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Design of a Web Services Based System for Remote Hearing Diagnosis

Jianchu Yao, *Senior Member, IEEE*, Yongbo Wan, and Gregg Givens

***Abstract*—This paper presents a web services based, distributed system that allows remote pure tone hearing tests. The system network follows browser-server architecture, which minimizes hardware and software requirements on the client computers and makes hearing test services more accessible to traditionally underserved population groups. Thanks to the three tier software design, the system functionality is easily scalable to include other audiological services. Since testing data are stored in a standard database, they can be potentially integrated into established electronic medical records.**

I. INTRODUCTION

Hearing loss poses the third most common disease, after hypertension and arthritis, among American seniors; it is strongly associated with elder functional decline and depression because individuals who experience hearing problems are likely to withdraw from social occasions to avoid embarrassment [1-4]. Unfortunately, hearing loss is often under detected and undertreated [1].

In order to expand traditional hearing care services, several efforts have been made previously to apply recent technological advancements to the tele-hearing discipline. Among these projects, mobile phones were used in an audiometric test system [5], which supports screen hearing loss at early stages. A real-time diagnostic audiometric application that allowed audiologists to conduct remote hearing tests via the Internet was developed in [4, 6]. This prototype, although demonstrating that remote hearing tests can obtain comparable results to their conventional face-to-face counterparts, required software installation on dedicated computers and supported only point-to-point connection between an audiologist and a patient. Another interesting project utilized standard sound cards in personal computers as the pure tone generator for hearing diagnosis [7], making connection to the Internet very convenient. This system, however, similar to [4, 6], did not consider software installation and system maintenance issues.

In recent years, web services architecture has experienced rapid progress, changing the landscape of software development. Among the different types of network architecture, the browser-server (BS) architecture has become popular because of its support of very "thin" users, minimizing hardware/software requirement on the client computers.

In this paper, a tele-hearing test system based on BS web services is presented. Section II describes the system layout, the hearing test procedure for using the system, and the system test methods. Section III presents the test results from three different test conditions. Section IV discusses the features of the prototype and our future plans for the project.

II. METHODS

Figure 1 illustrates the layout of the proposed tele-hearing system. Physically, the hearing test system consists of five parts: a clinical professional's computer, the web server, the database, an Internet access point on the patient side, and an audiometer. The most important part of this distributed system is an application server, which provides the Internet Information Services (IIS) [8] to users. Services offered by the server primarily support hearing test procedures; but they can be extended to other processes such as appointment scheduling, billing, and reimbursement. Users with different roles have different access privileges, managed by the system administrator. The user group on the clinic side may include any hearing care medical professionals: physicians, audiologist, nurses, or general caregivers. Audiologists or other medical individuals can use any Internet access devices with a regular web browser to visit the application server to conduct hearing tests.

On the patient side, an audiometer, either with built-in Internet connectivity or accessing the Internet through a bridging device, functions the same as those utilized in conventional face-to-face hearing tests. The audiometer's connection to the Internet can be wired or wireless. Once the audiometer is connected to the Internet, regardless of the connectivity mode, its presence is monitored by the application server and reported to the system list, from which medical professionals can select the audiometer with which they can associate their hearing diagnosis sessions.

A well-trained care assistant is usually needed to help with the audiometer setup and the transducer placement. However, presence of a care assistant is not mandatory in cases that the patient is confident and technically capable to operate all the devices after receiving sufficient training.

Jianchu Yao is with the Department of Engineering, East Carolina University, Greenville, NC 27858 USA (phone: 252-737-1029; fax: 252-737-1041; e-mail: yaoj@ecu.edu).
Yongbo Wan is with the Electrical Engineering Department, Shaanxi University of Science and Technology, Weiyang District, Xi'an, Shaanxi, China 710021.
Gregg Givens is with the Department of Communication Sciences and Disorders, East Carolina University, Greenville, NC 27858.

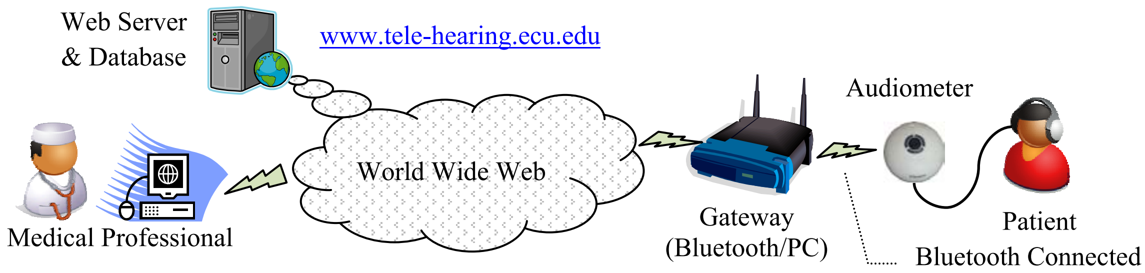

Fig 1. The distributed layout of the tele-hearing test system.

A. *The Three-tier Software Architecture*

The application server utilized in the system was designed with three-tier architecture, including three independent yet correlated layers: a Presentation Layer, a Business Logic Layer, and a Data Access Layer as shown in Fig. 2. The presentation layer is the topmost level of the system software that allows all the users to operate the system and observe system information. The business logic layer contains logic and rules that are required to conduct hearing tests. This layer contains mostly audiology domain knowledge. The data access layer comprises the data access methods to save and extract information to and from the database. The system database contains all the user management information, patient demographics, patient hearing test results, etc.

a. Presentation Layer: User Interface

The user interface of the hearing test system comprises several web pages, which can be categorized into five groups: Patient Demographics, User Role Management, Hearing Test, Test Results, and Test Scheduling. All users are required to login to the system before they can access any information in the system. Different user roles (administrator, audiologist, and patient) are assigned with different levels of information access privileges (defined in the Business Logic Layer as described next) to prevent unauthorized information access. For example, an audiologist can use the "Hearing Testing" page to perform remote hearing tests and access both "Patient Demographics" and patient "Hearing Test Results" pages. Through the "Hearing Test" page, the audiologist has full control of the remote audiometer: he or she can change pure tone frequency and level, select air or bone conduction, and select stimulus modes (steady or pulsed sounds).

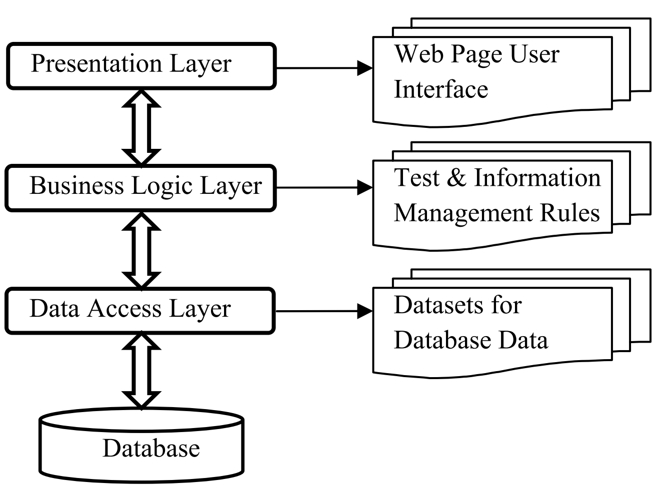

Fig. 2 The three-tier software architecture.

b. Business Logic Layer

The business logic layer primarily contains logics in three categories: user role management, hearing test sequences, and data exchanges between the presentation layer and the data access layer. All information exchange between the presentation layer (user interface web pages) and data access layer (which exclusively operates on the database, as detailed next) are governed by the logic defined in the business logic layer. The methods provided by the business logic layer allow only information related to a specific login user as mentioned earlier. For example, when an audiologist logs in the system, the logic defined in this layer returns information only for this individual's patients.

Visual Studio 2008 has a website administration tool (WAT), ASP .NET 2.0, that allows administrate user roles for website accesses. WAT has a number of static methods and built-in functions supporting user role management with regard to performance, security, and flexibility. For example, WAT can block a user with a patient role from attempting to access information other than his/her own. For user role management in our hearing test system, the website configuration file was modified by overwriting the default setting in the server to enable all the embedded functions.

The business logic also defines the operation sequence during hearing tests (explained in the next subsection). The logic specifies that a) an audiologist must first select the patient and his or her audiometer before further steps; b) after the server receives a response from the patient, the results will be saved immediately; and c) after a test session finishes, the audiologist must end a test to disconnect the audiometer devices from the system. One other important task the business logic layer accomplishes is the validation of operations and parameters received from the presentation layer: prior to the execution of a received command, the logic checks whether the input parameters are sufficient and valid. It provides alert messages when input errors are detected to prevent possible incorrect operations.

c. Data Access Layer

The system data are stored in a database server. The database server can be a physically separate machine or implemented on the same machine as the application server. The data access layer provides the system applications with methods to access data in the database (e.g., create, delete, update, read, sort, and search), separating data from their applications and logics. The data access layer serves as the only way in which a user can work with system data and improves system scalability and security.

B. Hearing Test Procedure

The tele-hearing system is designed to enable remote operation of the audiometer so that it produces pure tones at various frequencies and volume levels. Clinical hearing tests are based on a stimulus-response behavioral model: the audiologist, through the web page on his or her computer, operates the audiometer to generate pure tone stimuli; the patient, if hears the sound, responds by pressing a button on the audiometer to send the signal, which is captured by the server and displayed back to the audiologist. For each frequency point, the lowest sound intensity received positive patient response is recorded in the test results.

In practice, the hearing test starts with scheduling through the web services. Prior to the scheduled time, a patient (or a care assistant) connects the audiometer to the internet so that the audiologist can find the desired device from the server device list. In our implementation, there are two specific access methods to connect a Bluetooth-enabled audiometer [8] to the Internet: to use a dedicated Bluetooth-to-Internet gateway [9] or a regular computer with Bluetooth dongle [10]. For the first option, the patient only needs to turn on the power and plug in gateway device to an Internet socket. For the latter, a software Bluetooth driver needs to be installed prior to successful connection of the audiometer to the Internet.

On the medical professional side, an audiologist, using a web browser, first logs into the system at the scheduled time, finds the audiometer for his/her patient, and establishes the logic connection. At this point, a hearing test session starts.

During the session, the audiologist, following standard testing protocols, sends out the test commands through the server "Hearing Test" page. These commands, through the server and the Internet, arrive at the remote audiometer and generate sounds with specified frequencies and levels. The patient, upon hearing the signal, presses the response button on the audiometer. The response, again through the Internet and the server, is displayed on the "Hearing Test" page. The audiologist, if a response is received within a certain amount of time, continues accordingly to complete the test and obtain thresholds for all the required frequencies.

C. System Testing

To test the proposed system, twenty five volunteers (age range 25-60; 10 males, 15 females) were recruited to participate in hearing tests. The tests took place over a period of two months. Hearing tests were conducted with three different testing conditions to verify the effectiveness of the proposed remote system: (1) conventional face to face test; (2) remote test with a computer connecting the audiometer to the Internet; and (3) remote test with a Bluetooth gateway device connecting the audiometer and the Internet. All the tests are double blinded: the volunteers sat in the same sound booth for tests with all three modes and were not aware of the testing conditions. The audiologist using a certain testing condition was not aware of results of the same subject from other test conditions conducted by other audiologists. For all tests, air conduction was used to collect thresholds of six frequencies (250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz, and 8000Hz).

III. RESULTS

Figure 3 shows hearing test results collected from the 25 subjects. The means and standard deviations of the thresholds for these subjects at the six frequencies are presented in the figure, where "Standard" data were from conventional face-to-face tests; "Remote I" utilized a laptop as a connecting device, while "Remote II" had a wireless gateway device. Note that the standard deviation reflects the threshold variations among different subjects, not the variation among testing conditions. The means and standard variations from all three conditions are similar. Figure 3 shows that the three modes obtained comparable results.

Completion time for test sessions with the three conditions mentioned above was also collected. The average times to collect six thresholds are 3.7, 5.8, and 6.4 minutes, respectively. Post experiment analysis reveal that longer time of the remote test was primarily due to the premature of the developed software, which required frequent repeated operations. Later tests with improved software did not experience such a large time difference (unfortunately, completion time was not collected for these tests).

IV. DISCUSSION

The initial results from our experiments demonstrated that the proposed remote hearing test can achieve comparable results to traditional face-to-face modes. Technically, there are several things that deserve more discussion:

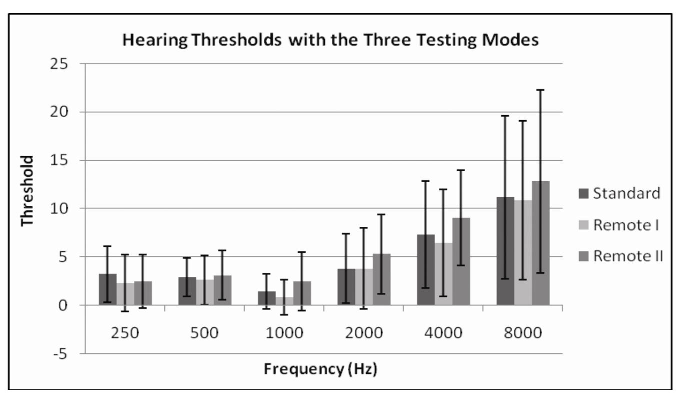

Fig. 3. Hearing test results with three test conditions

The three-tier software architecture: With this architecture which separates user interface, business logic, and data from one another, the system can easily be expanded to include other tele-audiological services such as speech test.

Internet bandwidth requirement: When an audiologist uses the system to perform hearing tests with a low speed Internet connection, the client terminal computer may experience white screens for short periods of time when the sever web page refreshes with dynamic information due to the large amount of information required to be transmitted from the server to the client end. This problem was partially alleviated by employing a web programming technique called AJAX (stands for Asynchronous JavaScript And XML). However, there is still room for future improvement.

Interfacing the system with electronic medical records: Data collected in the system, rather than being saved in the audiologist's local computer in proprietary databases, are stored in a standard database on a public server. Interfacing the system with standardized medical records should be convenient. This should encourage future integration of tele-audiology with other tele-medicine application.

V. CONCLUSIONS

This paper presented a distributed, web services based system that allows remote diagnosis of patient hearing using off-the-shelf audiometers. The system can work in flexible configurations and support hearing tests anytime, anywhere as long as Internet access is available. Experimental results demonstrated the technical feasibility of using remote test to extend face-to-face hearing services. The system is promising to better serve traditionally underserved population, reduce service cost and improve quality of life.

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