Remote ECG-based Diagnosis Support Via Web

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ABSTRACT

In this paper we present the development of a remote server that provides a user-friendly access to advanced ECG signal processing techniques. The prototype supplies telemedicine facilities to doctors for clinical indexes remote computation to support diagnosis through Internet. The user-friendly interface is based on the selection of the desired ECG signal processing tools on a web browser window. The centralized structure of the system permits unique and user-independent update and management of the software and therefore is especially suitable for remote or rural regions to have access to the new ECG information techniques.

Keywords: Telemedicine, Remote diagnosis, Graphical user interface, ECG, Signal processing.

I. INTRODUCTION

Telemedicine has during the last years undergone an important development thanks to technologies such as Integrated Services Digital Networks (ISDN), Asynchronous Transfer Mode (ATM) networks as well as emerging mobile communications networks. Both patients and healthcare professionals will benefit from this development [1]. The development of the Internet and World Wide Web (WWW) has directed research interest to the design of new teleconsultation systems. The WWW constitutes not only a universal network, but also system-independent platforms providing access to many different computer systems at client sites with the only requirement of having a web browser installed and a network connection. It is necessary to facilitate the information interpretation for medical users, simplifying the interface between computer and physician. The new telemedicine systems may help to reach that situation [2].

Cardiology is one of the areas in which telemedicine is showing major progress. Different telemedical services have been proposed including general information or database systems [3], systems offering recording and monitoring of cardiac measurements to patients in remote locations or at home [4, 5, 6] and when the patient is subject to transportation, e.g. to the hospital in an ambulance [7, 8].

The electrocardiographic signal (ECG) is today the most widely used tool for non-invasive diagnosis of cardiovascular diseases. Computer-based analysis of the ECG has been used during the last decades with significant success. However, innovative signal processing and analysis techniques have been recently developed, resulting in more powerful clinical indexes. Nevertheless, their implementation remain a difficult task in small-sized hospitals because of technical, support and economical factors.

The main objective of this project was to develop an interface which permits the client (medical user) to connect via the web to a remote server where advanced signal processing tools are available, to send (original or compressed) locally acquired ECG files to be processed, and to receive clinical information from the remote server in a suitable format.

II. METHODS

Two different environments were involved in the development of the interface: HyperText Markup Language (HTML) standards, and MATLAB [9] code, which permits the mathematical development of ECG signal processing techniques.

The MATLAB WEB SERVER toolbox [10] was used since it allows the design of MATLAB programs under HTML applications, using WWW facilities to send data to the MATLAB code and vice versa. Data received from the user (ECG signals and analysis parameters) are processed inside the MATLAB environment located on the remote processing server. The results are returned and presented on a web browser window at the client computer (medical user).

With this configuration the client computer only needs to run the web browser to access to the HTML document, since the MATLAB programs, the MATLAB WEB SERVER toolbox and the web server run on the remote server station. Therefore the process is transparent to the user who does not need to know MATLAB to have access to the available signal processing capacity. A block diagram of the system is shown in Fig. 1, and different aspects of the interface are described below.
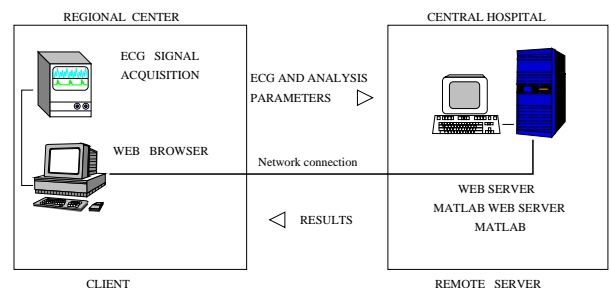

Fig. 1. Basic structure of the system.

A. Graphical user interface

The graphical user interface (GUI) is based on a HTML document which presents selection menus on the web browser running in the client computer (see Fig. 2). These selection menus correspond to different variables and are grouped into forms which contain several characteristic fields or controls. Each of these controls define different

parameters such as the ECG recording to be processed, processing technique to be selected, and exactly how it will be applied once the process button is pushed.

When the user pushes the transfer or start buttons, a Common Gateway Interface (CGI) is activated, and the user-selected parameters are sent to the MATLAB WEB SERVER. First the ECG file and the analysis parameters are tansferred.

Afterwards, the signal analysis is performed (the corresponding program is executed under MATLAB in the remote processing server). Finally, the results are returned in a new structure of data which is passed to the web environment updating the HTML document (see Fig. 3 for an example of graphic results obtained after applying the waveform limits detection technique). The results can, e.g., be numerical, graphics, etc. and the corresponding files generated by the processing techniques are saved in a user-folder.

B. User authentication

In order to maintain confidentiality of patient information, the access to the remote server is restricted to authorized users that have a login and password defined in the server. All the actions including transfer, editing or deleting of files are done in a user-folder restricted area.

C. ECG file transfer

The transfer of the ECG recordings from the client to the server is also based on the use of a form included in the main web page. A browser menu is presented to the user in which the local file can be selected. A send button then activates a CGI which transfers data.

D. ECG data compression

The interface permits compression of ECG files using different techniques prior transmission to the remote server. The ECG files are then automatically decompressed in the server before signal analysis.

Classical lossless data compression (e.g. zip) can be applied in the local station in order to reduce the transmission time. A specific lossy multilead ECG data compression [11] can be alternatively applied to significantly improve the compression ratio (35:1). The compression algorithm is called by a GUI running in the client computer, which permits the doctor to select the quality of the compression, the signal interval and the leads to be analyzed (see Fig. 4). The compressed file is afterwards decompressed in the remote server and then processed.

E. ECG processing techniques

Different types of signal processing techniques can be applied to the ECG. In this project, several innovative ECG techniques have been included which may support clinical diagnosis. The selected tools include conventional processing functions (e.g. beat detection, beat averaging, etc.), automatic detection of ECG waveform limits and intervals estimation, late potentials (LP) analysis, ischemia monitoring based on Karhunen-Loève transform (KLT) time series, and ischemic changes detection (see Fig. 2).

A set of menus provides customization of parameters related to each signal processing technique. Figure 5

Fig. 4. GUI for ECG signal compression.

illustrates the setup forLP analysis. Each setup menu initializes the corresponding MATLAB code parameters and is independent for each technique. This setup process needs to be done before data processing unless the default configuration is desired.

E.1 Basic Processing (Resting ECG)

This option includes basic processing techniques that usually are needed as pre-processing to more advanced tools. Some of these functions are detection of QRS complexes in order to determine beat location, beat averaging, beat morphology classification, etc. [12, 13]. Basic processing tools permit the analysis of e.g. resting ECG recordings.

E.2 QT and other ECG intervals analysis

In this technique we include the detection of the different wave fiducial points that compose the ECG signal. The evolution of the wave amplitudes (P, Q, R, S and T waves) and intervals of interest as QT or QRS duration during a clinical test can be estimated. The onset and offset of the different waveforms are detected by the automated detector of waveform boundaries described in [14].

E.3 Late potentials

Late potentials are low amplitude potentials inside the terminal QRS and ST segment on the ECG signal [15, 16]. This activity is measured in the high-resolution ECG after application of different processing techniques (signal
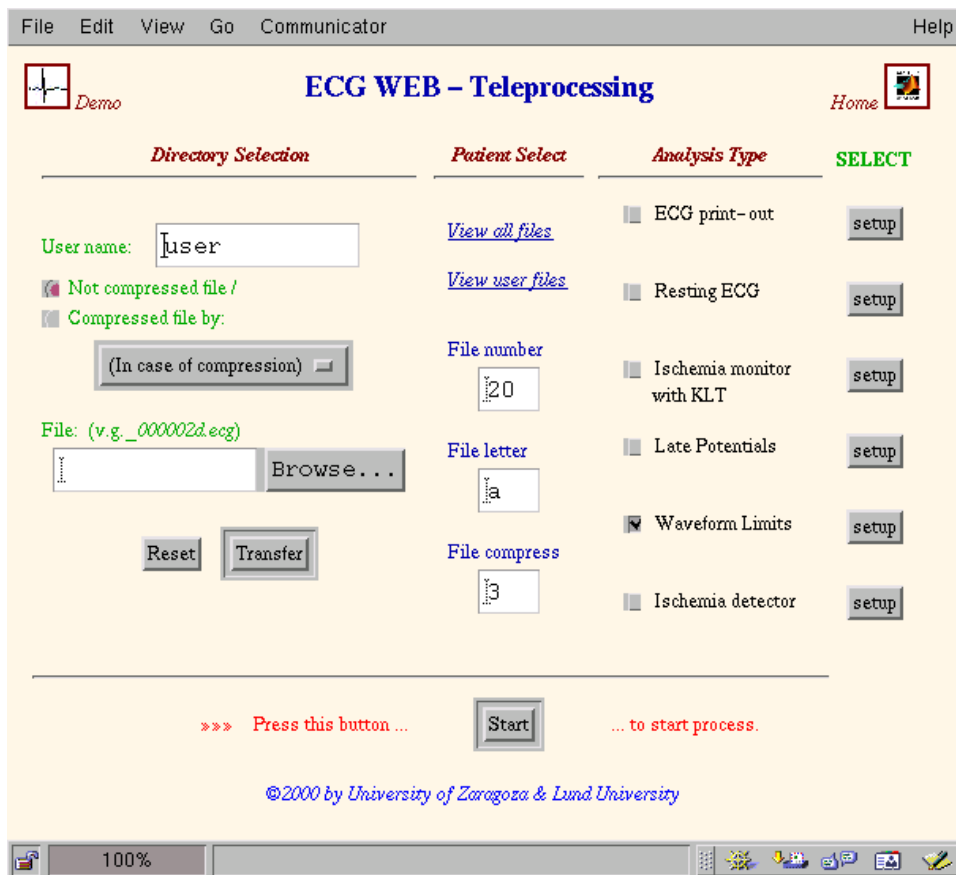
Fig. 2. Main web page showing the GUI where file and ECG signal processing techniques are selected.
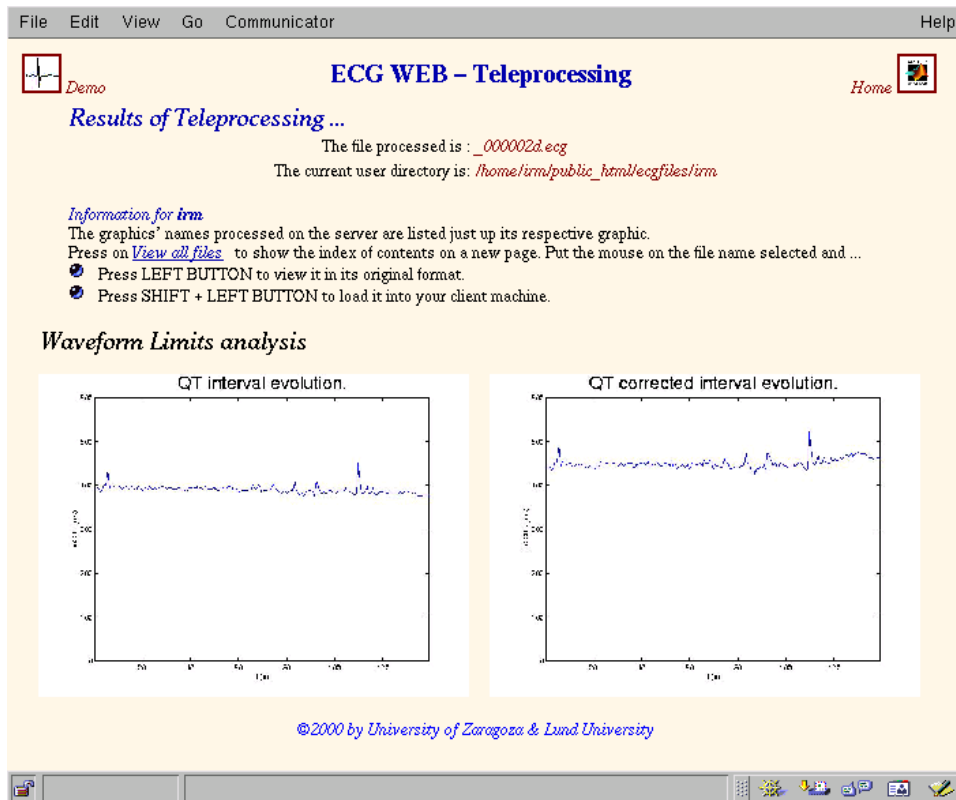

Fig. 3. Results web page showing summary graphics corresponding to the waveform limits analysis.
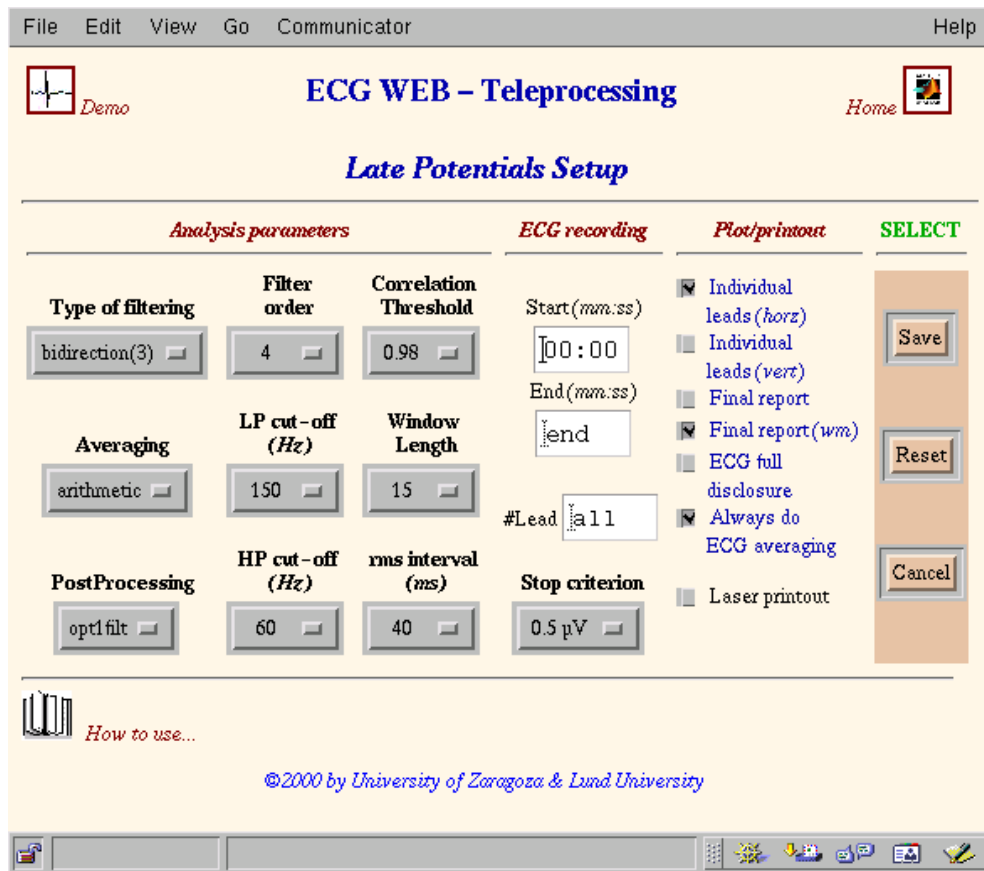
Fig. 5. Setup web page corresponding to the *Late Potentials* analysis.

averaging, spectral analysis, etc.) to improve signal-to-noise ratio making it possible to detect signals of very low amplitude. The primary interest for detecting LP has been the identification of patients prone to ventricular tachycardia following myocardial infarction.

E.4 Ischemia monitoring based on the KLT time series

Ischemia is one of the most common cardiovascular diseases which is associated to low blood flow in the coronary arteries. Monitoring of waveforms representing the ventricular repolarization of the heart provides information on ischemia disease. The beat-to-beat dynamic evolution of the ECG signal can be characterized by studying the evolution of the KLT time series, which capture information contained in the signal and concentrates it in a few coefficients. The KLT has been applied to different segments of the ECG showing larger sensitivity and earlier response of ischemic induced changes [17], therefore becoming a suitable tool to characterize a wide variety of ischemic patterns.

E.5 Ischemic changes detector

A detector of ischemia is also included in the processing server. The detector is based on the measurement of global changes on the repolarization period and has been validated using the European ST-T database, resulting in high levels of sensitivity and positive predictivity when detecting ST segment deviations and ST-T complex changes [18]. The detector provides a wider characterization of the potential ischemic events than usual detectors do (restricted to ST deviations).

F. Demonstration and help

An interactive demonstration of the system capabilities was designed. Following the steps of the demo the medical user gets an overview of the system and its facilities. In addition, help windows are available which inform about different controls and setup windows and a brief explanation of the corresponding analysis and related parameters can be found.

III. RESULTS AND DISCUSSION

The interface proposed in this work was intended to offer access to advanced ECG signal processing tools to rural or small-sized hospitals. Therefore it is important that the system is easy to use: the user-friendly HTML forms try to facilitate the integration of complicated techniques in medical environments. Thus the medical user will only need to run a simple web browser.

The centralized structure of the system permits update and management of the software in the remote processing server, that may be supported by a professional company. The software is installed in the centralized server and the client needs only to have a web browser running in a personal computer and a network connection. The technical programs can be updated and new tools can be easily added without interfering with the medical user.

One important point in the system is related to the

connection or link between client and central server because it determines the speed of ECG file transfer. A high-resolution ECG 5 minutes long (usual duration for many test ECGs), with 1 KHz as sampling frequency, 16 bits of resolution, and 8 recorded leads (which is enough to derive the 12-lead standard ECG), has a size of 4.8 Mbytes. A single 64 Kbps ISDN channel would need 10 minutes to transfer this ECG file without use of any compression technique, whereas in a 2 Mbps line or access it would take around half a minute. This transfer time can be reduced using the compression facilities included in the system, which also optimize information storage. If the clinical application of the ECG does not require high-resolution, such as HRV analysis, arrhythmia detection, QT analysis, etc. lossy data compression methods can significantly reduce the amount of data without altering the clinical information. However for high-resolution analysis such as late potentials, it may be convenient to use lossless ECG compression to avoid signal distortion.

The access is, at present, only permitted in a restricted domain. For use in a open domain it could be necessary to use e.g. cryptography, or simpler solutions as could be the restriction of information sent from the client to the remote processing server. If only raw ECG signals are sent, without any patient information (ID, name, etc.), private information is prevented: only the client knows the correspondence between patient name and ECG, which can be identified in the server by a file code.

IV. CONCLUSIONS

A user-friendly interface for giving access to advanced ECG signal processing has been developed. The client (rural or small-sized hospitals) only need to have a personal computer with a web browser installed and a network connection. This interface facilitates the installation, update, and management of the software which is done in a centralized way, without running programs on the local stations. The system allows transfer of raw or compressed ECG signals, to process the signals and to return the results on a web page. The interface reduces data transmission and information storage on the server. The use of the system constitutes a valuable support for ECG-based clinical diagnosis.

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