A web-based approach for electrocardiogram monitoring in the home

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Abstract

A Web-based electrocardiogram (ECG) monitoring service in which a longitudinal clinical record is used for management of patients, is described. The Web application is used to collect clinical data from the patient’s home. A database on the server acts as a central repository where this clinical information is stored. A Web browser provides access to the patient’s records and ECG data. We discuss the technologies used to automate the retrieval and storage of clinical data from a patient database, and the recording and reviewing of clinical measurement data. On the client’s Web browser, ActiveX controls embedded in the Web pages provide a link between the various components including the Web server, Web page, the specialised client side ECG review and acquisition software, and the local file system. The ActiveX controls also implement FTP functions to retrieve and submit clinical data to and from the server. An intelligent software agent on the server is activated whenever new ECG data is sent from the home. The agent compares historical data with newly acquired data. Using this method, an optimum patient care strategy can be evaluated, a summarised report along with reminders and suggestions for action is sent to the doctor and patient by email. © 1999 Elsevier Science Ireland Ltd. All rights reserved.

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1. Introduction

Advancements in Internet technology have made possible new and innovative methods for the delivery of healthcare. Universal access and a networking infrastructure that can facilitate secure sharing of patient information and clinical data, make the Internet an ideal tool for remote patient monitoring applications. Web-based systems recently reported in the literature include a real-time
intensive care unit patient monitoring service [1], a cardiac telemonitoring system in which pacemaker telemetry has been integrated with Internet communications [2] and a multimedia medical information system [3].

The WebECG system described in this paper enables remote communication of clinical data, specifically electrocardiogram (ECG) information, to facilitate home healthcare. The importance of managing a disease condition by monitoring a patient in the home environment is being increasingly realised [4–6]. Home monitoring is seen as a way of allowing patients in hospital to be discharged early. In an Australian study in 1992, cardiac monitoring for follow-up of patients who had pacemaker procedures or cardiac arrhythmia treatment, was estimated to reduce hospital stays by 1.5–5 days with a potential annual saving of $2.6M [7]. Similarly, a long-term home care facility is useful for, but is not necessarily restricted to, the management of a chronic illness like asthma. The concept can be extended to include other cardiorespiratory conditions and also diseases like diabetes [8].

2. Web-based monitoring: an overview

The WebECG concept is based on using the Internet to facilitate collection, review, analysis and archiving of a longitudinal ECG record for the management of at-risk patients. A PC-based measurement module, which has been designed and developed in our laboratory will be used for the review and acquisition of clinical data from the patient’s home [9]. A database server is a central repository where patient information and clinical data is stored. An intelligent software agent is activated whenever new clinical data is sent to the server. The agent compares historical data with newly acquired data, and graphs the trends in key variables for longitudinal comparison. Medical interventions and other relevant data are compared to a scientific patient management plan based on links to population epidemiological databases and on-line risk factor analysis. A summarised report along with reminders and suggestions for action is then sent to the doctor and patient by email. For ease and flexibility, a Web browser provides instant access to the patient’s records. Up to date clinical data is available for review, either in summarized or original graphical form.

3. Methods

An overall architecture of the longitudinal patient monitoring service is shown in Fig. 1. The PC based measurement module WinECG, consists of an ISA bus card, defibrillation protected ECG cable and ECG acquisition, i.e. review and interpretation software, for patient safe recording and analysis of single or 12 lead clinical ECGs. Software for this module has been implemented

![Fig. 1. Illustration of the Web-based patient monitoring service.](image-url)
in Windows 95. All measurements are recorded and displayed in real time on the computer monitor using advanced graphics and a sophisticated user interface. An interpretation module performs off-line disease classification [10].

The patient database has been implemented in Microsoft Access 97. It consists of relational tables that store patient details, clinical measurements, medication and doctor information. The clinical measurements table consists of fields for time and date of recording, current patient information (height, weight, medication, smoking status), as well as the raw ECG data and associated measurements. This latter information is stored as a Binary Large Object (BLOB) within a variable length memo field in the table.

WebECG utilises dynamic user customised Web pages to provide the longitudinal patient monitoring service. The server configuration is shown in Fig. 2. It was developed in Allaire's Cold Fusion (CF), a Web to database connectivity tool. The CF language uses the open database connectivity (ODBC) standard to communicate with a database via structured query language (SQL). A Web browser (Internet Explorer, Microsoft Corporation) is a universal client. It forms the interface between clinical measurement software on the client computer and patient database on the server.

A CF application is a collection of Web pages and components. The Web pages are connected to databases using a proprietary mark-up language (CFML) and the hypertext mark-up language (HTML). The appli-
cation is deployed on the CF Application Server, a Windows NT service that runs on the server. It is completely integrated with standard Web servers on Windows and supports connections to email servers and a wide range of other services. When a Web page is requested, the application server processes the CFML and dynamically generates a Web page that is returned to the browser.

The Web server communicates with the CF NT service by means of a server API (CFAPI). The server API is a published interface that lets software developers write programs that become part of the Web server itself. Server APIs were developed as an alternative to Common Gateway Interface (COI) applications, a common technology for the dynamic creation of Web pages. When a CGI Web page needs to be displayed, the Web server runs a CGI executable and captures its output, sending it to the client as HTML, or any other format supported by the browser. The process of creating sessions and executing CGI scripts is time consuming since they are loaded and unloaded each time. Also CGI programs are entirely separate entities from the Web server and cannot be used to change the behaviour of the Web server itself. Server APIs are dynamic link libraries (DLLs) that reside in the same address space as the Web server. They can therefore directly access the HTTP (hypertext transfer protocol) services available from the server. They load into memory more quickly and have much less overhead when it comes to making a call from the server.

An intelligent agent is used to parse incoming ECG data. The agent can be executed either at regular intervals or attached to database insert and update triggers. The agent can be configured to automatically send email via SMTP to the patient and/or the supervising doctor.

3.1. Clinical data

Cold Fusion functions only handle text types and cannot return binary objects from the database via ODBC, hence custom tags were written in Delphi (Borland) to read and write BLOBs from the database. The custom tags are CF Extensions (CFX) that are used to connect to legacy systems. They can handle complete application logic or any range of other functionality. Registered CFXs may be called from within an application through a straightforward CFML custom tag. These extensions are DLLs that allow full control over CF queries and output. They are also able to pass data between CF, the Windows NT operating system, and APIs from other vendors. The intelligent agents that are responsible for analysis and reporting of ECG data on the server are also implemented as CFXs.

The file transfer protocol (FTP) is used to transfer clinical data between the client and server. When a user requests a record for viewing, the clinical measurement that is stored as a BLOB in the database is written as a file to an FTP server that is also running as an NT service on the server. The FTP transactions are completely hidden from the user. They were implemented to automate the file handling on the client. Unique file names have been implemented to maintain data integrity in a multi-user environment.

HTTP functions are an alternative method for exchanging clinical data, but this method would require a separate server API that would monitor HTTP requests from the client during a data upload. Also the implementation of HTTP functions for transferring files is more complicated.
3.2. **ActiveX controls**

On the client side the WinECG reviewing and recording program is a ‘Helper Application’, that is called as a secondary window outside the browser. ActiveX™ controls are used to co-ordinate the viewing and acquisition of clinical measurements from the browser environment. These controls are compiled software components based on Microsoft’s Component Object Model (COM) technology. They are essentially modular programs designed to give specific functionality to a parent application. They can be embedded in Web pages for use over the Internet as well as combined to create client/server applications that run over a network. ActiveX controls may be programmed to perform tasks, compute information, and communicate to other programs, modules and the Internet. These controls are the third version of OLE controls (OCX), which have a number of enhancements specifically designed to facilitate distribution of components over networks and to provide integration of controls into Web browsers. The enhancements include features such as incremental rendering and code signing, to allow users to identify the authors of controls before allowing them to execute.

The ActiveX controls in WebECG, are simple button controls, which are embedded in the Web pages and provide a link between the various components necessary to automate ECG recording, reviewing and storage. They implement FTP functions to retrieve and submit clinical data to the server, using the WinInet API, a high level Win32 interface to Internet Protocols. The controls are also responsible for calling WinECG once the clinical data files have been automatically downloaded via FTP in the review mode and updating the database in the acquisition mode. In order to accomplish these tasks successfully the controls communicate with the Web server, Web page, the Client application (WinECG) and the local file system.

Code signing using Microsoft Authenticode™ has been implemented to ensure the authenticity and integrity of ActiveX controls that are downloaded from the Web. Code signing uses digital signatures to identify the publisher and validate the integrity of the code. Safe initialisation and scripting algorithms have also been included.

3.3. **Typical session**

Registered users are provided with a unique username and password that allows access to the WebECG system. When a user logs on, the authentication data is used to create a Web page containing the patient information and a list of clinical procedures that are associated with the patient profile (see Fig. 3). A special CFX was written to prevent random access to the pages from a URL address.

Users are allowed to edit their patient record by submission of an HTML form. Javascript functions were implemented to check data for structural integrity at the client side before entering into the database. In addition, server side validation of data is provided by code written in CF.

Fig. 4 illustrates a typical data exchange between the Web server and client. In the review mode, when a user selects a particular record, the BLOB containing the ECG data is written out to the FTP server. The ViewECG button control when pressed downloads the clinical data files via FTP and saves them on the client machine. Upon a successful download, WinECG is called to view this record (see Fig. 5). In the acquisition mode, information associated with the new measurement is entered into the database by submission of an HTML form. The
NewECG button control is responsible for recording new clinical measurements by calling WinECG and subsequently uploading clinical data files to the server via FTP, where a CFX is responsible for updating the database. Transaction processing is used to maintain the structural integrity of the data when the tables are being edited and updated.

Confidentiality of medical records is maintained by implementing two separate access levels. Patients are allowed to view only their own records (without viewing doctor’s notes for particular ECG procedures). Doctors and administrators are designated with a higher access level that allows them to access all records for their particular patients.

**4. Discussion and conclusions**

In this paper, a Web-based application that maintains a longitudinal ECG record by monitoring in the home has been described. ActiveX controls are used to automate the retrieval and storage of clinical data from a patient database, and the recording and reviewing of data on WinECG. When clinical data is received at the server, it is automatically analysed and an optional summary report along with suggestions for treatment can be sent via email to the patient and doctor. The system can easily be adapted to provide an off-line ECG acquisition facility, so that an Internet connection is only required when uploading data to the server.
Web-based monitoring technology promises to present new methods for management of a disease condition in the home. Security of data on the Internet is a major issue, hence special features have been included for the safe handling of patient details.
and clinical data. WebECG uses an authentication system to restrict access to patient records. In addition, code signing and unique file names have been used to ensure authenticity and integrity of downloaded data. A secure communications channel can also be used as Internet traffic in its basic form is not encrypted.

Although use of the Internet as a universal platform for the expansion of telemedicine services has been widely recognised, there is a considerable need for the co-ordinated evaluation of these new applications of technology [11]. Using the WebECG system described in this paper, a comprehensive pilot study is currently under design, with the aim to introduce and evaluate the effectiveness and impact of this new technology in terms of improved healthcare delivery, reduced health expenditure and improved patient outcomes.

References


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