Using Wireless Telecommunication Technology to Promote Tele-audiology

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Abstract— **The purpose of this research is to investigate how wireless telecommunication technologies, more specifically Bluetooth, can be utilized in a tele-audiology assessment system to promote remote hearing diagnosis in the following aspects: supporting multiple hearing test modalities (e.g., pure-tone audiogram and speech test); providing a convenient communication means among three-party (i.e., audiologist, assistant and patient) involved in a typical test session with fairly limited software and hardware resources; and improving its reliability when unexpected scenarios occur during test sessions. This enhanced tele-audiology assessment system is composed of a web server, an integrated console device, and a Bluetooth-enabled audiometer. The console device is the portal to the users, which exchanges numeric commands and responses of various data types between the audiologist and patient, transmits audio and video data among the three parties, and introduces a reliability mechanism. Test results show that this tele-audiology assessment system can satisfy the requirement of clinical diagnostic hearing assessment.**

Keywords— *tele-audiology assessment system; Bluetooth; test modalities; console device; reliability mechanism*

I. INTRODUCTION

Tele-audiology has gained more and more attention in the hearing care community, as its concept moves from idea to reality, which is needed especially by underserved regions and populations all over the world. The rapid development of wireless communication technology and embedded system technology brings significant benefits to telehearing applications.

In 2003, Givens and Elangovan introduced a system that was able to administer pure-tone audiometry by remotely manipulating a standard audiometer via the Internet [1]. Elangovan described a similar study that tested the feasibility of assessing distortion produce otoacoustic emissions (DPOAEs) by remotely manipulating a computer that housed the required testing software [2]. Some areas of research focused on providing audiology services via telepractice including video-otoscopy [3], auditory thresholds [4], cochlear implant programming [5], and etc. Swanepoel investigated the reliability, accuracy, and time efficiency of automated hearing assessment using a computer-based audiometer in light of the global shortage of specialized healthcare personnel at University of Pretoria and University of Texas at Dallas [6]. In recent years, Internet-based browser-server (BS) architecture has been introduced to simplify the client terminal requirements in a tele-audiology assessment system which allows pure-tone hearing test [7]. For example, a web-service based tele-audiology system was designed and implemented at East Carolina University which was composed of a Bluetooth-Ethernet gateway device (Parani 1000, SENA Technologies, California), an OTOpod audiometer (Otovation LLC, Pennsylvania), and a Polycom videoconferencing unit as an auxiliary subsystem [7, 8]. However, this system has several limitations: (1) it only supported pure-tone audiogram test, since the Bluetooth-Ethernet gateway device used in the system didn't hold the capability of delivering patient's voice data, (2) the videoconferencing unit in this system required additional hardware and software support, (3) it didn't allow three-party communication among the audiologist, assistant, and patient [8], which is needed by local and remote site coordination, (4) due to the limitation of Bluetooth-Ethernet gateway device, this tele-audiology system was not reliable

To address the abovementioned issues from the previous system, this paper presents the design and development of an improved tele-audiology assessment system that utilizes wireless telecommunication technologies. Through designing and developing a smart gateway apparatus called "console device", the promoted system will support transmissions of both numeric commands and voice data, integrate communication components such as headsets and web-cameras, provide an access to audiometers with several different interfaces, and increase the system reliability through software implemented on both the server and console device. The advantages of the new tele-audiology assessment system include the following: (1) it provides multiple hearing test modalities such as pure-tone audiogram, speech test, etc, (2) it supports three-parity communication with fairly limited hardware and software infrastructure, and (3) it enhances system reliability by introducing a fault tolerance and recovery mechanism. Section II describes the new system architecture, the design method of the console device, the integrated videoconferencing subsystem, and the reliability mechanism. Section III presents the test results of the command transmission latency between the server and audiometer, voice communication latency and throughput, etc. Section IV discusses the features of the prototype and our future plans for the project.

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II. METHODS

A. *The Improved System Architecture*

Figure 1 illustrates the layout of the improved tele-audiology assessment system. Physically, the tele-audiology assessment system consists of five parts: a professional's terminal (e.g., a computer or an iPad device), a web server, a database, an Internet access point on the patient side, and an audiometer [9]. Three types of roles are involved in a typical hearing test session: an audiologist, a well-trained care assistant, and a patient. Through introducing a smart console device (an audio and video capture devices at patient's side) the improved tele-audiology assessment system integrates audiometer command data flow, audio voice stream flow and video stream flow together to support more tele-audiology modalities and three party communication necessary in a hearing assessment session. At present, an audiometer (otoPod, Otovation [10]) with wireless Bluetooth interface is attached to the console device.

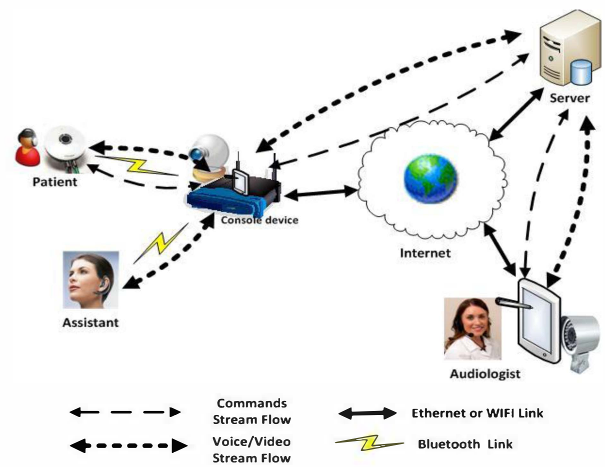

Fig. 1. The architecture of promoted tele-audiology assessment system

B. *Design of console device*

In order to realize this tele-audiology assessment system, we have designed and implemented the smart console device which forwards all three types of data flow between the web server and audiometer. Figure 2 describes the layout of the module components in the console device.

The console device is composed of several modules, including a TCP socket module, a UDP socket module, an audiometer module, an audio and video (A/V) capture and playback module, and a user interface (UI) module. The TCP socket module is responsible for connecting to the server, receiving messages from the server, sending response to the server, and realizing the reliability mechanism. The UDP socket module is aimed at exchanging audio and video data between the server and the console device, while the control messages of the audio and video data are transmitted through the TCP socket. The audiometer module should initiate a connection to a specific audiometer via a certain type of interface such as a Bluetooth link, UART, USB, etc. The A/V capture and playback module is to open the audio and video devices, capture the specific streams, and send them to the UDP socket module under the control of the TCP messages. The UI module provides functions for displaying the connection status between the server and the audiometer, setting up the network interface and audiometer parameters, etc.

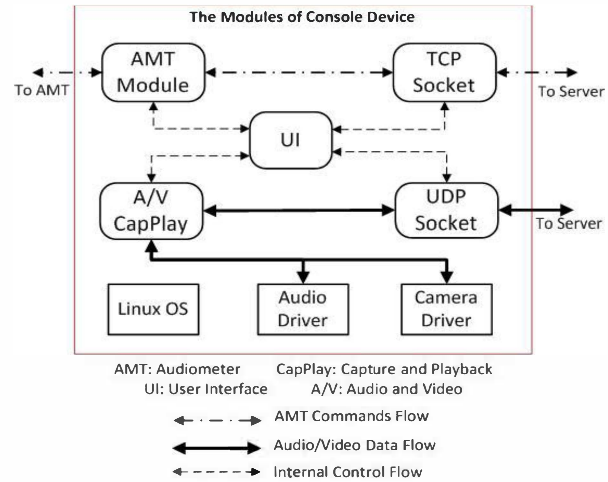

Fig. 2. The modules of the console device

The prototype of the console device is developed based on a high-performance evaluation board which consists of a 720MHz ARM Cortex-A8 processor, 512M Bytes SDRAM, and numerous peripheral interfaces including audio input/output interfaces, a USB port, a LAN port, a serial port, a touch screen and a keyboard interface. These hardware capabilities satisfy the needs to implement the modules mentioned above. In additional, an extended Bluetooth interface enables the connection and data communication between the console device and the audiometer. Multiple profiles such as the serial port profile (SPP), headset profile (HSP), and hands free profile (HFP) are supported by the Bluetooth interface, which in return enables both the pure-tone audiogram test and speech test.

C. *The typical test procedure*

A typical hearing test procedure consists of a preparation phase, a logon phase, a test progress phase, an assisted communication phase, and a test assessment phase. At the preparation phase, the console device should connect to the server, setup a wireless Bluetooth serial port profile (SPP) link with the audiometer, and calibrate the connected audiometer.

1) Pure-tone audiogram test: An audiologist should logon to the web server, select the specific appointment, connect to the console device, and start the pure-tone audiogram test after the assistant and patient are ready. The audiologist should first click a button to start the pure-tone audiogram test. Then he will set the test parameters such as frequency, level, headset type, stimulus type, and tone mode. After setting these parameters, he will click a button to send a test message to the console device. After being forwarded to the audiometer, this test message generates a sound at the selected frequency and volume. If the patient hears this pure-tone voice, he should press a button on the audiometer to send a response message back to the audiologist.

2) *Speech test:* First of all, the audiologist notifies the console device to start a speech test. At the wireless Bluetooth audiometer side, a wireless Bluetooth HSP link will be setup with the console device. Then he needs to choose a track file to send the play command message to the audiometer. After the specific track file is played on the audiometer at patient side, he repeats the content that he hears. The voice data will be transmitted to the console device through the HSP link, and then forwarded to the audiologist side. The audiologist can then check the response accordingly.

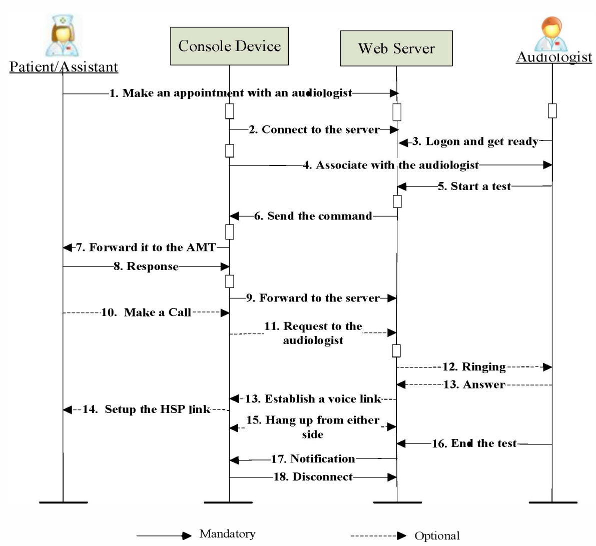

Fig. 3. A typical hearing test procedure

D. *Three party communication*

At present, the audiologist can have a call with an assistant and patient each at a time. When the audiologist needs to make a call to an assistant or vice versa, the call originator should first check the status of the hearing test session: if a hearing test is not in progress, a call request message can be sent to the other side. The peer then clicks the answer button to respond to the request. At the same time, the console device will setup a voice link with the assistant's Bluetooth headset or the patient's audiometer. When the call is finished, either side may end the call by sending a hang-up message.

E. *Enhanced reliability mechanism*

Figures 4 and 5 present the reliability mechanism which is implemented on the web server and the console device. A heartbeat packet as a beacon signal is used to maintain the online status of the console device while the response packet to the console device is assigned to represent the online status of the audiologist. When the console device is abnormal or the network access is down, the web server can detect the online/offline status change and then save the test site. Similarly, when the webpage is closed due to incorrect operations by an audiologist, the console device will disconnect to the server automatically after sending three heartbeat packets without any response received.

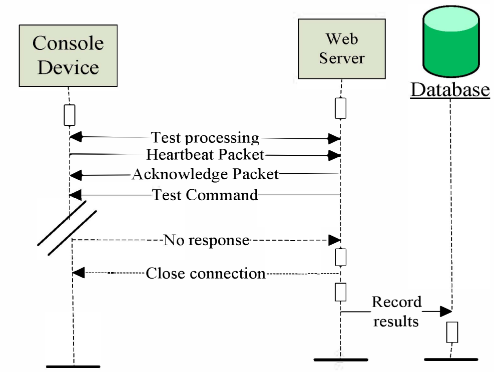

Fig. 4. The reliability mechanism when the console device fails

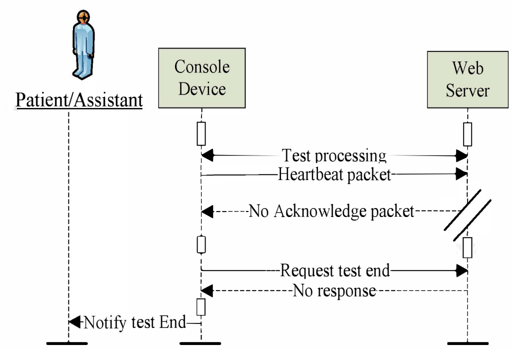

Fig. 5. The reliability mechanism when the audiologist unexpectedly gets off line

III. RESULTS

Initial tests and calculations are performed to verify that latency involved in the data transmission and bandwidth can satisfy the application needs.

Table I illustrates the response rate of the Bluetooth audiometer responding to numeric commands; the average, minimum, and maximum latency between the time of sending a command and receiving response message at the server in the pure-tone audiogram test. The maximum latency of about 0.6 seconds is acceptable in the pure-tone audiogram test session. Table II presents the results of transmission rate of the audio data in the speech test; the average, minimum, and maximum latency of the audio data from the patient to the web server. The maximum unidirectional latency of voice data is reasonable in both of the speech test and the three-party communication. Another concern is the time required to setup a voice communication session. Table III describes the setup time of voice communication between an audiologist and an assistant. The max setup time is ~1 second, which is also acceptable in the three-party communication.

TABLE I. RESULTS OF PURE-TONE AUDIOGRAM TEST (5000 REPEATS)

Response rate	**Average latency (ms)**	**Minimal latency (ms)**	**Maximal latency (ms)**
100%	399	156	641

TABLE II. RESULTS OF VOICE TRANSMISSION (2000 UDP PACKETS)

Transmission rate	Average latency (ms)	Minimal latency (ms)	Maximal latency (ms)
100%	49	19	96

TABLE III. RESULTS OF VOICE COMMUNICATION SETUP TIME (100 REPEATS)

Average time (ms)	Minimal time (ms)	Maximal time (ms)
767	500	1047

The network communication capacity is also examined. A pure-tone audiogram test only needs fairly limited capacity since it transmits messages with length of only dozens bytes during each test points (at a certain frequency and dB level). Therefore, no bandwidth verification is necessary for pure-tone audiogram testing mode. In the speech test session, the voice of the audiometer is captured at the rate of 8,000Hz, stereo, 16 bits per sample, which will need the maximum bandwidth of 256 kbps to transmit these voice data. According to the Bluetooth Enhanced Data Rate (EDR) specification v2.0+, the enhanced data rate is about 3 Mbps, although the practical data transfer rate can be lower at 2.1Mbps.It is apparent that the Bluetooth link capacity can meet the higher bandwidth requirement from typical speech tests.

To the end, the authors have successfully developed a functional system ready for test. Figure 6 illustrates the packaged console device.

Fig. 6. The interface of console device in the system

IV. DISCUSSION

As shown in the previous section, the system experiences a maximum latency of ~0.6 seconds, which is perfectly acceptable when an audiologist expects a response from his patient. The simple calculation also verifies that the designed system provides sufficient bandwidth for both hearing test modalities. The initial results from our experiments demonstrated that the proposed tele-audiology assessment system can meet tele-hearing application requirements. However, due to time constraints, these tests were performed when the audiologist and patient were connected to the system within the same Internet domain. More connection cases need to be examined in order to thoroughly explore the system connectivity issues. Additionally, more work is planned to perfect the software on the console device and test its reliability and stability.

ACKNOWLEDGMENT

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