TeleMedSys - Web-based Telemedicine System to Support Diagnosis in Rural Areas

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Abstract— **This article describes the concept for a web-based telemedical system for use in rural areas with limited communication infrastructures and a lack of medical professionals. The TeleMedSys consists of a patient management system and a medical device system that are available to the doctor and the patient-side assistant during treatment via an Internet browser. The combination of local and remote web applications enables a seamless integration of the medical devices required at the patient's location into the doctor's remote station based on browser technology. The implementation of this system represents an improvement in the living conditions of populations in rural areas.**

Keywords-Web-based telemedicine; remote medical device; distributed medicine system; web technology; rural telemedicine.

I. BACKGROUND AND STATE OF THE ART

Significant efforts are currently underway in various Latin-American countries (e.g., Ecuador, Cuba, Mexico, Brazil) to improve the healthcare situation in hard-to-access, rural and underdeveloped regions; using telemedical solutions.

The Foundation for Telemedicine and eHealth in Ecuador (FUNDETEL) [26] is an example of an institution that together with local universities, is currently working on the collaboration and promotion of telemedicine and telehealth in Ecuador and internationally, not only as a teleconsultation and second opinion tool for rural areas such as the ANDES and COASTAL AREAS, but also in the area of training / online education in telemedicine, participating in the IDBA project for Latin-American Politics and Standards for Telemedicine and Telehealth.

In highly developed industrial countries with an extensive medical infrastructure, telemedical systems are mainly used to improve the quality of life for older people [1][2], as well as in emergency healthcare systems [2][3], and for systems used in particular situations (on ships [5], in the space flight industry [6][7], and in military applications [8][9]).

The available telemedical systems are not suited for regular and conventional treatment processes with only untrained or semi-skilled medical staff available at the patient's location. In addition, the costs of conventional systems available on the market by far exceed the cost limit for practicable systems in developing countries. The technical solutions are based on proprietary and supplier-specific components, while ICT standard technologies are hardly used.

Some web-based telemedical projects planned to be deployed in underdeveloped regions and countries already exist [10][11][12]. However, the respective concepts in most cases only address the required telemedicine, while not considering the actually required telemedical stations, for which conventional systems available on the market shall be used. Further interesting solutions and discussions about telemedicine concerning the topic of this paper you can find in [14-25].

In rural and isolated areas with geographical limitations, telemedical stations that take into account satellite connectivity, power supply such as solar panels, and ready-to-use teleconsultation equipments is urgently needed and not easily available or affordable.

Furthermore, in the year 2008, during the REV conference in Düsseldorf, Maria Teresa Mijares presented a keynote speech [27] on the benefits and advances of telemedicine. This sparked the interest of many of the institutions and universities present at the event, in telemedicine.

Duesseldorf University of Applied Sciences / Competence Center Automation Duesseldorf (CCAD) together with Universidad de Oriente / Centro de Neurociencias Procesamiento de Imagenes y Señales (CENPIS) / Santiago de Cuba decided to research and create a telemedical system (short: TeleMedSys), as an important and affordable tool for the application of telemedicine in rural and isolated areas.

The main problem of this research is a lack of a control system that allows doctors to take care of patients from different rural areas directly from hospitals.

The current status of TeleMedSys is a demonstration example (prototype) that is analyzed and discussed in the present article.

In the next sections of this paper we described different aspects of TeleMedSys. First a deep analysis of the main Requirements and objetives. The Scientific and Technical Solution for the prototype is also made, here is exposed the equipment structure of the TeleMedSys, the functional structure, problems of data analysis and the design and implementation. We finish this paper with the proposal for the use of this system in other environments after finish with first version.

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II. REQUIREMENTS AND OBJECTIVES

The main objective of TeleMedSys is to support telemedicine and the remote diagnosis of people living in rural areas, from the doctor stations. TeleMedSys respects the natural and economic conditions of each area and works in dependence of it.

This prototype is not supposed to be a technological innovation; we were trying to solve a critical problem in rural areas using different technologies, particularly Web-technologies.

The main requirements and functionalities of the system are listed below. They were defined in agreement with FUNDETEL for the new telemedical system (TeleMedSys):

- A doctor station (DS), which will be able to cooperate with n patient stations (PS) respectively, will be set up.
- The PS deployment site has no power supply or communication infrastructure. The TeleMedSys will be transported through harsh terrain to the deployment site.
- Only medical assistants will be available at the PS site, which will have to be guided by the doctor during the treatment process.
- The TeleMedSys shall be web-based in order to integrate simple e-learning elements in parallel (work-integrated learning).
- 95% of the treatment process is performed asynchronously between the patient/assistant and the doctor while the remaining 5% are performed synchronously via video conference and/or real-time chat.
- The weekly period of use for a PS amounts to 3-4 hours. The maximum distance between the PS and the respective DS is 2,000 km.
- The medical examination equipment is connected to the PS; it will be unlocked by the DS and operated by the assistants according to the doctor's instructions. The measuring data are automatically provided to the DS.
- The acquisition costs of the TeleMedSys should not exceed EUR 20,000. The operating costs should be less than EUR 1,000 per month.

A particular challenge is the asynchronous treatment process, because in traditional medical practice such a procedure is not required and unknown.

The Düsseldorf University of Applied Sciences initiated a university-internal research project with the involvement of the Universidad de Oriente in Santiago de Cuba for developing the first prototype in 2011.

III. SCIENTIFIC & TECHNICAL SOLUTION

A. *Equipment structure of the TeleMedSys*

The device-related part of the DS can be realised with a standard computer, as the physician has the required infrastructure (fixed power supply, Internet access) and no medical devices need to be connected. The development of the PS was the biggest project challenge. Based on the above-mentioned requirements, the PS will therefore be equipped with the following components:

- A robust notebook for use under critical environmental conditions (ruggedized).
- A solar power station featuring a buffered battery operation for the power supply (solar output: 28W; battery: 15Ah, 12,8V; module output: 15V, 1800mA).
- Satellite modem (Inmarsat satellites) for setting up Internet access with 384 Kbit/s download and 240 Kbit/s upload.
- Medical examination devices with Bluetooth interface. The prototype, for the time being, will feature a blood pressure measuring device and a 6-channel ECG device.

Figure 1 shows a picture of the PS device components.

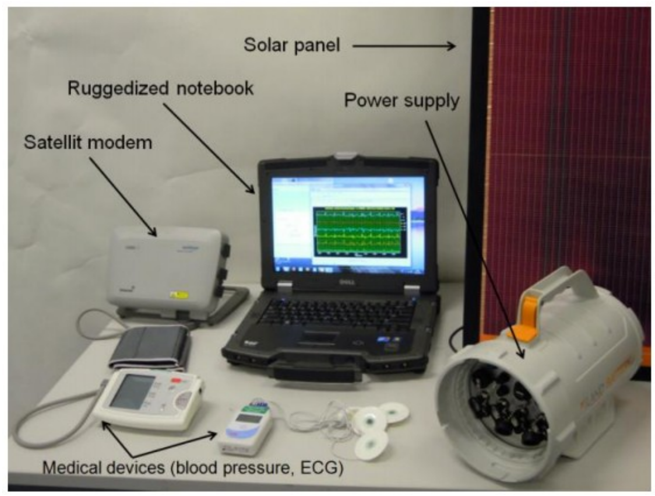

Figure 1. Device components of the Patient Station for the TeleMedSys

The appropriate technology devices will be implemented in accordance with the primary health needs and common diseases of the area. For further development the system should be connected to at least the following additional equipment for medical examinations:

- Ultrasonic diagnostic device;
- Digital camera;
- Body temperature measuring instrument;
- Spirometer.

For all equipment components of the PS, the development of a special shipping box that is suitable for transport over rough terrain is also being planned. After a field test of the prototype, we will also re-examined the appropriateness of the used medical devices with Bluetooth connectivity. Although the wireless connection of the medical device with the PS is a flexible and elegant solution, all units require an extra power supply with batteries, which may in some cases not be available. Moreover, for the communication interface of medical devices (Bluetooth, USB or serial), the respective communication protocols and APIs are required. This is usually not the case, since the devices commonly come as a complete application solution. Exceptions are the devices of the German company Corscience [28] which are used in the prototype of the PS.

The serial protocol is published by Corscience and can be used very well for development purposes. The protocol is designed for simple and memory-saving implementation in a microcontroller. The overhead was kept as low as possible. The principle of this protocol is basically modeled on the PPP (point-to-point protocol), which is often used to establish modem connections. Furthermore, escape sequences are used to filter out reserved bytes (start flag, end flag, escape flag) from the data stream.

B. Functional structure

The TeleMedSys software consists of the following three key components:

- Patient Management System (PMS),
- Medical Device System (MDS), and
- Online Collaboration System (OCS).

The prototype requires the PMS and the MDS (only for asynchronous operation). Later, the prototype will be extended with the OCS.

Figure 2 depicts the functional software structure of the TeleMedSys.

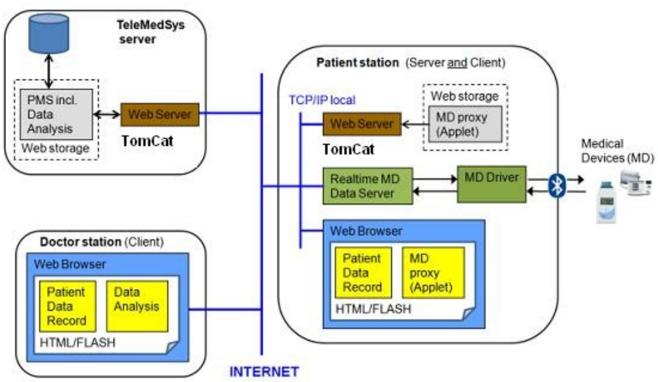

Figure 2. Functional structure of the TeleMedSys

All patient information is stored by the Patient Management System (PMS) on a TeleMedSys server. Both the DS and the PS (doctor and assistant) have access via a web browser to the PMS database on the TeleMedSys server and can edit the information in a Patient Data Record (PDR). The DS is working as a client and uses only a web browser.

The asynchronous patient treatment is the main issue of the PMS (see Figure. 3). It requires separating the overall treatment session for a patient into individual steps for the assistant at the PS and the doctor at the DS. These individual steps are performed alternately by the assistant and the doctor. The system automatically displays the status of all patient sessions and provides information about the next required step for each patient through an event screen.

In principle, the treatment is done in the asynchronous mode of operation similar to the remote diagnostic and service procedures in a technical system: the entire process is well structured and each sub-step ends with a conclusion. Completed individual steps are not repeatable in the current session.

A relatively stringent regulation of the treatment steps is required because only semi-skilled or non-professional medical personnel will be working at the patient's side. A field test of the prototype under real conditions will show whether this step-by-step process is suitable for medical treatment and whether it will be accepted by the participating medical staff.

The doctor can unlock the required medical devices via the PMS at the PS site and provide the assistant with additional context-related support instructions. The assistant at the PS will be also be instructed by the doctor, in order to make no mistakes when carrying out the medical measurements.

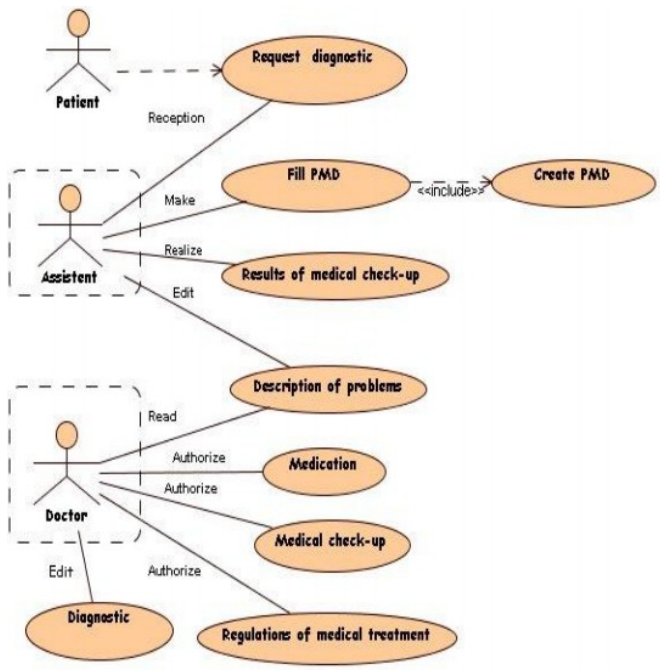

Figure 3. Graphic description of the asynchronous mode

The MDS consists mainly of the following components:

- *MD driver*: Implementation of the Corscience protocol interface to medical devices.
- *MD data server*: Recording and preprocessing of the measured medical data and implementation of a TCP/IP command interface.
- *MD proxy*: implementation of the TCP/IP command exchange between the MDS web page and MD data server.
- *MDS web pages*: The operation of each medical device is made via a web page with an MD device operator panel.

All MDS components are located on the PS and will be activated via the MDS web pages in the web browser of the PS. For this purpose on the PS is running a local web server which is used in order to start the MDS web pages. The PMS (loaded from the remote server TeleMedSys) and the MDS (loaded from the local web server in the PS) are connected in a frame website according the MashUp principle. Only by this way is possible for this web page to provide access to the peripheral components (medical devices) of the PS.

Figure 4 shows the frame website of the PS. The visual design of the PS website is not yet optimized. At the moment it is a design difference between the MDS (right grey part) and the PMS (left light-blue part).The reason is these two parts are implemented using different web technologies – MDS through pure HTML/JavaScript and PMS through Flash. The next version of the PS/DS will also have a unified user interface design.

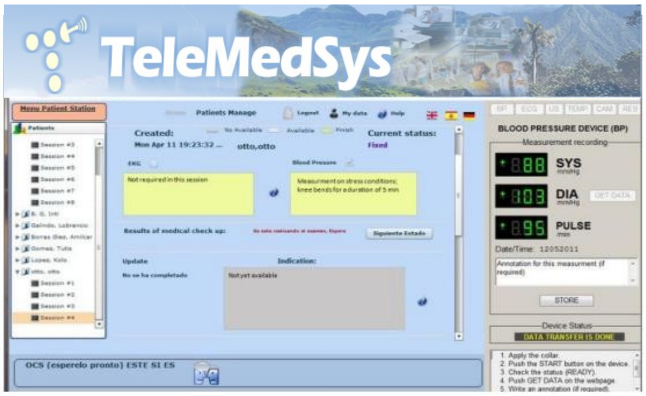

Figure 4. The frame website of the Patient Station in the prototype

In case of a limited data value volume, the MDS transmits the measuring data (e.g. blood pressure) in real-time to the PMS and stores the data in the database. The real time term is just for representing the immediacy of the information in the network between the PMS and MDS. In case of larger data volumes (e.g. ElectroCardioGram ECG) the data are saved locally in a measuring file first and subsequently transferred remotely in a corresponding file of the TeleMedSys server. In this case, only the name and location of the data file (not the data itself) are stored in the database.

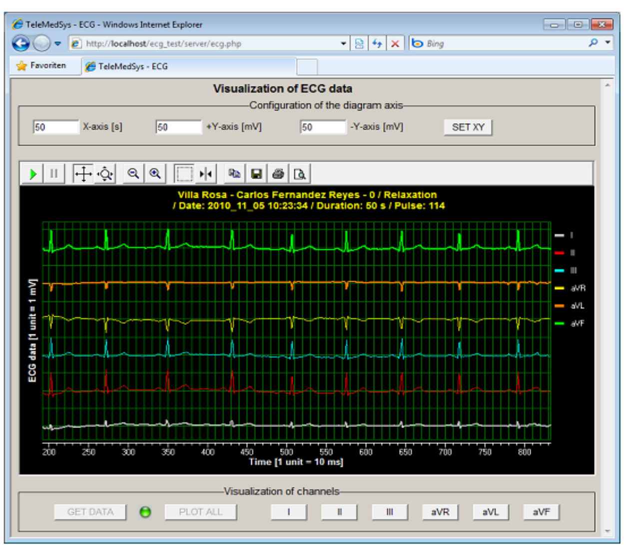

Figure 5. Analysis of a 6-channel ECG with a measuring time of 50 s in the Doctor Station's web browser

C. *Problems of data analysis*

The measuring data can be analyzed at the DS. Figure 5 shows an analysis example for the 6-channel ECG in the DS web browser.

The XY plot object (ActiveX object) from the Iocomp visualisation package is used for the graphical ECG data presentation [13]. Here, however, a problem arises for the visualization of long-term ECG measurement, which has not yet been optimally solved:

The recording of ECG data occurs at a clock rate of 100 Hz or 500 Hz. A normal stress ECG with e.g. 20 min duration and a resolution of 10 ms (100 Hz) results in 120,000 data values. The representation of these data in the XY plot object is in principle not a problem, but the plot object requires about 2 ms for the visualization of each data point in the XY object. Add to this the retrieval of data from the TeleMedSys server, which takes about 30 seconds. For the above example a delay of 4.5 min for the initial display of the data data thus follows. Once the measurement data in the data RAM of the XY plot object are stored, the analysis of data can be done quickly and in a very detailed way.

D. *Design and Implementation*

The PMS realisation is based on HTML/Flash (Macromedia eXtensible Markup Language - MXML/ActionScript) in combination with Java for accessing a database. mySQL is used as database server and the design of the relational database was made according to the specification of business applications.

The MDS is developed with HTML, JavaScript and Java applets. The MD server is a Java application that is operated via a Bluetooth interface and controlled through TCP/IP commands by a Java applet (MD-Proxy, see Figure 2).

The technology selection for the development of PMS was based on capabilities offered to end users as well as developers by using Rich Internet Applications (RIA) such as Flex Builder 3.0; that was the tool selected for PMS implementation. The use of the Web 2.0 tool in a system like TeleMedSys; includes the optimization of time and resources. The applications development, with RIA, provides some advantages to the systems user and reduces information traffic on networks, because it is not necessary to reload all of the page but just that portion that needs to be updated.

The MDS uses a special Java applet with the Live Connect method for communication between the medical devices and JavaScript functions on the MDS webpages. Originally this Java applet was developed for the remote operation of industrial devices by TCP/IP commands

TeleMedSys is structured according to classic architecture for web systems: architecture of three levels supported in a Server – Client architecture. In order to ensure the usability of TeleMedSys, the architectural pattern Model View Controller (MVC) was selected. This pattern guarantees an effective information management; it separates the model of the user view layer, using a controller to intercede between these two levels.

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To ensure the persistence of the PMS the binomial Hibernate/Spring framework is used. The main task of Hibernate is the Object-Relational Mapping (ORM). This makes it possible to store ordinary Java objects with attributes and methods in relational databases, and to create objects again from these records. Relations between objects are mapped to corresponding database relations. This guarantees that in the case of a connection abort or bad Internet connection no data are lost during treatment process, and the system can reset to the last treatment date.

The selection of the binomial also guarantees access to remote data transparently to the user; all procedures are performed using Remote Procedure Calls (RPC). Figure 6 shows the distribution of the PMS components in the TeleMedSys within the MVC pattern.

An Apache web server is running on the PS as a local web server. The PMS uses a Tomcat web server with a Spring Framework as Java application support.

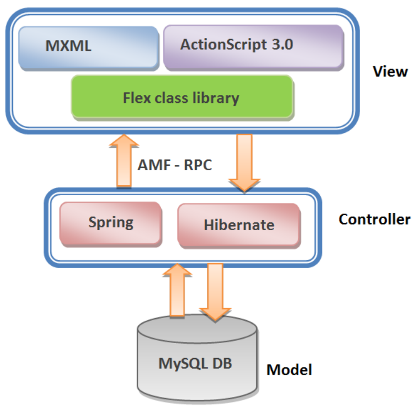

Figure 6. Architecture of the PMS

The DS will function as a TeleMedSys server simultaneously during a first field test of the prototype. Later, the TeleMedSys server will, however, operate on a dedicated computer; to provide the required safety and data security. For data transmission between the application and the server, the protocol implemented by Hibernate to access the data base was used.

TeleMedSys is a data transfer system; it must therefore ensure methods that ensure the integrity of these data. The system has three different kinds of users:

- Doctor user: Access to Patient Data Record (PDR), realization of diagnosis, records indications
- Assistant user: Access to PDR and MD, execute the indications of Doctor and has contact with the patient
- Administrator: Has the control of the system, adds, deletes or updates information about the rest of the users and the software configuration.

Each user can have access to the system using a password unique for each one. This password changes every time the user logs in the system. This password is encrypted using the MD5 algorithm.

For further versions of this system, we recommend using a data encryption algorithm in order to protect the patients' data, as well as the information of the diagnosis and the security of the system in general.

A database was designed in consideration of the data integrity. The final design of this database model reaches a 3rd normal form of normalization level. The design of the database takes into account the requirements of the system itself.

Figure 7 shows the final model design for the database

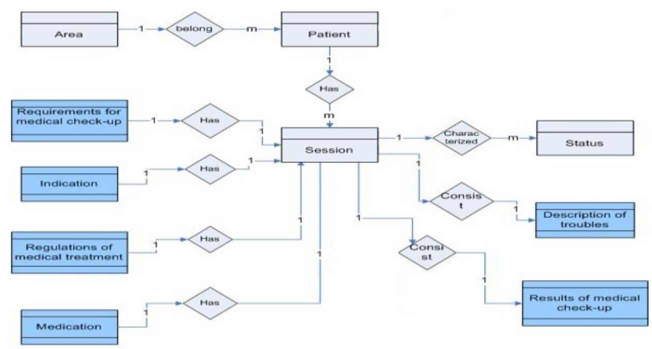

Figure 7. Database Entity Relationship Model

IV. CONCLUSION AND OUTLOOK

The article describes a web-based telemedical system for use in rural areas. The combination of remote-based and local web applications enables direct remote access to medical devices through a web browser without technological gaps. The doctor station and N distributed patient stations are provided with a structured access to all patient data through a common web browser, enabling them to perform asynchronous treatment procedures.

Upon completion of the prototype (May 2011), a first field test in cooperation with the CENPIS of the Universidad de Oriente in Cuba was realized with real patients and the positive opinion of the doctors in July 2011. The test results showed that TeleMedSys represents a big step for rural health, not only because the population will benefit from better health conditions, but also from advances in the technology. This result will be integrated in a revised prototype, which will be deployed in one of the selected rural regions in Ecuador in 2012/13.

The logic distribution and architecture of the components of TeleMedSys, make it a simple and useful system that is to easy maintain and easily migrated to other media and technologies. TeleMedSys is easy to attach to mobile platforms. It is therefore conceivable to implement a system for remote diagnosis and telemedicine using technology and perhaps even mobile telephony.

In this case, the possibilities offered by these devices (cameras, sensors, microphones) will be useful for the next versions of TeleMedSys; this would make them practical, inexpensive and easy to use for all users. The proposal considers that only the PS uses the mobile device and that Android is considered as a platform for devices.

PS will have the following components: Mobile device – Smartphone and Web browser with HTML/Flash Player by

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default. The device should also include the software for MD and a local Web server. The Web server in PS can be an Android Web server (KSW [29] or I-Jetty [30]) or can be TomCat. The selection should be accord with the designer and also with the priorities of the TeleMedSys.

The implementation of this solution brings inconvenience to the users, which must be analyzed.

- The connection between the mobile device (Smartphone) and TeleMedSys server should be using Wi-Fi, which means data transfer will be slow and it is also possible to lose some information in the process. Of course, that depends on the quality of the Wi-Fi.
- The TeleMedSys server should be near the radio zone of the Wi-Fi.

To put this proposal into practice a number of actions must be taken first. For instance, the general security of the system must be ensured, because the mobile environment is very hostile and vulnerable to attacks. We recommend, once the first version of TeleMedSys is complete, that the necessary bases for the migration to mobile platform are created because of the advantages offered by it.

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