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Remote Hearing Screening As Part of Auditory Telerehabilitation; A Preliminary Report

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***Abstract*— It is well known that implementing a universal hearing screening program is one of the most effective ways for hearing impairment prevention/rehabilitaion. With limited resource on both medical and supporting staff especially in developing countries, concepts such as teleaudiometry increasingly come in to consideration. As a work in progress, this paper discusses the system design, service delivery model, and its key component that is a low-cost software audiometer designed to run on computers with moderate computing capability such as cost-effective netbooks. The audiometer employs a good dynamic-range, low-latency professional USB soundcard as the sound source to overcome hardware limitation found in earlier attempts on software-audiometer. The software developed also has extra features such as acoustic calibration, network accessibility, and video conferencing not found on alternatives in the market. A preliminary trial result from our pilot scheme is reported.**

***Keywords-** Audiometer, hearing screening, rehabilitation, teleaudiometry, telemedicine*

I. INTRODUCTION

Telemedicine is a discipline that is gaining interests worldwide. With universal problem of limited resource on both medical personal and equipments, quality medical services accessible to all have been a challenging goal. Via appropriate technology, infrastructure and servicing model, it is conceivable that telemedicine can be the concept that will provide patients with an access to proper medical care. One simple scenario could be tele-consultant where a simple video conferencing system could be set up for local medical staff to have a channel for consulting with medical experts who are based elsewhere in real time. Sharing the infrastructure other advanced features may be added to the system depending on the requirements for each treatment. As the world demography is shifting towards an aging society, caring for this important category also adds to the burden. Within this group, hearing loss is statistically one of the most common disabilities found. Generally, it is estimated that more than 10% of world population suffers some form of a hearing loss. It is therefore imperative that any hearing problems are detected as early as possible for the rehabilitation to be effective. If in doubt, a patient should undergo hearing loss assessment performed by medical and technical professionals (doctors and audiologists) to find if proper treatments will be needed. For example, in case of mild to moderate sensorineural hearing loss, the patient may be fitted with a hearing aid, whereas as in severe cases, cochlea implants may be needed. Unfortunately, similarly to other medical situations especially in developing countries, access to qualified doctors and audiologists needed for the screening purpose can be limited. Application of telemedicine in the form of teleaudiometry is therefore both interesting and challenging. This paper discusses one possible system, including its service delivery model and key component that is a low-cost software audiometer designed to run on computers with moderate computing capability such as cost-effective netbooks. Preliminary results on both engineering and usability trials will also be discussed. The paper is organized as follows. Section II reviews the concepts of hearing loss and hearing screening. System topology proposed is discussed in section III. Section IV focuses on the design and development of key components in the systems that are the audiometer and the data management system. Preliminary results on engineering and usability trials, including discussions on future work, will also be discussed in section V. Section VI concludes the article.

II. HEARING LOSS AND HEARING SCREENING

At various stages of a life, different testing and evaluation methods are used to determine the characteristic of hearing loss in each patient. For example, a newborn child may undergo OAE (Otoacoustic Emission, a measure of inner ear health) and ABR (Auditory Brainstem Response, a measure of hearing nerve's response to sounds) tests for initial evaluation and early detection. Theoretically universal newborn screening is encouraged but at present not widely applicable due to the limited access on both high-cost equipments and trained medical staff needed to perform such measurements. More often, from an early age of young child to adult and beyond, audiometry is used as a primary screening measurement for objective assessment of hearing loss. In this measurement, an audiometer is used to measure the ability of a patient to hear at specific frequencies. Fundamental to this measurement is pure-tone measurement. The audiometer is used to generate pure tone signals at specific frequencies within the 250 Hz to 8 kHz range. For each frequency the level of loudness is incremented from soft to loud. The patient is asked at which point he/she starts to hear the sound, which will then represent the patient's hearing threshold at that frequency. The final result is plotted as an audiogram that will be interpreted by medical professionals to determine proper treatments. Generally, there are two methods for conducting the sound into the ears for the hearing assessment that are air-conduction and bone

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conduction. For the air conduction method, varying air pressure corresponding to the intended sound is generated from the calibrated headphone (usually a TDH-39 type) placed outside the outer ears of the patient. The sound pressure is converted into hearing at the middle and inner ear sections through human's auditory mechanisms. In cases such as conductive hearing loss where there is a problem at the middle ear, the testing sound is generated via a vibrating device placed on top of the scull. The sound generated is conducted directly via the bone into the inner ear, bypassing the middle section. Usually, these devices are stand-alone, meaning that any measured data is stored locally. Considered in the context of telemedicine, this can be a problem in cases where remote evaluation by an audiologist is required, or in scenarios such as when medical experts overseeing the health care wanting to analyze data collected from a number of audiometers located at different sites for health system research. We are therefore proposing an internet based solution as discussed in the next section.

III. SYSTEM TOPOLOGY

The proposed system is depicted in Fig. 1. For universal usage, with the intention for the service to be accessible at the primary care level, the system is designed to run on the ubiquitous internet network. The system consists of a central server that hosts the central database system. The clients are computers, each of which located at the hearing assessment site and equipped with a sound generating device and an output device (headphone). All the audiometric functions are implemented on software running on each client computers. At the hearing assessment site, the technician uses the computer to evaluate patient's hearing ability. The internet provides the access for the system's multi-users, who can be technicians, audiologists, or doctors, to connect to the central database via TCP/IP protocol, and to share data such as patient's information, hearing test results, or treatment recommendations. Furthermore, via video conferencing system that employs the UDP protocol and the internet as a communication channel, the user can directly connect with the team if there are some issues needed to be further discussed.

As function of the audiometer is not too complex, a computer or notebook with moderate computing capability would be sufficient. For cost effectiveness and extra portability, a netbook is employed here as the processing unit. Another advantage of using the device is its readily available network connectivity. Detail design of each main component is given in the following sections.

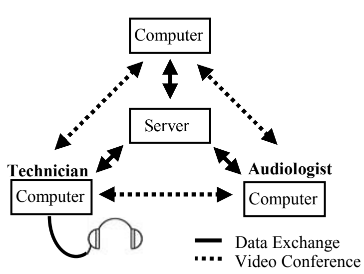

Figure 1. System Topology

IV. AUDIOMETER DEVELOPMENT

A. *Audiometer*

At present, there are various types of audiometer readily available on the market. They can be different depending on the specifications and features, but generally a dedicated hardware is needed for high-quality and reliable measurements, resulting in high price. In terms of research, historically the earlier work focused on hardware implementation, usually at the integrated circuit (IC) or embedded system levels [1-4]. Techniques such as direct digital synthesis (DDS) have been considered [5]. As the availability of good-quality personal computer expanded, the focus has shifted towards PC-based systems [6]. Some has also attempted on integrating other hearing loss measurement features into the same device [7-10]. In general, the difficulty in software implementation of the audiometer is on the limited capability of the underling hardware available in the PC. For example, the dynamic-rage of built-in soundcards cannot match the measuring range required of the audiometer. This tends to limit the usage of PC-based devices to only for preliminary hearing screening, where lower level of the sound's dynamic rage is necessary.

In our proposed device (Fig. 2), the computer is connected to an external USB soundcard that is used as the source for sound generator. Usually, a complete audiometric measurement requires signal range of up to 100 dB, which cannot be supported by the built-in hardware. The soundcard ideally should also have as minimal latency as possible. We investigated devices available on the market and found that an external professional soundcard such as the E-MU used in this project is suitable. Using the external USB concept, investment in infrastructure is minimized as those in the remote areas can also use existing PC or laptop, as long as they have the USB ports. The second USB port of the computer is connected to an in-house developed single switch. The device is used as the interface for the patient to provide measurement feedback. Completing the system, a headphone is provided to the patient. When running the system, the audiologist controls the software on the computer that will generate pure tones via the soundcard. Patient listens to the sound via the headphone and gives the respond by clicking the single switch.

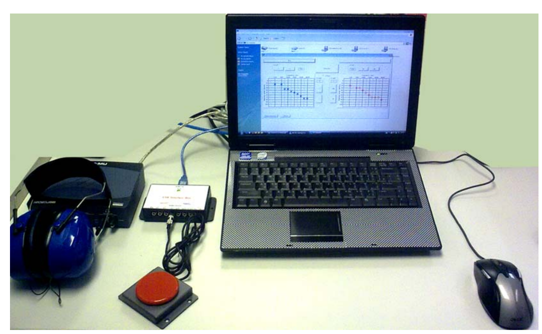

Figure 2. PC-based audiometer

B. *Acoustic considerations*

Key to the validity of the results is the audiometer being accurate. With an external sound meter and a calibrator, the system can be properly calibrated. Within the acoustical loop chain of the system implemented, the last piece of device is the headphone. It is important that the headphone has flat response for measurement accuracy. Usually, available devices use a specific type of headphone such as the TDH-39 for this purpose. We develop a substitute TDH-39 headphone using convention earphone embedded on a customized rubber modeled after standard shape. Note that in cases where a purpose-built quiet room is not available such as when performing outdoor screening, it helps that the headphone has sound protection ear cups, which can reduce external noise interference by up to 30 dB. The system developed also follows that strategy by inserting the calibrated earphone inside protective ear-cups.

C. *Software development and features*

The software is written using Visual C++ language. The software consists of 4 main components that are audiometric testing, calibration, data management, and video conferencing. Details of each feature are given in the following sub-sections.

1) *Audiometric testing*

The audiometric testing function is as in Fig. 3. The user may select testing on either the left or right ear. The testing frequencies programmed are 250, 500, 750, 1K, 1.5K, 2K, 3K, 4K, 6K, and 8K Hz. The basic sequence is to start from low to high frequencies. At each frequency, pure tone signals are generated, from softest continuously increasing until reaching the loudness level the patient just about to hear. He/she will press the switch, indicating the hearing threshold at that frequency. Although the concept is easy to understand, usually this is not the most effective way to remove perception error by the user. The software is designed such that specific sequences can be manually controlled by the audiologist who runs the measurement step-by-step, or automatic sequences can be pre-stored using known rules. Also, the user can pre-configure different levels of loudness and frequency, and adjust the threshold line for the purpose of basic hearing screening.

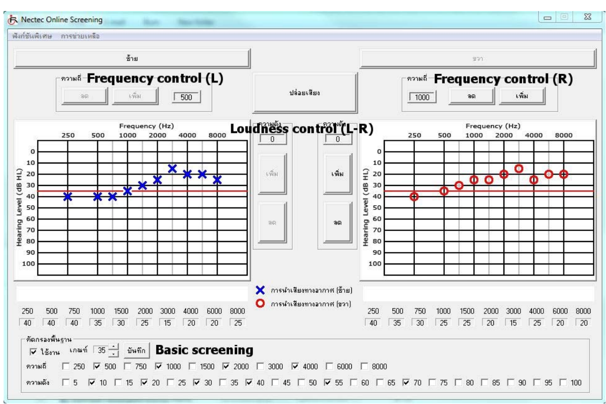

Figure 3. Audiometric testing

2) *Calibration function*

As a TDH-39 headphone is rather expensive, the software is designed to support other types of headphone. This is done using the calibration function as shown in Figure 4.

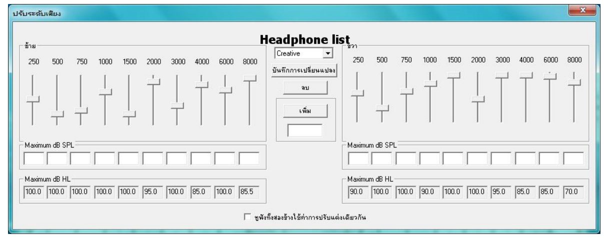

Figure 4. Calibration function

3) *Data management*

After completing each measurement, the resulting audiogram may be shown on screen or plotted out. The measured data, together with patient information created when opening each user account is stored at the local database. The system is networked to the server via the internet such that data stored at the server is synchronized with any updates on the client(s). Fig. 5 shows an example when user profile is loaded from the server and displayed on the remote computer.

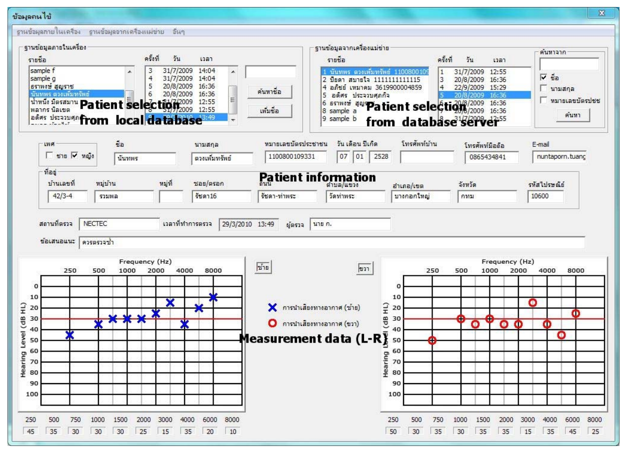

Figure 5. Data management

4) *Video conferencing*

To complete the system following the concept of teleaudiometry, video conferencing function is provided. This function enables video and voice communication between doctor and audiologist, doctor and technician as well as audiologist and technician. On each pair of communication, the parties can conveniently share their opinions on test results, interpretations, or diagnoses. Fig. 6 shows a sample display when using the video conferencing function.

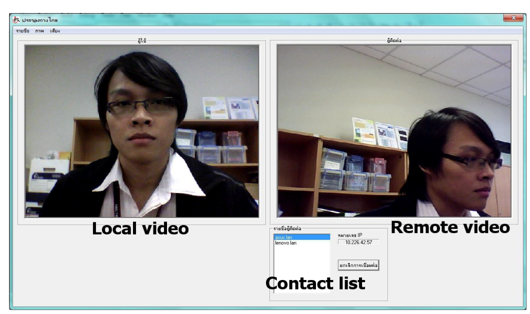

Figure 6. Video conference

V. Engineering Test and Usability Trials

The system developed has undergone both engineering tests and usability trials. Pure-tone auditory measurements were performed on 5 patients; each was tested using 10 frequencies. The measured results of the audiometric functions in terms of accuracy (Tp+Tn / Tp+Fp+Tn+Fn, the ability to correctly identify hearing conditions), sensitivity (Tp / Tp+Fn, the ability to detect hearing loss, hearing level is greater than 25 dB), and specificity (Tn / Fp+Tn, the ability to identify normal hearing) are found to be 80%, 76%, and 81% respectively which are reasonably good compared to around 90% values obtained by those available in the market that are more expensive. The meanings of Tp, Tn, Fp, and Fn are shown in Table 1.

TABLE I. MEANINGS OF TP TN FP AND FN

		Hearing condition	
		Positive (loss)	***Negative (not loss)***
Test result	***Positive (loss)***	Tp (True positive)	Fp (False positive)
	Negative (not loss)	Fn (False negative)	Tn (True negative)

In terms of usability trials, the audiometer is field-tested as a servicing tool to provide hearing test measurement for sample patients at Chiang Mai University Hospital. To accompany the device a protocol for using the system to perform teleaudiometry is also developed as shown in Fig. 7. It is designed to address the unavailability of on-site experts by letting the trained technician perform the tasks of audiometric testing and interpretation. Through the data management system, the audiologist may advice and/or approves these results. Finally the doctor may view the results, as well as the approved interpretations, and order medical treatments considered appropriate for the patient. In case the doctor has some further issues he/she may ask the technician to re-test or to have a meeting via the video conferencing system. Based on this system set up, all the selected patients have been successfully provided with basic hearing test service as determined by the trial audiologist. It is further commented that the software would be more beneficial to include following features:

- Bone conduction testing – to enable the audiologists to more accurately diagnose the type of the patient's hearing loss.
- Noise masking – to solve the problem of crossover hearing
- Speech testing – to determine the Speech Reception Threshold

Finally it is recommended that the software in this present form may now be appropriate for hearing screening in applications such as hearing screening for factory workers. Based on these recommendations, our work next phase will involve developing additional features for more universal usage as well as to employ the networked audiometer at more remote test sites to collect data of long-term usage

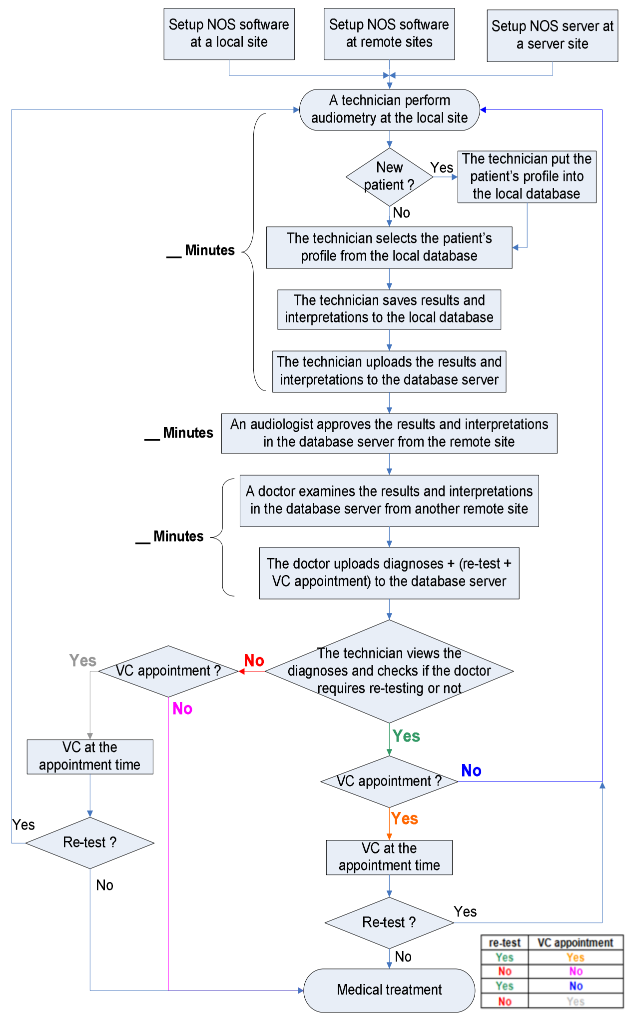

Figure 7. Guideline for using the system

VI. Conclusion

A work on teleaudiometry targeting hearing screening in rural areas is discussed. Fundamental to the system is software-based audiometer connected to central server via internet. The use of cost-effective netbook together with professional USB soundcard allows accurate, practical and cost-effective pure-tone auditory measurement. Through the networked system developed, with features such as database management and video conferencing, it has been confirmed via our pilot trial that the concept of teleaudiometry is implementable and can provide real benefit to patients. It is envisaged that the system can be a solid candidate for demonstrating a practical concept of telemedicine.

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