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Tele-Auscultation Support System with Mixed Reality Navigation*

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Abstract— **The aim of this research is to develop an information support system for tele-auscultation. In auscultation, a doctor requires to understand condition of applying a stethoscope, in addition to auscultatory sounds. The proposed system includes intuitive navigation system of stethoscope operation, in addition to conventional audio streaming system of auscultatory sounds and conventional video conferencing system for telecommunication. Mixed reality technology is applied for intuitive navigation of the stethoscope. Information, such as position, contact condition and breath, is overlaid on a view of the patient's chest. The contact condition of the stethoscope is measured by e-textile contact sensors. The breath is measured by a band type breath sensor. In a simulated tele-auscultation experiment, the stethoscope with the contact sensors and the breath sensor were evaluated. The results show that the presentation of the contact condition was not understandable enough for navigating the stethoscope handling. The time series of the breath phases was usable for the remote doctor to understand the breath condition of the patient.**

I. INTRODUCTION

In a traditional primary medical treatment, a doctor interviews, observes and auscultates a patient for screening. Primary tele-screening is expected for reducing costs of community healthcare. Tele-interview and tele-observation is enabled with conventional video conferencing systems. [1] However, the video conferencing systems are not enough for supporting tele-auscultation.

In auscultation, a doctor diagnoses a patient by listening to internal sounds of a human body, such as heartbeats, blood flows and breaths through a stethoscope. In telemedicine, all required information for diagnosis needs be digitized by input devices, transmitted through a communication line, and presented on output devices. [2] Auscultatory sounds are required to be digitized and transmitted in tele-auscultation. For example, Internet Tele-Stethoscope [3] digitizes auscultatory sounds into a PC with an electronic stethoscope. The evaluation of the Internet Tele-Sthethoscope shows that tele-auscultation with the transmitted digital sounds is reliable enough as traditional acoustic auscultation. However, the auscultatory sounds are not enough information for diagnosis.

The doctor must understand a condition of auscultation, such as position of a chest piece of the stethoscope, contact condition of the chest piece, and breath phases, to adjust the chest piece to capture noiseless auscultatory sounds. Tele-auscultation requires that a remote doctor understands position and contact condition of a stethoscope, and breath phases of a patient over information systems, in addition to realtime audio streaming of the auscultatory sounds.

The remote doctor cannot handle medical equipment, including a stethoscope, at a patient's site in telemedicine. If a clinical staff is at the patient's site, he/she can proxy the remote doctor. In the evaluation of the Internet Tele-Stethoscope, for instance, a trained nurse positioned the stethoscope under webcam-assisted audiovisual guidance. [3] However, the existence of the clinical staff decreases meaning of the primary tele-screening. Thus, a helper with non-clinical skills or a patient himself/herself need to proxy the doctors to handle the medical equipment. For smooth diagnosis, intuitive ICT support to convey doctor's will to the proxy handler is indispensable for telemedicine with medical equipment, including auscultation.

In this research, the authors develop an information support system for tele-auscultation. Mixed reality (MR) technologies are applied for intuitive remote navigation of stethoscope handling. Efficiencies of the proposed system are evaluated in a simulated tele-auscultation experiment.

II. INFORMATION SYSTEM FOR TELE-AUSCULTATION

For an information system of tele-auscultation, realtime audio streaming of the auscultatory sounds is indispensable. The auscultatory sounds are digitized through an electric stethoscope. Conventional video conferencing system is also required for communication between a patient's site and a doctor's site. The video conferencing can be used for tele-interview and tele-observation. In addition, information support for understanding the situation of auscultation is required to diagnose the auscultatory sounds correctly.

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In auscultation, a doctor must put a chest piece of a stethoscope on a suitable position for a purpose of a diagnosis. For example, the doctor diagnoses heart diseases with putting the chest piece on the body surface above a heart and thick blood vessels for listening to heartbeats, heart sounds and heart murmurs. The doctor diagnoses lung diseases by listening to rhythm and noise of expiration sounds and inspiration sounds by putting the chest piece above tracheas, bronchi and pulmonary alveoli. In tele-auscultation, a remote doctor needs to check the position of the chest piece through an information system. Realtime video streaming of the view around the patient's chest is usable.

A remote navigation system of stethoscope handling is also required for the remote doctor to navigate a proxy handler with non-clinical skills to put the chest piece correctly. The non-clinical handler has insufficient skills of stethoscope handling for effective auscultation. Vision based navigation of the chest piece is simple and intuitive for the remote doctor and the non-clinical handler to support in realtime.

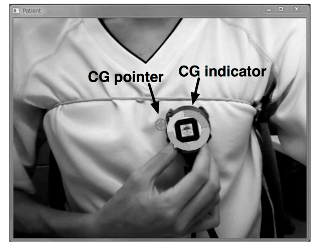
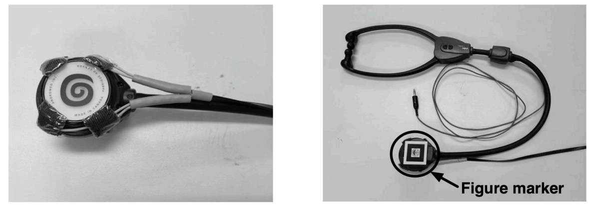


Fig. 1. The mixed reality interface of the stethoscope navigation



(a) The e-textile sensors on the chest piece

(b) The marker for the ARToolKit on the chest piece

Fig. 2. The electric stethoscope with the contact sensors and the figure marker for the ARToolKit

A. Stethoscope Navigation with MR Technology

In the proposed system, MR technology is applied to integrate a navigation interface of the chest piece handling with a monitoring interface of ongoing auscultation process. The MR technology is a particular subset of Virtual Reality related technologies that involve the merging of real and visual worlds somewhere along the "virtual continuum" which connects completely real environments to completely virtual ones. [4]

For the remote doctor, camera view around the patient's chest is enough for checking the position of the chest piece. However, intuitive navigation of the chest piece position is required for the non-clinical handler. The proposed system overlays a pointer as a computer graphics (CG) on the chest view to visualize the doctor's navigation. The remote doctor places the CG pointer on the chest view using a pointing device. The CG pointer is displayed on both monitors at the doctor's site and the patient's site.

Checking contact condition of the chest piece is also required for navigating the stethoscope handling to the non-clinical handler. The contact condition of the chest piece affects quality of the auscultatory sounds. The proxy handler must put the chest piece on the body surface with suitable and uniform pressure without gaps between the chest piece and the body surface. However, the non-clinical helper does not have enough skills for handling the chest piece to acquire fine auscultatory sounds. For navigating the contact condition of the chest piece correctly, the contact condition is required to be measured in realtime with contact sensors that are attached on the chest piece. The measured contact condition is transmitted as data stream and presented on the output device. The presentation of the sensor values is required to be simple and intuitive to understand rapidly for both the remote doctor and the non-clinical helper. Visual presentation of the measured contact pressure is effective for intuitive understanding.

In the proposed system, the contact pressure distribution of the chest piece is visualized by a ring-shape colored indicator (Fig. 1). The contact pressure values are shown as gradation of red, green and blue. The red means that the chest piece pushed strongly on the chest. The blue means that the chest piece is weakly pressed. The doctor can instruct the handler on the contact pressure of the chest piece with intuitive verbal instruction, such as "adjust the pressure balance to yellow", "a little bit weaker to turn to green", and so on.

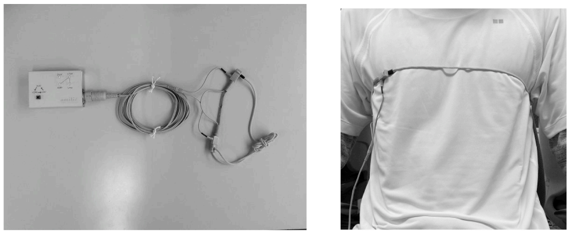
B. Chest Piece Sensing

To present the contact condition of the chest piece, a sensor device is required for measuring the pressure distribution of the contact surface. In the proposed system, an e-textile contact sensor [5] is applied.

The e-textile contact sensor is a contact sensor with a piece of e-textile, textile of conductive fiber, as an electrode of a sensor probe. The sensor measures change of capacitance between an insulated e-textile electrode and a target human body. The conductance is influenced by size of contact area between the insulated electrode and the body surface that is changed by contact pressure.

Four pieces of the e-textile sensors are attached on the edge of the contact surface of the chest piece as shown in the Fig. 2(a). The color distribution of the indicator is calculated with outputs of the four sensors.

For intuitive understanding of the contact condition, position and posture of the contact indicator must be adjusted to follow the position and the posture of the chest piece in the chest view. The posture of the indicator is especially important to understand the contact condition rapidly, intuitively and correctly. In the proposed system, the position and the posture of the chest piece is estimated in the chest view by using ARToolKit[6]. An AR marker, a figure marker for the ARToolKit, is stuck on the opposite side of the contact



(a) The sensor device (b) Mounting arrangement

Fig. 3. The band type breath sensor

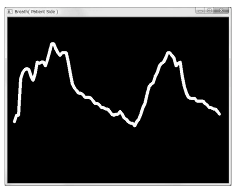


Fig. 4. A time series graph of the breath phases

surface of the chest piece as shown in Fig. 2(b).

C. Breath Phase Sensing

For respiratory auscultation, the doctor requires to follow breath phases to recognize expiration sounds and inspiration sounds separately. In traditional ”face-to-face” auscultation, the doctor can involuntary perceive the breath phases through the movement of the chest piece that he/she holds. In tele-auscultation, however, the breath phases are required to be measured in realtime by using a sensor device, to be transmitted as time series data with realtime data streaming, and to be presented to the remote doctor with an intuitive output device.

In the proposed system, a band type breath sensor, as shown in Fig. 3(a), is applied to measure the breath phases continuously. The sensor is put on the patient’s chest (Fig. 3(b)). The breath phases are measured as change of the girth of the chest.

The time series graph of the breath phases is presented in Fig. 4. The graph is overlaid on the chest view in the doctor’s site. The position of the graph needs to be adjusted not to hide the position of the chest piece in the chest view.

III. EXPERIMENT

In the experiment, the proposed methods, the presentation of the contact condition of the stethoscope and the breath phases, were evaluated by doctors with auscultation skills.

The experiment system was constructed in a conference room as shown in Fig. 5. The room was separated into a doctor’s site, as shown in upper side of the figure, and a patient’s site, as shown in lower side. The two sites were separated with a partition.

The proposed system consisted of three subsystems; the audio streaming system of the auscultatory sounds, the video conferencing system, and the MR stethoscope navigation system. In the video conferencing, audio streaming was not used, because voices of subjects could reach each other site directly.

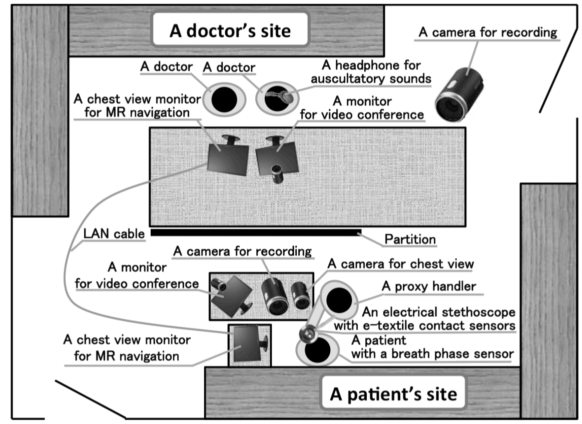


Fig. 5. Overview of a tele-auscultation simulation environment

The subjects were two doctors as remote doctors and two master course students in informatics as a proxy handler and a patient. Protocol of the experiment was as follows:

1) Set the sensor band of the breath phase sensor to the patient’s body.
2) Initialize and calibrate the e-textile contact sensors and the breath phase sensor.
3) Perform tele-auscultation process.
   - Have the remote doctors navigate the proxy handler.
   - Have the proxy handler follow the doctors’ orders to handle the electric stethoscope.
   - Have the subjects discuss effectiveness of the proposed system freely, while the two doctors diagnose the auscultatory sounds by turns.
   - The doctors can finish the tele-auscultation when they feel they perform enough auscultation.
4) Have the doctors fill out evaluation forms as shown in the first column of Table I

The performed tele-auscultation processes were recorded by two cameras in both of the doctor’s site and the patient’s site. After the experiment, discussions about the effectiveness of the proposed systems were extracted by analyzing the recorded video.

IV. RESULT

The doctors answered in the evaluation form as shown in Table I. In the discussion in the experiment, the subjects gave following comments:

- The auscultatory sounds captured by the subject with non-clinical skill were too noisy to auscultate.
- When the doctor handled the chest piece as the proxy handler on trial, the auscultatory sounds were noiseless enough for auscultation. The doctor of the proxy handler unconsciously adjusted the chest piece to capture the auscultatory sounds clearly for auscultation.
- The presentation of the contact condition of the stethoscope was not accurate enough for instruction if the contact condition was incorrect.

TABLE I

THE RESULTS OF THE EVALUATION FORM

Question	Doctor 1	Doctor 2
How fine did you understand the contact condition of the chest piece? (ten-point grading)	1 / 10	5 / 10
How fine did you understand the breath phases? (ten-point grading)	4 / 10	7 / 10
How little did you feel disturbed by mispointing of the CG marker for patient move? (ten-point grading)	8 / 10	2 / 10
Was the auscultation affected by the presentation of the contact condition of the chest piece? (choice: never affected / almost not affected / neither / weakly affected / quite affected)	almost not affected	never affected
Was the auscultation affected by the presentation of the breath phases? (choice: never affected / almost not affected / neither / weakly affected / quite affected)	little affected	neither

- The contact condition presented in the CG indicator was fluctuated by sensor errors. The condition was often changed unexpectedly when the contact sensors were not touched to the patient's body. The fluctuation amplitude of the measured pressure was sometime large to hide small change of the contact pressure in fine adjustment of the chest piece.
- The graph of the breath phases was useful for understanding the breath phases. However, the patient's chest view was enough information to understand it.
- The graph of the breath phases was often useful when it was hard to understand the breath phases from the chest view.

V. DISCUSSION

As the results, the presentation of the contact condition that was measured by e-Textile contact sensors on the edges of the chest piece of the stethoscope was not usable for the remote doctor to navigate the proxy handler and to auscultate. However, as one of the comments of the subjects, the transmitted auscultatory sounds were noiseless enough when the doctor handled the stethoscope. The navigation of the contact condition of the chest piece will be effective.

The results shows that the doctors of the subjects have not been able to understand the actual contact condition from the presented CG indicator of the measured contact pressure. The doctors had a sense of suitable contact of the chest piece. However, the doctors did not know evaluation criteria of the CG indicator whether the contact condition of the chest pieces was correct or not. The doctors could not determine a way to instruct the proxy handler to correct the contact condition of the chest piece from the CG indicator. The unexpected fluctuation of the presented contact condition would also interfere with the doctors to understand the actual contact condition.

A cause of the unexpected fluctuation of the presented contact condition is the way to attach the contact sensors on the chest piece. The e-textile contact sensor is enough accurate as evaluated in the previous research [5]. In the experiment, the stuck e-textile sensors were not well pressed, because the edge of the chest piece was not thick enough. Unconscious touch of the e-textile sensors would be also a factor of the sensing noise. The handlers unconsciously touched the sensors when they hold the chest piece.

In the presentation of the breath phase graph, the results suggest that the presentation has been usable for understanding the breath phases. However the presentation was not mainly used. As the comments of the subjects, the patient's chest view was enough information of the breath phases. The graph was supplementary used when the view was not suitable for understanding the breath phases.

VI. CONCLUSION

In this paper, the information support system for tele-auscultation is proposed. Tele-navigation support of the stethoscope operation is required in addition to audio streaming of auscultatory sounds and video conferencing. MR technology is applied in the proposed system for rapid and intuitive support of the stethoscope navigation.

The MR navigation of the proposed system is evaluated by doctors with auscultation skills. The results suggest the navigation of the contact condition of the stethoscope is required to capture suitable auscultatory sounds for diagnosis. However, the presentation of the contact condition in the proposed system was not suitable for the subjects to understand the actual contact condition. The graph of the breath phases is effective in supplementary use of the patient's chest view.

In future researches, presentation design of contact condition of a stethoscope, including a definition of evaluation criteria of correct contact condition, is required to be modified. Attachment of contact sensors on a stethoscope is also a problem to be solved. In this research, the proposed technologies for the stethoscope navigation are evaluated. However, effectiveness for tele-auscultation is not evaluated. The proposed system is required to be evaluated how the system affects tele-auscultation process. The authors plan to evaluate the proposed system in a simulated tele-auscultation experiment with communication analysis techniques.

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