, all the receivers connected and started streaming data from the operator. Metadata were sent between the nodes to convey information about which patient is examined, what type of observation it was, the positioning of the measurement and a full description of the signal measurement parameters. When the users started their software they were automatically connected to their team of co-workers, much like Instant Messaging (IM) and the user could see the online status of people they had added to their list. To start a consultation they clicked on their co-workers name. A message and ringing then appeared at the consult asking him or her to accept the consultation. If the request was accepted, then they could start sharing patient information. If the operator had already done some measurements or entered some information this information was synchronized as soon as they connected so that they could see the same patient, observations, past registrations and ongoing registrations. Messaging was based on publish / subscribe model where the sender was asynchronously broadcasting to all receivers, with an optional acknowledgement response. The nodes would initially discover each other by asking a dedicated name server about who was connected.

2) Streaming. Streaming the continuously sampled physiological parameters over the Internet used the Transmission Control Protocol (TCP). Data was pre-buffered at the receiver to handle variability in network packet delays. Overall latency depended on network bandwidth, load and congestion, but usually it was between 200-500 ms. To reduce the required bandwidth, a lossless compression was used. Sound was typically reduced to 1/3 of the original size, without loosing any information. The transmitting application was running a TCP-server that clients connected to by sending a signal descriptor of the desired signal.

3) Real-time presentation. The physiological signals were presented in real-time to both the operator and the specialist. Live graphs and sound were an element of feedback for the one who was measuring, and the basis of diagnosis for the specialist. Managed DirectX was used for both graphs and sound. Pre-buffering and effective rendering was the key to present multiple signals simultaneously in a smooth flow even on a low end computer. Unnecessary copying was avoided by letting the graphs, sound players and filters read directly from the one and only physiological variable instead of using multiple buffers. The graph was interactive so the users could scroll to navigate in the history of data and select specific sections to replay.

4) Data acquisition. Signals was sampled from different measurement devices. Each device had it's own software driver. All the drivers share a common interface that allows them to be started, paused and stopped. This was a convenient design that enabled the streaming server to connect to any type of source and send the signal over the network. It could be sound from the stethoscope, some signal measured with a wireless data acquisition system [3], or even relayed signals from one client to another, e.g. working as a network proxy. Sound from the stethoscope was sampled efficiently by using DirectSound and notifications which made use of the sound cards direct access memory capabilities. The sound recording buffer was a ring buffer divided into 6 blocks. A special voice-sampler was used to transmit voice as a mean to communicate with each other if IP-phone or videoconference was not available.

5) Applications. We built four different applications to accommodate the different types of users we wanted to support in different types of scenarios. The "Remote Consultant" was used to register data and have a consultation with a specialist making an assessment. A lightweight version of this software was also build with a one button solution; as soon as the operator pushed the button on the stethoscope, sound would be heard in the headphones of the specialists. No interaction with the software needed. Yet another program was the Measurement Journal where the users got an overview of the observations that had been registered. An Phonocardiography (PCG) application was also developed to give the doctors the band pass filtering of the heart sounds that they were used to.

C. Computing devices and medical equipment

A small laptop computer was used by the operator for registering different types of physiological parameters. When measuring ECG it was connected with Bluetooth to the wireless acquisition system. When measuring heart- and pulmonary sounds it was connected with USB to a patient isolation (Meditron TheAnalyzer) connected to an electronic stethoscope (Meditron M30). The specialist used a regular stationary computer equipped with high fidelity sound card and head phones (Sennheizer HD497).

D. Signal representation and storage

A data model was defined that described signals, observations, patients, patient encounters and other health care entities. It was a hierarchical and object oriented structure that could be serialized and sent over the network which made it possible to synchronize the state of the different nodes. The storage solution was a service oriented software architecture built on top of a Microsoft SQL 2005 database. The services were partitioned into four layers: presentation layer, service layer, domain layer and information layer. For each application a new presentation layer was written. Each application also needed its own service layer. It took care of the flow control and translation of data structures from the presentation layer to the domain layer. The domain layer was the same for all applications. It was an object oriented layer representing the business logic. Factories in the information were responsible for calling the right Data Access Object (DAO) in the information layer. Data carried between the domain layer and the information layer were simple data types. To connect to the web services you had to be authorized and authenticated to the system and for this purpose we used Web Service Enhancements (WSE) 3.0. The system also could handle different roles, groups, access control and logging.

III. System Evaluation

Four user groups working in different medical areas were engaged in the development process which gave us a broad perspective on how to create a generic design that could be customized to fit each user group. A group of paediatric cardiologists wanted to listen to children hearts remotely to avoid healthy children with physiological murmurs being remitted to University Hospital of Northern Sweden (UHNS). A health care centre in Lövånger wanted to improve their hypertension treatment by consulting a doctor at a distance thru videoconference and using remote auscultation. Logopaedics at UHNS wanted to use the platform for transmitting high quality voice sound that would not be altered or compressed in any way. And finally, a geriatric team at UHNS wanted to be able to work more efficient when operating in the home health care. We are currently writing an article evaluating the clinical effectiveness together with the user group in Lövånger. For the other user groups we need more measurements before we can evaluate the clinical effectiveness.

We have however evaluated some quality aspects of the system. With the cardiologists we compared the medical assessment done by a doctor using a regular acoustic stethoscope to the assessment done by a doctor remote monitoring the heart sound from an electrical stethoscope. Also we conducted an experiment where they would listen to sound files with heart sounds recorded at different sample rates. They were asked to assess each recording and write down what kind of heart disease it was and comment on the sound quality. With the user group in Lövånger we did the same thing with different sample rates but with cough sounds instead of heart sounds.

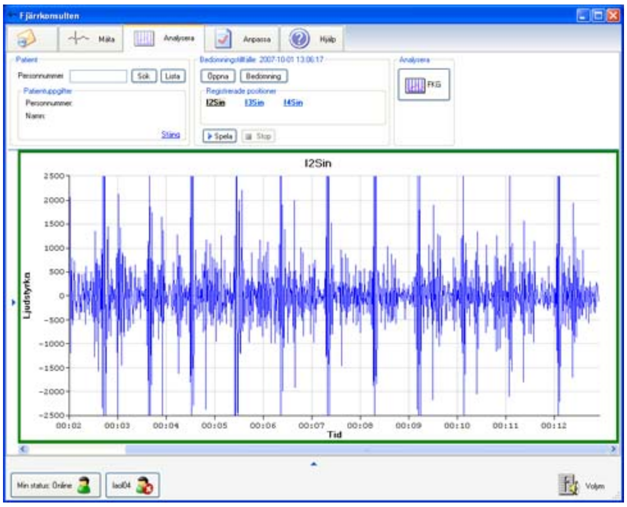


Fig. 1 Remote monitoring software registering heart sound.

E. *Interaction model design*

Developing the platform and then specialize it to specific monitoring needs was an iterative process in cooperation with users in the medical profession. User studies gave us an understanding of how the users work; frequency and sequence of actions, tools and method of clinical examination. This guided us in designing a system that was easy to use and solved the right problems. The first user group identified and targeted for evaluation of the platform was paediatric cardiologists at UHNS, Umeå, with a need to remotely monitor auscultations of children at Skellefteå Hospital, 130 km away. These children were frequently referred to specialist cardiologists in Umeå since the common healthy functional heart murmurs could not be definitely distinguished from the pathological ones in Skellefteå. Remote auscultation could save patients and specialists from unnecessary travels and reduce the cost of the examination.

Persona and scenario building resulted in a low fidelity prototype and an interactive prototype. Software implementation focused on modularity and reusability. The design was object oriented and multithreaded to handle software complexity. Scenarios, use cases, object interaction diagrams and class diagrams lead to an implementation that was modularized into separate software packages for handling graphics, sound, sensor digitalization and network communication. Specific features were implemented for the paediatric cardiologists, such as registering the stethoscopes position on the body during auscultation, customized filtering and high fidelity headphones for listening.

A platform for remote monitoring of physiological parameters in real-time over the Internet has been implemented and tested. The core of the software is techniques for reliable network streaming and presentation of the physiological parameters as graphs and sound. The main concept is that you share your sensors with colleagues over the internet. Any or all of the physiological parameters currently monitored on your own computer such as files, remote sources or locally measured signals, can be shared with others in real-time. Sharing sensors and connecting to others is easy since a central hub keeps track of online users and their signals. Navigation controls are used to make selections in the graph and play the sounds repeatedly. Filters applied in real-time enhance the sound quality and selected frequency bands.

IV. Discussion

This software sends physiological parameters in real-time over the Internet. But, as opposed to the technology typically used for live Internet feeds of music, radio or videoconference it uses more reliable transmission channels; no medical data is lost or distorted. Another major concern is to create an interface and features that fit the profession and their method of examination. Therefore we do not base our software on any proprietary components that would effectively prevent us from customizing and making it work exactly the way it needs to.

TCP is reliable; no network data packets are lost, reordered or duplicated during transmission. We considered defining mechanisms for recovering from packet loss on top of User Datagram Protocol (UDP) or Real-time Transport Protocol (RTP). This way, reliability could be implemented with better real-time performance, without enforcing the congestion control mechanisms that decrease the congestion window when packet losses are detected. We decided against it though, since it is quite an effort for little gain; monitoring is not very delay sensitive, and voice communication can be solved separately if necessary, with lossy high ratio compression and UDP or RTP streaming. The next generation of Internet protocols, IPv6, will give a better quality of service for real-time streaming and new possibilities for this platform implementation.

Meditron M30 electronic stethoscope, used to perform auscultations, amplifies the sound and is perceived differently than traditional acoustic stethoscopes. The doctors need to practice to listen and analyse sound from electronic stethoscopes to feel comfortable with the technique.

Soundcards can sample with rates up to 96 kHz and 24 bits/s but this is not necessary for auscultation; the frequency range of acoustic stethoscopes is typically 20-2000 Hz and higher frequencies are effectively damped by the body tissue [4]. Psychoacoustic modelling methods like Ogg Vorbis or Advanced Audio Coding were not used for a number of reasons. The fact that they are lossy may ruin future analysis of the data. They only work for sound data and also they are quite computationally expensive. Our design was built on the principle that no medical data should be lost or altered, and not be saved in any closed standards format.

The computing device used for measuring is a laptop PC. We choose to use a laptop instead of a PDA or a Smartphone because we found it more versatile. It can be used in home health care to access the patients journal and other health care services. It can be used to register physiological parameters. Another advantage is that is has a superior user interface with a full size keyboard and a 12 inch screen.

The remote monitoring system depend on some kind of network connectivity with at least 300 KBit/s. We have had consultations over WiMAX connection. 3G, NMT450 and HSDPA would work as well. A major obstacle though, is connecting users that can only connect their computers to their own organisations private intranet. Traversing different local networks is a problem that is hard to solve since it concerns the security policy of the different organisations. With TCP-hole punching techniques you will get thru the firewall in some cases, but this is not the security model we want for our software platform.

ACKNOWLEDGMENT

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