WEB BASED LONGITUDINAL ECG MONITORING

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Abstract - A Web based 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 server acts as a central repository where this clinical information is stored. A Web browser provides access to the patient’s records and clinical data. An intelligent software agent on the Web server is activated whenever new patient data is collected remotely from the home. The agent compares historical data with newly acquired data. Using this method, an optimum patient care strategy can be evaluated, with reminders and suggestions for action sent to the doctor and patient by email.

INTRODUCTION

The Internet will be used extensively as a communications medium for the provision of telemedicine services. Some Web based applications reported in the literature include a real-time ICU (Intensive Care Unit) patient monitoring service, cardiac telemonitoring by integration of pacemaker telemetry with Internet communications and a multimedia medical information system [1,2,3].

The WebECG system described in this paper enables remote communication of information to facilitate a home health care service. Home monitoring is seen as a way of allowing patients in hospital to be discharged early [4, 5]. In an Australian study, cardiac monitoring for follow up of patients who have had pacemaker procedures or cardiac arrhythmia treatment, is estimated to reduce hospital stays from 1.5 to 5 days with a potential annual saving of $2.6M [6]. Similarly, long-term home care facilities are useful for management of chronic illness like asthma.

WEB BASED MONITORING

The WebECG concept is based around using Internet services to facilitate the collecting, reviewing, analysing and archiving of a longitudinal ECG record for management of at-risk patients. Using this system, objective clinical data will be collected from the patient’s home. A PC based measurement module, which has been designed and developed in our laboratories will be used [7]. It consists of an interface card for patient safe recording and analysis of single or 12 lead ECGs. The software for this module has been implemented in Windows95. 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.

A database server acts as a central repository where patient information and clinical data are stored for analyses. An intelligent software agent is activated whenever new clinical measurements are collected remotely from the home. The agent compares historical data with newly acquired data, and graphs the trends in key variables for

Figure 1. Overall structure of Web based patient monitoring system

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longitudinal comparison. The patient's historical health record is then automatically scanned, 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. An optimum or best practice patient care strategy is evaluated and compared to actual services provided. Reminders and suggestions for additional action are then recorded and sent to the doctor and patient by email.

For ease and flexibility, a Web browser provides access to the patient's records. Clinical data is available for review, either in summarised or original graphical form.

IMPLEMENTATION

WebECG utilises dynamic user customised Web pages to provide a longitudinal patient monitoring service. Figure 1 shows the overall architecture of the Web server. It was developed in Allaire's Cold Fusion (CF), a Web to database connectivity tool. A Web browser ie. Internet Explorer (Microsoft©) is a universal client, it forms the interface between clinical measurement software on the client computer and patient database on the server.

A Cold Fusion application is a collection of Web pages and components. The Web pages are connected to databases using the products proprietary markup language (CFML) and the hypertext markup language (HTML). The application 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 Solaris and also supports connections to a wide range of other services, including directories and email servers. When a Web page is requested by a browser, the Application Server processes the CFML and dynamically generates a Web page which 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 applications (CGI), which used to be 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 they are used. Also they 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 (hyper text 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.

The patient database has been implemented in MS Access. It consists of tables that store patient information, ECG procedures, medications and doctor information and clinical measurements. The ECG procedures table consists of fields relating to time and date of recording, current patient information (height, weight, medication, etc.), as well as the raw ECG data and associated measurements. This latter information is stored in the procedures table as a Binary Large Object (BLOB).

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.

Figure 2. Data exchange between Web server and client.
When a user requests a record for viewing, a clinical measurement which is stored as a BLOB in the database is written as a unique file in a directory on the server. This data file is subsequently transferred to the client via FTP (see Figure 2). An FTP server that is set up alongside the Web server makes these clinical data files available to users.

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 coordinate 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 that are embedded in the Web pages and provide the 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 order to accomplish these tasks successfully the controls communicate with the Web server, Web page, the Client application (WinECG) and the local file system.

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

Figure 2 illustrates a typical data exchange between the Web server and client. In the review mode, once the user has selected a particular record from a drop down box, the 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. In the acquisition mode a Button control is responsible for recording new clinical measurements by calling WinECG and subsequently uploading clinical data files to the server via FTP, where it is stored back into the database.

Registered users are provided with a unique username and password that allows access to the WebECG system. 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

![Figure 3. Screen shot of WebECG displayed in Internet Explorer.](image)

![Figure 4. Screen shot of the WinECG viewer](image)
administrators are designated with a higher access level that allows them to access all records. A custom tag in CF prevents random access to the Web pages from the URL address.

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 for clinical data files that are written out to the FTP server.

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.

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.

DISCUSSION AND CONCLUSION

In this paper, a Web based application that maintains a longitudinal clinical record by monitoring in the home has been described. A screen shot of the main Web page is shown in figure 3. ActiveX controls are used to automate ECG recording and reviewing on WinECG (see figure 4), and the retrieval and storage of clinical data from the patient database. The application can easily be adapted to provide an off-line ECG acquisition facility, so that an Internet connection is only required to update the database.

Web based monitoring technology promises to present new methods for management of disease conditions in the home. Using the technologies 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 health delivery, reduced health expenditure and improved patient outcomes.

REFERENCES