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Using Digital Stethoscopes in Remote Patient Assessment via Wireless Networks: the User's Perspective

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---ABSTRACT---

Digital stethoscopes assume an important role in telehealth and mobile (m-) health for capturing sounds over a communication infrastructure. However, few studies have explored the users' experiences and views on using the current models of digital stethoscopes on a telehealth network. The authors were provided with an Australian Research Council grant to explore the possibilities of developing a suitable digital stethoscope that would function at acceptable levels with Queensland State-wide Telehealth Services. A major Indian university is collaborating in this research. As an initial step, users' views and feedback were sought for using a digital stethoscope on a telehealth platform and these were reported in this paper in a consolidated manner. The issues identified in the multiple-case study cover the aspects of sound quality, signal transmission, hardware/software design, functionality, and cost considerations. The finding of this study can assist researchers and practitioners in making informed decisions for procuring digital stethoscopes, as well as providing useful information to the manufacturers in designing future digital stethoscopes.

Keywords- digital stethoscope, electronic stethoscope, m-health, telehealth, remote patient assessment.

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1. Introduction

Telehealth organises and integrates resources of health services to be used more efficiently and systematically [1]. Through the information and communication technology (ICT) infrastructure, healthcare services are delivered to remote and rural areas. Combining medical expertise and equipment, computer hardware and software, telecommunication infrastructure and Internet as a system, telehealth provides essential assistance for both medical professionals and patients. For example, a local physician can carry out treatments of a patient by taking advice from specialists in remote areas [2]. Therefore, in recent years, telehealth has become an integral part of healthcare service in the developed countries. The benefits and applications have been well realised in both developed and developing countries [3]. Despite the availability of many tools such as imaging scanners and electronic patient records, digital stethoscopes have not yet found their way into telehealth infrastructure in a big way. This has constrained the physicians from listening to real time body noises through telehealth, crucial for certain remote diagnostics.

Digital stethoscopes (DS) or electronic stethoscopes (ES) require conversion of acoustic sound waves to electrical signals, which can then be amplified and processed for optimal listening. A digital stethoscope can transmit various sounds that healthcare professionals would like to hear during their assessment process over telehealth infrastructure [4]. Prior studies have indicated that sound quality is very important in providing accurate assessment when a digital stethoscope is used on a telehealth infrastructure [5].

Digital stethoscopes can assist physicians in capturing body noises of a patient from a remote location using a telehealth network. However, limited information is available as to the usage aspects of a digital stethoscope on a telehealth network. This may be due to the fact that there is no common protocol in testing a stethoscope or not many digital stethoscopes are available for telehealth networks. This has prompted the authors to explore the research question:

'*What are the issues of using digital stethoscopes in the telehealth context, based on the users' perspectives?*'

2. Background

Telehealth or telemedicine generally refers to the use of telecommunications or videoconferencing technology to deliver health services. Telehealth is used across a broad range of clinical specialties, and for a variety of purposes, from standard consultations to remote monitoring and home care scenarios [6]. In telehealth context, sound capture and transmission is essential, and digital/electronic stethoscopes take an important role for this purpose [7].

A digital stethoscope comprises, in addition to the chest piece and the headset, a sound transducer, an adjustable gain amplifier, frequency filters, a mini-speaker, and dry cell(s) or a battery [8]. A digital stethoscope is a useful tool for physicians using telehealth network. For example, the sounds could be amplified and recorded in real-time for further analysis [9]. Moreover, such amplified sounds could be used for teaching purposes in a classroom [10]. An experienced cardiologist will be able to distinguish various types of murmurs using a digital stethoscope on a telehealth network. The sounds extracted through a digital stethoscope and transmitted through a telehealth network can be analysed using computer software, providing augmented services [11].

Since 1960, researchers have focused on the development of stethoscopes [12]. In 80s electronic stethoscopes with various degrees of amplification and filters were launched [13]. However, the early models had issues regarding to the usability, such as distortion of sound. Other drawbacks in the construction of digital stethoscopes may include size of the device, electronic circuit, and power supply options as these will impede their functional aspects [9]. Previous studies also indicated the reliability of sound transmission could vary significantly on different models of digital stethoscopes and telehealth infrastructures [14].

Health industry, particularly cardiology, has already embraced telehealth. Telehealth can help patients by providing access to medical specialists, decrease patients' stress and waiting period, reduce travelling time, and provide more accurate treatment which leads to improved healthcare services [15]. For example, in Queensland, Australia, the telehealth pre admission clinical (PAC) service operates from 22 regional health services connected to Toowoomba Hospital, and over 1400 patient consultations have been conducted across a range of medical specialties since 2004. The accumulated data shows that almost 720,000 kilometres of travel have been saved by the telehealth PAC service, representing over 9,400 hours of patient time in the first few years. On average, each consultation conducted via videoconference saves 490 kilometres and over 6 hours of travel [16]. In other words, the telehealth service has resulted in cost savings of $83,296 to Queensland Health and $423,454 to patients in travel and time savings. Over a four year period, the service has therefore resulted in a net cost benefit of over $500,000. Considered on a per consultation basis, the service saves Queensland Health $57 and at least $289 per patient [16].

To identify the issues of using digital stethoscopes in telehealth, a previous study aimed at providing suggestions in designing new digital stethoscopes [8], 13 criteria were developed to evaluate the usability and performance of the stethoscopes. These criteria covered the medical, technical, and ergonomic aspects. Latter studies indicated that there exist other issues. For example, if clinicians believe that the technology will decrease their control over patient care, they may avoid using it and therefore precluding the benefits. Moreover, clinical acceptance may depend on the degree of clinicians' confidence in making decisions in the absence of face-to-face interaction with patients [5].

In the last census of India, it is found that the majority of population (72.2%) live in isolated villages [17]. Due to the shortage of quality medical facilities in rural areas, the demand for telehealth is significant. In this case, telehealth can improve the efficiency of utilizing the medical resources such as equipments and personnel, as well as reduce the non-medical expenses [18].

Australia, on the other hand, has its uneven population density in the opposite way. Three quarters of the Australian population live in the urban areas, and more than 60 % of population live in the eight capital cities [19]. Health departments in Australia use significant budgets to assist patients travelling to major centres for routine checks or assessments prior to surgeries. Due to the relatively low population density and vast geographic area, the telehealth can also play an important role in maximising the efficiency of medical resource utilization, and significantly save time and expenses of travel (medical professionals and patients). On average, the telehealth pre-admission clinic (PAC) service was found to save patients almost 500 km, or approximately 6.5 hours, of travel [16]. In some cases, travel including accommodation costs can go to thousands of dollars per individual patient based on current rate of expenditure [14].

Thus adding a digital stethoscope to a telehealth network would improve the quality of healthcare service provision, and minimise cost associated with healthcare service. As stated in the abstract, the Australian Research Council (ARC) provided a grant to the authors to explore issues associated with a digital stethoscope in order to develop a device that is suitable to function at satisfactory levels with Queensland State-wide Telehealth Services. A major Indian University has partnered in this research, leading to major data collection exercises in India.

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3. Research Process

In this section, research methodology and ethical consideration are provided in Section 3.1. In Section 3.2, the testing environment and process are provided. Interview protocol, data collection and analysis are discussed in Sections 3.3 and 3.4 respectively.

3.1 Methodology and Ethics

With limited studies for using digital stethoscopes in telehealth, the exploratory and qualitative research method is considered to be appropriate [20]. Moreover, the method of case study is ideal for learning more about a previously little-known situation such as users' experiences towards using a DS [21]. To improve the quality of data and research findings, a multiple-case study with face-to-face interviews and observation technique were employed in this study for obtaining the primary data from the practitioners and telehealth professionals [22; 23]. Based on users' perspectives, issues for using the existing digital stethoscopes in telehealth settings were collected and analysed.

There is no patient experiment in this study. For the ethical considerations, all interviews with the participants (e.g. physicians) have been approved by their supervisors and the hospitals/organisations. During the interviews, the participants were allowed to either terminate the interview or leave the interviews at any time. Names of the participants, job titles, and their organisations were removed for the reasons of confidentiality and privacy. The brand names of digital stethoscopes and other devices mentioned by the participants were also removed from the interview transcriptions.

3.2 Testing of the prototype

Before the interviews, all the users tested the prototype model of a digital stethoscope that is designed and developed by this team. The components included in the testing environment are: voluntary participant, DS facilitator, local clinical staff, remote specialist, wireless local area network, local desktop/laptop, remote desktop/laptop, local and remote DS applications, and Internet connections for all computers.

The first step of testing is attaching the receiver onto the participant's chest for the heart sounds, with the assistant of local clinical staff and DS facilitator. Once it is connected, then the DS is switched on for capturing and sending signals to the local computer. The heart sounds of the tester will be transmitted to the clinician's computer via a wireless network.

The second step is to present the heart sounds into digitized figures on the local computer. The figures are processed and monitored by the local clinician with the assistance of a customized application. A sample screen is presented as in Fig. 1 and 2. The web-based application is developed for connecting the data between the DS, local computer and the remote computer. Once the participant's heart sounds are presented in the local computer, the clinician will connect the computer to the remote specialist via the Internet.

The screen of the remote specialist is the same with the local clinician. A diagnosis report will then be made by the specialist and sent to the local clinician. The communication channels between the local and remote clinicians include the voice calls, instant text messages, and emails. The application enables the function of generating, storing, and re-accessing the assessment report.

In this study, the opinions and feedback from the 18 clinicians and specialists are collected and summarised in the manner of future considerations of the design, quality and usability issues. In next section, the instrument and process of data collection and analysis is discussed. The findings from the testings are summarised and discussed in Section 4.

Figure 1: Control panel of the DS application

Figure 2: Samples of heart sound waves

3.3 Interview Protocol

Prior to the commencement of data collection, an interview protocol was prepared to guide the in-depth interviews. The protocol was aimed to collect users' previous experiences in using stethoscopes in their works, as well as the feedback on using and testing existing digital stethoscopes including a prototype developed by the team of authors. This protocol has also been reviewed by colleagues and potential interviewees for its clarity, suitability and integrity. The users' feedback was divided into the components of hardware, software, sound quality, costs and other issues. The structure of the interview protocol is listed in Table 1. The interviews were open-ended and free flowing in nature, thus providing maximum freedom to participants to express their views.

Table 1: The structure of Interview Protocol

No.	Topic
1	Introduction of this research and interview
2	Experience of using (digital) stethoscopes
3	Feedback of testing the DS models
4	Additional feedback and other comments
5	Summary and acknowledgement

3.4 Data Collection and Analysis

There were 18 medical doctors participated in the data collection of this research. Each interview took between 45 and 90 minutes. The interview protocol mentioned in Section 3.3 was used to guide the interviews. The interviews were conducted in a hospital where the interviewees were employed. Prior to the start of the data collection, the CEO of the hospital was contacted for approval and support. Two researchers conducted the interviews. The primary researcher led the conversation and asked the open-ended questions. The other researcher took key notes, prepared the recorder, and ensured the interviews were running smoothly.

Once the interview was completed, the recordings were transcribed by an experienced transcriber. Each of the interviews generated a transcript from 15 to 25 pages. These transcripts were then analysed by the authors with an aim to answer the research question of this study. The analysis was mainly done with the assistance of computer software (Leximancer v2.25 and Microsoft Word 2007). The first step of the analysis was to screen and format the transcripts as the preparation of analysis. The second step was to feed the transcripts into Leximancer as a preview for any noteworthy terms and ideas. The third and main step was to read through each transcript by the authors, analyse the content of conversations, and filter and underline any ideas or factors that may be relevant to the research question. As a result of data analysis, constructs and factors influencing the use of digital stethoscopes in a telehealth context were identified. The fourth step was to go through each factor to avoid duplications. The fifth and final step was to group these factors into major constructs. The result of data analysis is discussed in next section.

4. Findings and Discussion

The data analysis indicated that six constructs with 55 factors assumed important roles in using digital stethoscopes in a telehealth context. These constructs cover the aspects of 'hardware', 'software', 'sound quality', 'signal process', 'cost', and 'user's perception'. Under each construct, a series of factors were identified. The constructs and factors not only depict the considerations and concerns of using digital stethoscopes in telehealth context, but also indicated the directions in improving current digital stethoscope models for the future. These constructs are summarised in Table 2 and discussed in this section.

Table 2: Constructs and factors for using digital stethoscopes in telehealth

Construct	Factor/Issue	Construct	Factor/Issue
Hardware	1. Material 2. Weight 3. Appearance 4. Durability 5. Ear Plug Design 6. Tube Length Design 7. Neck Engraved Design 8. Volume Adjustment Function 9. Power Switch Function 10. Dual Mode Function 11. Tuning & Adjustment Functions 12. Battery Type (Disposable/Rechargeable) 13. Battery Longevity 14. Battery Re-Charge & Backup 15. Technical Revolution 16. Climate Suitability	Sound Quality	1. Sound Volume 2. Sound Stability 3. Sound Integrity 4. Sound Clarity 5. Sound Continuity 6. Sensitivity of Sound Input 7. Noise Level 8. Noise Reduction—Echo 9. Noise Reduction—Diaphragm 10. Noise Reduction—Environment 11. Noise Reduction—Body Friction 12. Noise Reduction—Respiratory System 13. Noise Reduction—Heart Beat
		Cost	1. Cost-Efficiency 2. Purchase Price 3. Recurring Expenses for Battery
Software	1. Software Reliability 2. Sound Enhancement Function 3. Decision Making Function 4. Patient Search Function 5. Amplification Function 6. Sound Filtering & Purification 7. Value-Added Function	User's Perception	1. User's Comfort 2. Training & Education 3. User's Health 4. Time Saving 5. Energy Saving 6. Convenience 7. Usefulness 8. User's Friendliness 9. User's Awareness 10. User's Adoption 11. World Trend
Signal Process	1. Patient Data Storage 2. Patient Data Retrieval & Reuse 3. Delay of Signal Transmission 4. Signal Accessibility 5. Data Security		

In the hardware aspect, 16 issues were identified in the data collection and analysis. The material (aluminium or stainless steel for chest piece), weight, appearance, durability of a DS have been in users' minds in using and selection of them. Stainless steel is considered to be a better sound transmission medium than aluminium. An additional option of using ear plugs can improve sound quality, especially in noisy situations. Suitable tube length and neck engraved design will increase the convenience of using a DS. Hardware-controllable functions such as volume adjustment, power switch off, dual mode option (can switch back to traditional stethoscopes), and other tuning and adjustment functions efficiently increase the usability and convenience. Power supply issues such as battery type (disposable/rechargeable), battery longevity, and battery recharge & backup design are important for the professionals using DS for longer hours at works. Additional features such as whether using the latest technology (e.g. LCD information window, Bluetooth, etc.), and compatibility for local weather including temperature and humidity have been mentioned in the interviews.

With regard to software, seven issues were considered important in using and selecting a DS. Software functions such sound enhancement (including volume and clarity); amplification and purification of target signal; user-friendly operations for patients' information search; software reliability; decision making assistance for diagnosis and judgement; and other value-added software functions are noted and discussed as users' feedback for completing the software functionality for a DS.

In addition, issues of signal process were discussed by users as a concern. The capacity of transmitting and storing signal capturing from patients when necessary enables the trace of patients' physiological history. For accomplishing this, information and communication technologies (ICTs) such as wireless data transmission (e.g. Wi-Fi and Bluetooth), central database server, operating system, database management system (DBMS), and other information and communication infrastructure will need to be deployed and managed well. On the other hand, appropriate software and applications needed to be installed into DS users' personal computers for data retrieval and reuse. Signal interference between medical equipments in the hospital environment and data (transmission) security need to be considered and solved.

One of the core construct for a successful digital stethoscope was the sound quality of its signal. In this area, 13 criteria have been identified and discussed in the data collection. Factors such as sound volume, clarity, continuity, signal stability, and signal integrity significantly decide the usability of a digital stethoscope. The sensitivity of sound input and the environment also influence the noise level of signal. The external noises will add into the body and other noises—such as echo, and noises caused by diaphragm, respiratory system, heart beating, body and friction (as a result of chest piece rubbing clothes) etc. Therefore, the noise reduction and filtering mechanism appears to be an important role for sound quality.

Costs and other issues of a digital stethoscope also contributed to the user's perception. The purchase price and recurring expenses for battery come to the users' concerns, especially for those who heavily rely on it at works. The cost concern eventually leads to the cost-efficiency issue. The visual benefits and actual requirements from both doctors and patients will need to override the investments. Users' comfort and health, time and energy saving, convenience, perceived usefulness, and user-friendliness of a digital stethoscope decide users' adoption. Other external conditions such as a good training and education scheme and the awareness from the users for such products will influence the adoption of digital stethoscopes as well.

5. Conclusion

Based on users' perception, issues of using current digital stethoscopes are investigated in this study. An exploratory study with in-depth interviews is used to collect users' experiences and feedback for using digital stethoscopes in telehealth environments. Six constructs with 55 factors/issues were identified and reported in a consolidated manner for answering the research question. The findings may not be applicable for all DS users due to the limitations of geography and users' backgrounds in data collection. As an initial study, this paper provides a good foundation to depict users' requirements for using a digital stethoscope in telehealth and m-health context. The information provided in this paper will facilitate the communication among the patients, doctors, and DS manufacturers, and further assist in designing and manufacturing digital stethoscopes in the future.

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