

Remote Processing Server for ECG-Based Clinical Diagnosis Support

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Abstract—In this paper, we present the development of a remote server that provides a user-friendly access to advanced electrocardiographic (ECG) signal processing techniques. The prototype supplies telemedicine facilities to doctors for clinical indexes remote computation to support diagnosis through the 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.

Index Terms—Electrocardiographic (ECG), graphical user interface, remote diagnosis, signal processing, telemedicine.

I. INTRODUCTION

TELEMEDICINE has undergone an important development during recent years thanks to technologies such as integrated services digital networks (ISDN) and 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]. Furthermore, when the systems are used in clinical routine, it is necessary to evaluate the impact of the telemedicine services [3].

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 [1], [4], systems offering recording and monitoring

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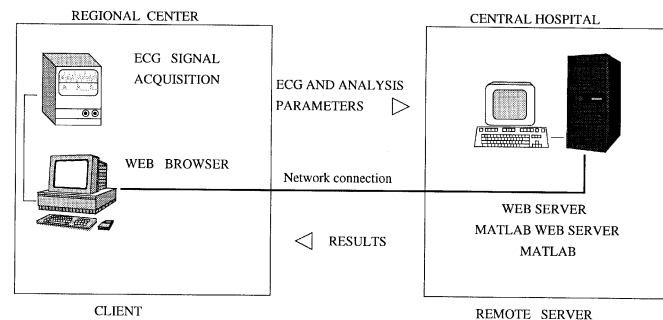


Fig. 1. Basic structure of the system.

of cardiac measurements to patients in remote locations or at home [5]–[7] and when the patient is subject to transportation, e.g., to the hospital in an ambulance [8]–[10].

The electrocardiographic (ECG) signal is today the most widely used tool for noninvasive 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 economic 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: HTML standards, and MATLAB [11] code, which permits the mathematical development of ECG signal processing techniques.

The MATLAB WEB SERVER toolbox [12] 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

```

%% HTML code of a data input form containing different parameters.                                %%
%%-----%%
<FORM action="./cgi-bin/matweb" method="POST" target=principal>
<INPUT type="hidden" name="mlmfile" value="procECG">
  ... <INPUT type="text" name="wvar1" size="4" value=$vvar1$> Var name 1
      <INPUT type="checkbox" name="wvar2" checked value=$vvar2$> Var name 2
      <SELECT name="wvar5"><option $s1a$ value ="$v1a$"><...></SELECT>
<INPUT type="submit" value="Send">
</FORM>

%% MATLAB code of the "procECG.m" function, called by previous HTML code.                    %%
%%-----%%
function retstr = procECG(instruct);
mlid = getfield(h, 'mlid'); % Extracts HTML user data.
cd(instruct.mldir); % Identifies directory and process.
varmat1 = str2num(instruct.wvar1); % Converts from HTML to MATLAB format.
varmat2 = instruct.wvar2;
if ... else ... end; % MATLAB processing code ...
...
outstruct.mres1 = vector; % Obtains final results in appropriate format.
outstruct.mres2 = num2str(ecgdirname);
retstr = htmlrep(outstruct, 'webFIG.html'); % Replace MATLAB output structure to HTML.

%% HTML code of the output web page "webFIG.html".                                        %%
%%-----%%
<HTML>
<HEAD><TITLE> ECG results preview web page</TITLE></HEAD>
<BODY><DIV align="center">Information for medical user:
  Simulation time: $mres1$ <BR>
  ECG directory: $mres2$ <BR>
</DIV></BODY>
</HTML>

```

Fig. 2. HTML and MATLAB code fragments showing how a general processing is performed.

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.

The remote processing server needs to be configured to provide access to other computers: first, the MATLAB WEB SERVER (MATLABSERVER program) is booted on the processing server (a UNIX workstation or a PC). The communication with MATLAB is fixed through the MATWEB program, which is a TCP/IP client of MATLABSERVER. MATWEB uses a common gateway interface (CGI) to extract user data from a HTML document and to transfer data to MATLABSERVER. A configuration file stores the names and paths of the MATLAB programs that can be called from the HTML document. At the top of Fig. 2, we show a piece of HTML code which corresponds to a Web page which calls a processing tool (procECG function). When the medical user pushes the submit button, the program indicated in the action field of the form is activated (MATWEB). The code calls the MATLAB function (procECG.m) which will process the data. Other lines in the HTML code correspond to buttons for input user variables that define how the processing will be done.

In the middle of Fig. 2, the MATLAB function which has been called by the HTML form is shown. This function recovers a user data structure from the HTML form (instruct), converts variables to MATLAB format (varmat1 and varmat2), and ap-

plies the selected analysis (MATLAB processing code). Then the results are converted to HTML format and a new structure (outstruct) is passed to an output Web page (WebFIG.html), which is shown in the bottom of Fig. 2.

The steps followed in the process are graphically shown in Fig. 3. First step is the user authentication from the corresponding Web page (controlled by the MATLAB program ifpass.m). Once in the main Web page (GUIfup.html), it is possible to select the parameters of analysis in the corresponding setup technique (procSETUP.html which calls procSETUP.m) or start the processing (calling the procECG.m function). The results obtained are presented to the user on a new Web page (WebFIG.html).

In the following, we will describe the different aspects of the interface, in terms of graphical user interface, authentication, ECG file transfer-compression, and ECG processing techniques.

A. Graphical User Interface (GUI)

The GUI is based on a HTML document which presents selection menus on the Web browser running in the client computer. These selection menus correspond to different variables and are grouped into forms. A form contains several characteristic fields or controls specified by the input label and which can be of text type (text), selection of a unique option (radio) or a multiple choice (checkbox), option menus (select), transfer buttons (submit), etc.

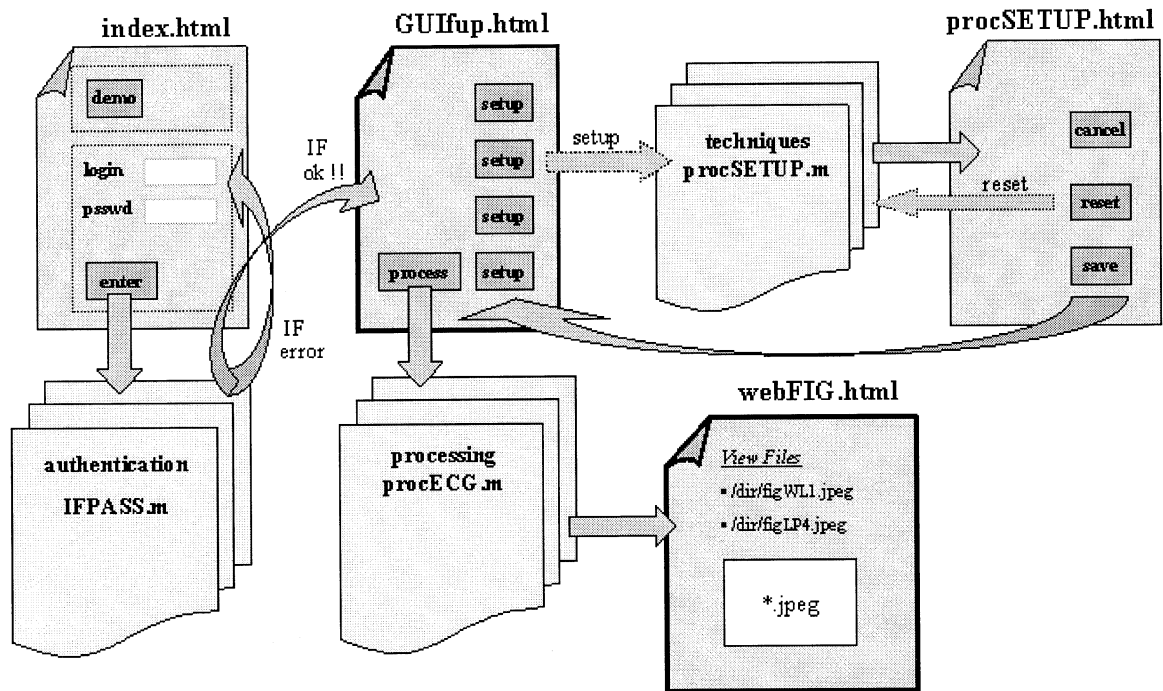


Fig. 3. Sequence of steps followed in a general processing.

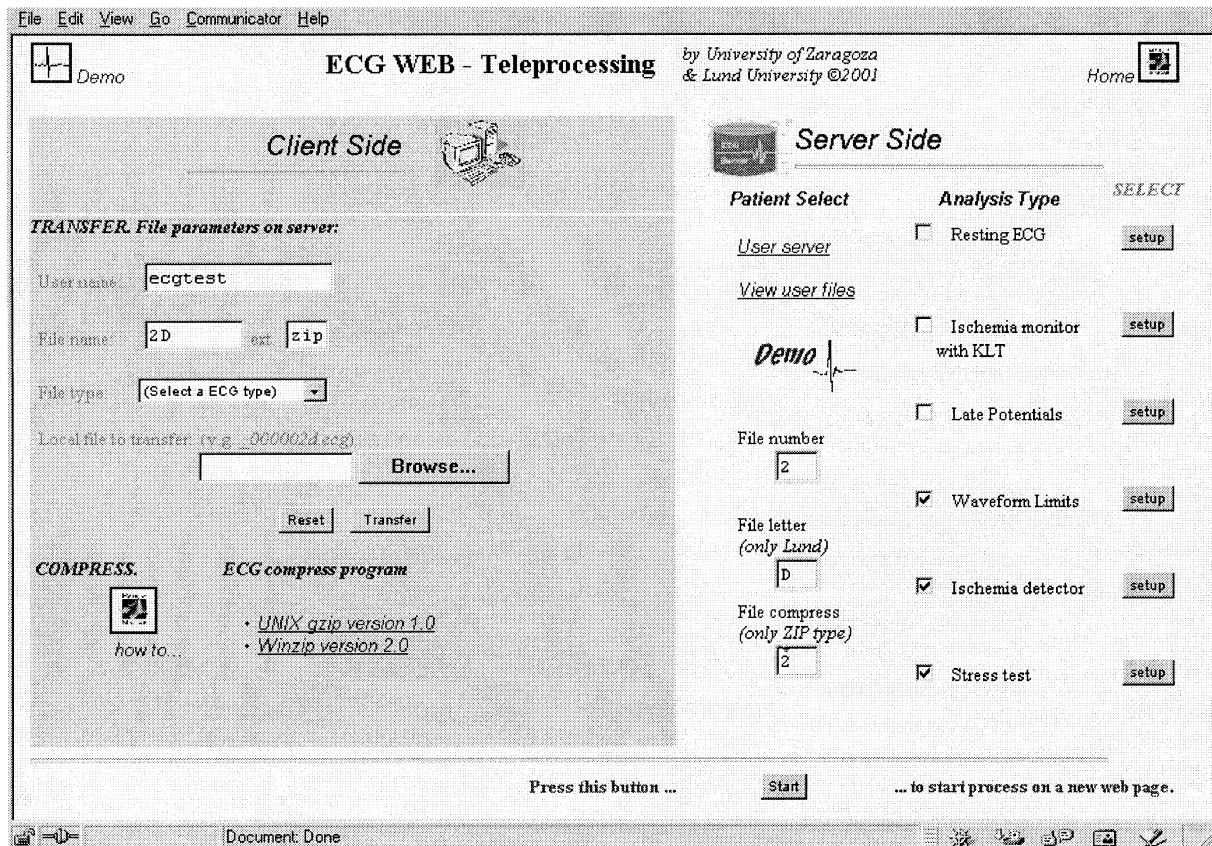


Fig. 4. Main Web page showing the GUI where file and ECG signal processing techniques are selected.

Each of these HTML variables define different parameters such as the ECG recording to be processed or the processing technique to be applied, and need an especial treatment in the MATLAB program, depending on their input label. The main

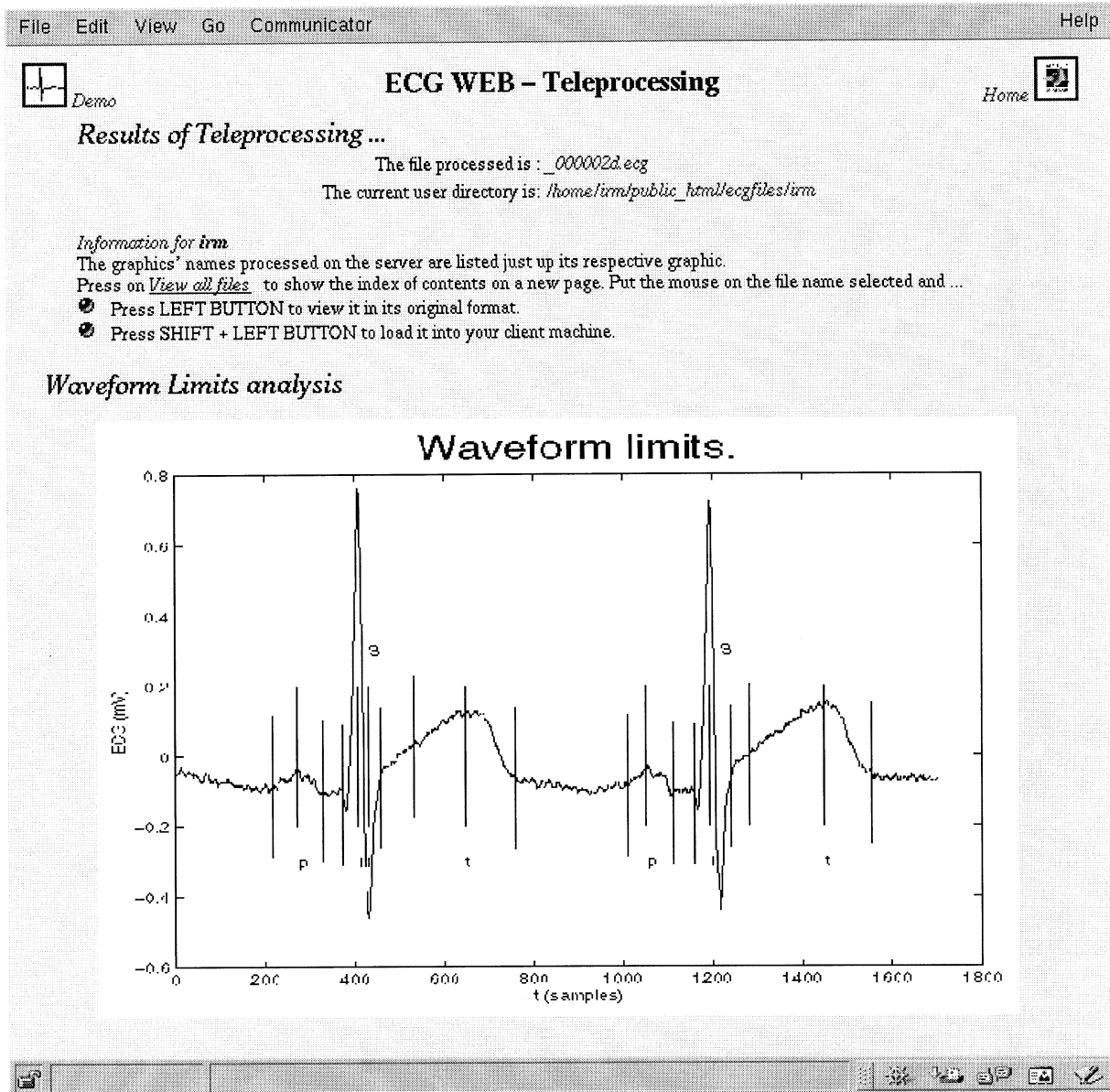


Fig. 5. Results Web page showing summary graphics corresponding to the waveform limits analysis.

Web page containing different controls is presented in Fig. 4. As it has been previously explained, once the user pushes the submit button, the MATWEB program is activated, transferring the user parameters to the MATLAB WEB SERVER and performing the selected signal analysis. Finally, the results are returned updating the HTML document (see Fig. 5 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. So far, access is only permitted in a restricted domain, and the use in a more open environment may require more advanced techniques to ensure security. 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. Finally, a confirmation message is shown on the Web browser to inform the user that the file was received in the server (it will be located inside the user-folder) and is ready to be processed.

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 can be alternatively applied to significantly improve the compression ratio. The lossy method consists of combination of wavelet packets, Karhunen–Loève transform (KLT), and vector quantization techniques [13]. This system was evaluated on a subset of the MIT-BIH database, two-lead Holter recordings, giving an average compressed data rate of 114 bps/channel (compression ratio of 35:1) with a mean distortion of RMS 21 μV [13]. The clinical impact of the error was quantified as differences between clinical variables (such as wave intervals and amplitudes) measured on the original and reconstructed signals. The measurement differences associated with data compression were in the same range as those resulting from two cardiologists analyzing ECG recordings on paper print-outs [14]. 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. 6). 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 KLT time series, and ischemic changes detection (see Fig. 4).

A set of menus provides customization of parameters related to each signal processing technique. Fig. 7 illustrates the setup for ischemia monitoring based on the KLT. 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.

1) *Basic Processing (Resting ECG)*: This option includes basic processing techniques that usually are needed as preprocessing 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., [15], [16]. Basic processing tools permit the analysis of, e.g., resting ECG recordings.

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

Fig. 6. GUI for ECG signal compression.

detector of waveform boundaries described in [17] and validated with cardiologists' measurements [18].

3) *LPs*: LPs are low amplitude potentials inside the terminal QRS and ST segment on the ECG signal [19], [20]. This activity is measured in the high-resolution ECG after application of different processing techniques (signal 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.

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 [21]. The KLT has been applied to different segments of the ECG (QRS complex, ST segment, T wave, and the entire ST-T complex) [22] showing larger sensitivity and earlier response of ischemic induced changes [23] and better identification of the occluded artery [24], therefore becoming a suitable tool to characterize a wide variety of ischemic patterns.

File Edit View Go Communicator Help

ECG WEB – Teleprocessing

Ischemia monitoring with KLT

Analysis parameters		Analysis options	ECG recording	Plot/printout	SELECT
Complex ST-T	N° of coefs. 5	<input type="checkbox"/> Normalize coefficients	Start (mm:ss) 00:00	<input type="checkbox"/> Leads & series	Save Reset Cancel
Basl Reject IIR filter	Estimation LMS	<input type="checkbox"/> Bazett correction	End (mm:ss) end	<input checked="" type="checkbox"/> Leads x Series	
μ coefficient (LMS) 0.1	Baseline Limit 200	<input checked="" type="checkbox"/> Baseline rejection	Format Select Lund	<input type="checkbox"/> Series x Leads	
		<input type="checkbox"/> Basl. excess beats rejection	Leads Select 12standard	<input type="checkbox"/> Printout	
		<input checked="" type="checkbox"/> Only normal beats		to file	

How to use...

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Fig. 7. Setup Web page corresponding to the ischemia monitoring with the KLT analysis.

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 [25]. The detector has the advantage of finding both ST segment deviations and entire ST-T complex changes in contrast to usual ischemia detectors, which only measure one specific point in the ST segment. Consequently, the detector provides a wider characterization of the potential ischemic events.

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. Thus, the advanced user has the possibility to tailor the analysis, e.g., the cutoff frequency in a filter for LP detection or a threshold amplitude for detecting Q waves.

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. It should be realized, however, that the end-user of this kind of systems is the medical doctor, who may not have the same interest in computers as an engineer or a scientist. 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. Other factors that have been considered in the design of the interface are clarity and simplicity both in use and results presentation.

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. The addition or incorporation of a new technique in the GUI is a quite simple task: a button is added which acts as a link to the function that runs under MATLAB and performs the corresponding processing. This fact makes the system into an open structure that can easily incorporate new tools as soon as they are developed, and therefore have an immediate presence in the support of clinical diagnosis.

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. Possible alternatives run from the public switched telephone network (PSTN) or ISDN to more advanced technologies such as frame relay or ATM networks. In a real situation it is necessary to consider the large amount of information that needs to be transferred, especially when the ECG recordings are of high-resolution (both in amplitude and sampling frequency). For instance, a high-resolution ECG 5 min long (usual duration for many test ECGs), with 1 KHz as sampling frequency, 16 bits of resolution, and eight 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 min 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 optimizes 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 computational load due to the use of the MATLAB WEB SERVER toolbox was also evaluated. The computation time (ECG file transfer time not included) when the processing is remotely done, increases with respect to the use of the same MATLAB programs when running in a local environment in less than 10%. This increase is mainly due to the interchange of variables from HTML to MATLAB platforms and vice versa, and the conversion of MATLAB figures to JPEG files to be presented in the client browser.

As mentioned in previous sections, the access is only permitted in a restricted domain. For use in an 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. CONCLUSION

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 PC 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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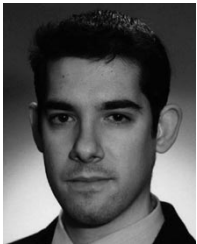
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