A Web-based Architecture Enabling Multichannel Telemedicine Applications

Fabrizio Lamberti   Bartolomeo Montrucchio   Andrea Sanna   Claudio Zunino

Dipartimento di Automatica e Informatica,
Politecnico di Torino, corso Duca degli Abruzzi 24,
I-10129 Torino (Italy)

{fabrizio.lamberti, bartolomeo.montrucchio, andrea.sanna, claudio.zunino}@polito.it

ABSTRACT

Telemedicine scenarios include today in-hospital care management, remote teleconsulting, collaborative diagnosis and emergency situations handling. Different types of information need to be accessed by means of etherogeneous client devices in different communication environments in order to enable high quality continuous sanitary assistance delivery wherever and whenever needed.

In this paper, a Web-based telemedicine architecture based on Java, XML and XSL technologies is presented. By providing dynamic content delivery services and Java based client applications for medical data consultation and modification, the system enables effective access to an Electronic Patient Record based standard database by means of any device equipped with a Web browser, such as traditional Personal Computers and workstation as well as modern Personal Digital Assistants.

The effectiveness of the proposed architecture has been evaluated in different scenarios, experiencing fixed and mobile clinical data transmissions over Local Area Networks, wireless LANs and wide coverage telecommunication network including GSM and GPRS.

Keywords: Telemedicine, mobile computing, Electronic Patient Records, Web technologies, Java.

1. INTRODUCTION

Telemedicine applications are a valid method to improve the quality of the delivered sanitary assistance. Mobile telemedicine is in particular useful both in places where standard telephone service is not easily available, and when emergency care is required. In order to build a global architecture for providing remote teleconsulting, collaborative diagnosis and emergency situations handling, many different technologies are required.

In particular, the Java programming language together with XML and XSL technologies can be useful for accessing telemedical systems by means of different devices, from personal computer to Personal Digital Assistants (PDAs).

Personal mobile telemedicine systems using wireless communication links have been employed in several applications and have been extensively studied [1],[2],[3].

Current development in telecommunications is toward the adoption of General Packet Radio Service (GPRS), a standard from European Telecommunication Standards Institute (ETSI) [4],[5] which basically provides a packed-switched bearer service in a GSM network.

Wireless LANs are instead used where a local network can be built and accessed (e.g. in a hospital); an example of wireless LAN is IEEE 802.11 [6].

Furthermore also satellite based wireless links are used. A high-speed satellite communication architecture was developed to supply a mobile computed-tomography scanner [7]. In this system a van has a whole-body computed tomography scanner and a second van is equipped with a satellite communication system. The system is used also for teleconferencing to a consultation center.

A problem related to the telemedicine is the images transmission. The use of digital imaging in medicine has benefited from the formation of the Digital Imaging and Communications in Medicine (DICOM) committee [8]. For images the committee had adopted various JPEG variants, such as lossless JPEG and the new one JPEG 2000. Medical images compression techniques have primarily focused on lossless methods, where the image can be reconstructed exactly.

Also the European Community is supporting wireless telemedicine projects in the Fifth RTD Framework Programme 1998-2002 [9].

An important project in the Fifth RTD Framework Programme is EPI-MEDICS (Enhanced Personal, Intelligent and Mobile system for Early Detection and Interpretation of Cardiological Syndromes) [10]. The main expected result is the design of an enhanced, intelligent and portable PEM prototype that will be able to detect cardiac arrhythmias and ischemias and generate different levels of alarms that will be forwarded to the relevant health care providers.

A mean to help communication among different actors is Web technology. An example of using the Web for remote monitoring is reported in [11], where a system for live broadcasting of ECG signals over the Internet is presented. It uses a portable holter device, a browser-based Java Applet and a server application. Another example is in [12], which also consists in a portable data acquisition and preprocessing module and a Java-based client-server platform. In [13], the methodologies for making the Internet a tool for manipulating biomedical data are explored. In particular the choice of an appropriate database management system (DBMS) is addressed, since databases have to be accessed over the Web. Pollard [14] develops a hardware/software prototype for real time acquisition, wireless transmission/reception and connection to the Web.

A web based image processing system is in [15], which also supports image analysis such as MCA (Multi Channel Analyzer), ROI (Region of Interest) and DICOM encoding/decoding.

Lau [16] has developed a Web browser plug-in that simplifies the process of capturing video and transferring it to a Web site where both patients and doctors can access this Web site to monitor health status.

Another type of medical information environment which is fully Web-enabled is [16]. The system can handle any type of medical information including text, physiological waveforms, images and moving images. In particular it is an advanced web-browser based software integrated with a full DICOM library covering all modalities.

In [18], medical data representation is performed by means of XML and XSL, and the proposed system is implemented on Linux platform. The novelty of our approach is to combine all these elements, in order to develop a complete architecture enabling advanced telemedical applications. Java, XML and XSL are used to etherogeneous access devices, while a middleware and a storage levels guarantee information availability in various healthcare scenarios.

This paper is organized as follows: Section 2 presents the proposed architecture, Section 3 highlights client-side functionalities, while Section 4 reports about server-side applications. In Section 5, a detailed description of the designed database for clinical data storage is provided.

2. SYSTEM OVERALL ARCHITECTURE

The system has been organized by following a three-tier-based architecture (Figure 1), an evolution of the client-server scheme with an additional level, the middleware. By handling data transfer from client/presentation level to storage level, the middleware makes access to data transparent to the client level. Web technology acts as communication mean for the entire architecture. The three levels can be outlined as follows:

- **Presentation level**: it consists of a Web browser and of its extensions (Applets and JavaScripts) which acts as user interface for accessing the clinical database.
- **Middleware**: it consists of a Web server and of its extensions (Servlets and other Java applications) which allow access to storage level for information retrieval and formatting for suitable presentation to the client.
- **Storage level**: it consist of a standard Electronic Patient Record based database made up of all

resources containing information of interest for healthcare applications.

As far as the client-side is concerned, the advantages of using the Web as communication medium are the independence from the client hardware/software architecture and the unique environment for application access. The server-side may instead take advantage of the fact that the application software runs only on the Web server and thus software updating and maintenance does not require any changes on client hosts, but only on the Web server itself.

3. PRESENTATION LEVEL

In designing the presentation level, one of our ultimate goal was to deploy a flexible architecture able to cope with different clinical scenarios (Figure 2): in-hospital data analysis, remote data analysis (telediagnosis) and collaborative in-hospital and remote mobile data analysis (teleconsultation).

Each of these scenarios requires the adoption of suitable access devices and communication means. In-hospital care management can be carried on by using etherogeneous personal computers and workstations connected over an Ethernet-based Local Area Network (LAN). Moreover, to enable mobile teleconsultation and telediagnosis sessions in emergency situations outside traditional healthcare centers as well as to ensure medical staff continuous reachability, a portable device capable of wireless network connectivity is needed.

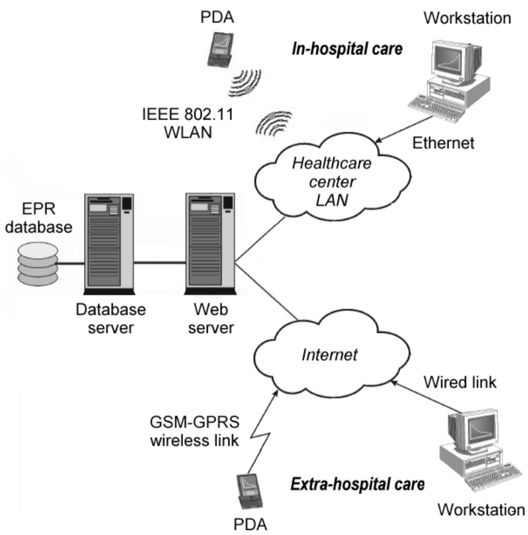

Figure 1: System overall architecture.

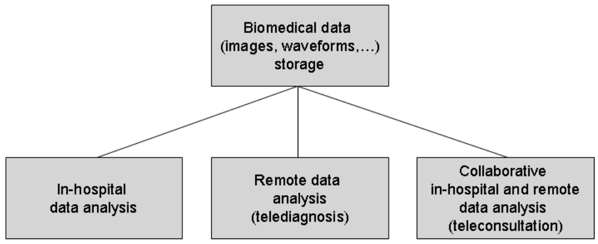

Figure 2: Some possible healthcare scenarios.

Therefore, code portability among different platforms had to be taken into great account. Furthermore, to deploy an effective multi-channel architecture, the end-user interface appearance and behavior has to be adjusted according to actual access device capabilities paying attention to maintain the same functionalities. In addition, especially in a telemedical system, data should be displayed in an intuitive way and its representation should be very close to the traditional one so as not to modify medical staff habits too much.

These issues can be effectively addressed by following a Web-based approach. In particular, by developing the user interface as a Java Applet, data can be retrieved in a simple and user-friendly way by means of any device equipped with a Java-enabled browser (e.g. PC and Personal Digital Assistant) over different communication links. By integrating also the XML and XSL technology, the graphical user interface can be dynamically adjusted according to the specific client devices capabilities without rewriting or recompiling application software.

The proposed Web-based visualization interface has been evaluated using both common personal computers and handheld devices (Figure 3) interacting with the storage subsystem over wired and wireless connections. In particular, both a wireless GPRS and a IEEE 802.11 WLAN communication environment has been designed in order to allow remote mobile diagnosis and consultation.

The Java Development Kit (JDK) 1.1.6 and the Abstract Window Toolkit (AWT) graphical APIs have been employed, in order to preserve backward compatibility with older browsers while ensuring portability on Java Virtual Machines with a limited set of APIs (e.g. JVM implemented on PDA devices). Several Java Applets for data retrieval and consultation have been developed. When the user perform a search for clinical information related to a particular patient, a list of available data sets (including medical images, vital signs acquisitions and administrative/clinical information in textual form) is shown by means of a dynamic HTML page.

When the user select a particular resource, a request containing details about the current communication mean and actual device capabilities is submitted to a Servlet running on the Web server. A dynamic page containing a suitable Applet for data visualization on the selected device is generated by the server and submitted to client.

With regard to medical images consultation, a Java Applet has been developed, which allows the user to perform rotate and zoom operations, carry out length, area and volume measurement, use drawing and writing features, apply image quality enhancement algorithms and record clinical reports.

The Java Applet for vital signs acquisition retrieval includes zooming, stretching and measurements functionalities and a prototypal automated diagnosis-oriented support tools for features extraction for ECG waveform.

Several screenshots of the user interface for information consultation deployed on a PDA device are shown in Figure 4.

The selected device is a Compaq iPaq H3630 PDA equipped with the Microsoft PocketPC operating system with PocketExplorer. Some basic features of the handheld device are: 206 MHz Intel StrongARM CPU, 12-bit color depth display, 240x320 pixels (2.26x3.02 inches) TFT touch screen, 32 MB

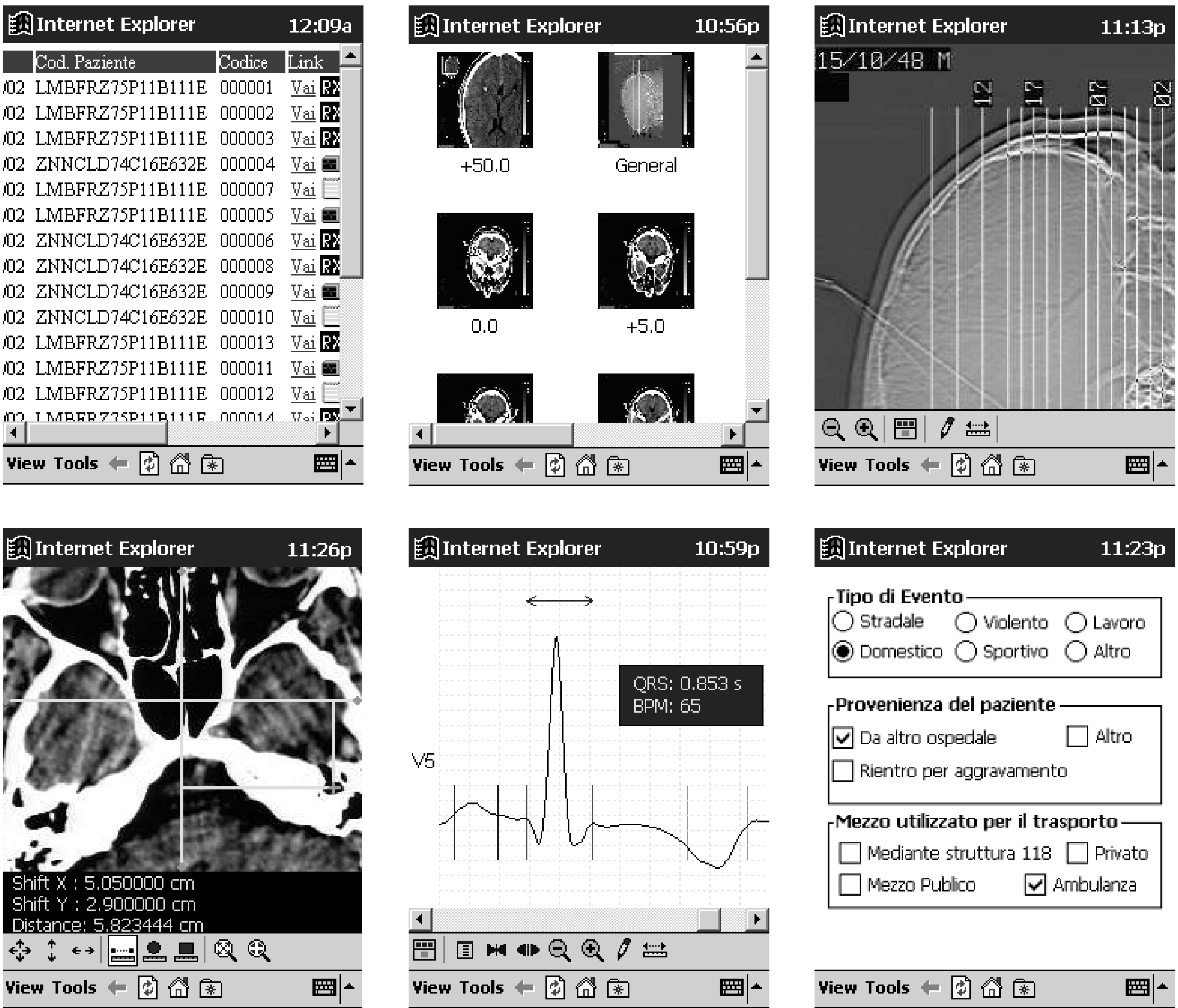

Figure 4: Several screenshots of the user interface deployed on PDA devices.

RAM and 16 MB Flash ROM. In Figure 5 and 6, the Java based user interface running on a traditional PC is presented.

It has to be remarked that, besides acting as a information visualization/manipulation interface, the Applets implement several techniques for data transfer optimization including lossless compression, data caching on client-side and broken transmissions recovery.

4. MIDDLEWARE

The core of the designed architecture is a Java Servlet, that is an application called by the Web server to process incoming requests from client Web browsers.

When the user wants to retrieve patient-related medical data, he only needs an Internet connection to browse the project Web site. As the user gains access to this service, the system displays a Web page that allows the selection of search parameters.

Selected search criteria are sent to the Servlet which executes the query on the database via the Java Database Connectivity (JDBC) APIs and generates an XML document containing query results.

Depending on the actual access device, a particular XSL stylesheet is then applied to the XML data thus obtaining a dynamically generated HTML page. Stylesheet suitable for data presentation on both mobile client endowed with limited displays and conventional PC-like machines have been developed.

The result page containing data related information and links to the matched resources is sent back to the Web client. When the physician selects a particular resource, the Servlet prepares a HTML page containing the proper Java Applet for data visualization and manipulation on the particular device and sends this page back to the client. When loaded in the client browser, the Applet downloads and displays the requested resource.

The proposed approach makes the system suitable for any type of client. The use of Java, XML and XSL technologies allow both to transport data over the net in a homogeneous way for various types of clients, and to present data to the end user in a similar way on devices characterized by different visualization capabilities.

Figure 3: The Compaq iPaq H3630 Personal Digital Assistant used as access device.

5. STORAGE LEVEL

The database for biomedical signals, medical images and patient related clinical data storage and sharing has been developed according to the conceptual model required by the standards on ICT medical applications delivered by the CEN/TC251 committee.

Standardization is a key issue in the development of modern telemedicine systems because it strongly facilitate data exchange and cooperation between healthcare centers thus enhancing the quality of the delivered sanitary assistance. Several standards have been approved by CEN/TC251 in order to provide a unified environment for integrating medical data from different sources in a complete Electronic Patient-based Record (EPR) making tracing a patient's clinical history quite a trivial task.

The core of the developed storage architecture is based on the ENV 13734 (VITAL) standard for Vital Signs Information Representation, which copes with biomedical signals and patient related data communication and storage requirements. The set of available data has been extended according to ENV 13734 specifications by integrating the original Domain Information Model (DIM) with the CEN/TC251 ENV 12052

(DICOM/MEDICOM) standard for Medical Imaging Communication, a widely accepted standard for medical images transmission and storage.

Future work will be aimed to further extend the current database scheme by introducing laboratory examinations and treatment prescription related data according to ENV 1613 and ENV 1260

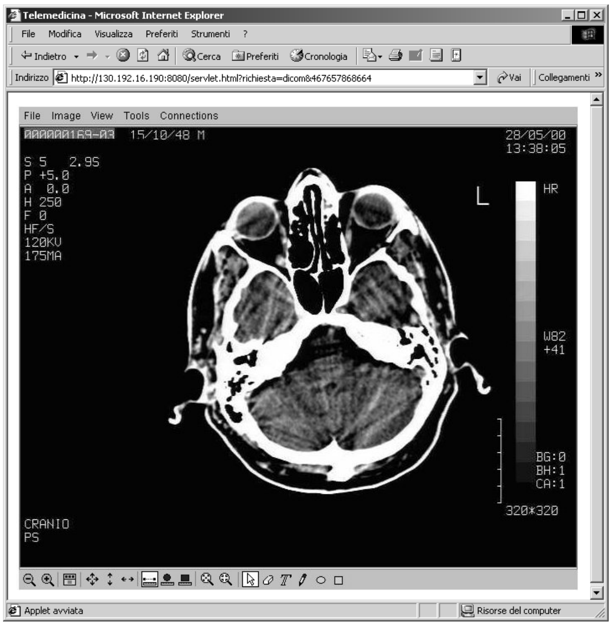

Figure 5: The user interface for medical images consultation on PCs and workstations.

recommendations. The resulting architecture will constitute a comprehensive environment able to cope with all the clinical information needs arising in a real clinical environment.

The conceptual model emerging from the proposed DIMs has been translated into a relational model by using advanced Unified Modelling Language (UML) techniques; the resulting database scheme has been deployed on an Oracle platform by using the forward engineering tools provided by the Rational Rose development environment.

With the aim of ease the development of client software, a set of access services including PL/SQL stored procedures and Java-based APIs has been also designed.

Stored procedures are complex queries stored in a compiled form inside the database itself which can be executed by the Database Management System (DBMS) on server side. The use

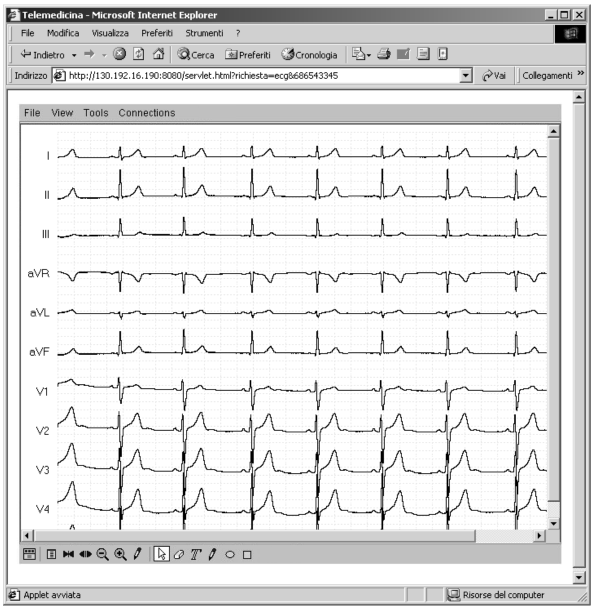

Figure 6: The user interface for biomedical signals consultation on PCs and workstations.

of stored procedures limits the need of client-side queries generation, reduces network load and processing overhead and increases independence between database and client software as the database may be modified, to some extent, without the need to change and recompile client applications. PL/SQL stored procedures have been provided to insert, delete, retrieve and update patient related data as well as vital signs measurements and medical images.

Moreover, a set of Java API has been developed, providing methods to manage incoming network requests for data storage and retrieval, to call the proper PL/SQL stored procedures and to map query results in an object oriented view of the database.

The choice of the Java language is due to its high portability across multiple platform, to the easy access to various DBMS allowed by the Java Database Connectivity (JDBC) APIs and to its integrated support in the Oracle environment.

6. CONCLUSIONS AND FUTURE WORK

In this paper, a Web-based multichannel telemedicine architecture has been presented. The use of the Java programming language and of XML and XSL technologies allows etherogeneous Web-browser enabled devices such as traditional PCs and modern PDAs to access clinical patient history over wired and wireless communication links.

Our main aim is now to integrate the proposed architecture in the existing medical teleconsultation system deployed by an important Italian sanitary center. Some of the aspects that still have to be dealt with are the implementation of a security framework and the integration of additional clinical data types thus extending the standard database scheme.

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