KINECT-Based Auscultation Practice System

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***Abstract*— Students in medical and nursing schools have to practice auscultation. Students usually learn disease sounds, correct points and order for locating a stethoscope on a body in the practice. Humanoid simulators have been widely introduced to practice auscultation. They are effective to learn disease sounds. However, most humanoids cannot detect whether or not a stethoscope is located on a body and which part of body a stethoscope is placed on. And also, since they are too expensive, the number of them is not enough for the number of students in a class. In this paper, we propose a low-cost and high performance system for the practice of auscultation. In this system, students themselves play the role of a patient, instead of a humanoid, and stethoscope locations on the body are measured with KINECT. Also, appropriate disease sounds including normal ones can be assigned at some points on the upper body. Practicing students hear such disease sounds, synchronized with the movement of breathing, through earphones when a stethoscope is placed on the assigned points. Movements of the upper body from breathing can also be detected by KINECT. Experimental results with a prototype showed that our system could perfectly detect stethoscope locations on a body, except for a few lower points, and it could also detect respiratory changes on the front body. The results of a questionnaire for nursing students and practicing nurses showed that our proposed system was useful for them to learn auscultation.**

Keywords-simulator; auscultation; nursing; KINECT.

I. INTRODUCTION

Generally, practicing auscultation is a required subject for students in medical and nursing schools. Students usually learn disease sounds, correct points and order for locating a stethoscope on the body in the practice. We proposed a new auscultation practice system to learn auscultation techniques effectively [1]. Humanoid-type simulators [2][3][4][5] have been widely introduced into medical and nursing schools, and several reports have found that such simulators improve auscultation skills [6]. These humanoid simulators are effective to learn disease sounds; and they enable determining correct stethoscope locations by marking these points on a mannequin. However, it is impossible to detect whether or not a stethoscope is actually placed correctly on a mannequin. Moreover, correct locations vary among patients according to body size. Cardionics provides a hybrid simulator in which a student plays the role of a patient instead of a mannequin to solve such problems [7]. In this hybrid simulator, patches are attached on a body to identify correct attachment points.

In either type of simulators, students have difficulty practicing auscultation by themselves. Teachers have to support students during practice. Moreover, both types of simulators cannot indicate the learning progress for each student using scores.

In our simulator, students themselves are the practice subjects instead of a humanoid model, and the location of a stethoscope can be detected with KINECT, which is a line of motion sensing input devices made by Microsoft [8]. The correct locations are normalized with respect to the positions of both shoulder joints and both hip joints for each student playing the role of patient. Therefore, our proposed simulator can both show correct locations on a body and can detect whether or not a stethoscope is placed on correct points without patches regardless of the change in body size.

In addition, most existing simulators cannot simulate the timing of breathing or the synchronized forward and backward movements of the upper body. However, our simulator can detect these forward and backward movements of the front body and provide exhalation and inhalation sounds synchronized with those movements.

We have developed a prototype system and evaluated it experimentally. The results showed that our system could perfectly detect stethoscope placement on a body at seven of ten points. Our system could not always detect a stethoscope because three lower points were easily shadowed from KINECT by the T-shirt worn by a student acting as a patient. Also, our system could detect changes of the front body in breathing.

The aforementioned mean that students could learn auscultation practice by themselves using our system and that our system could indicate the learning progress for each student through their increases in score during the KINECT simulation.

Moreover, we found that all students could set up our system by themselves. The results of a questionnaire for nursing students and practicing nurses showed that our proposed system was useful for them to learn auscultation.

After introducing related works in Section II, we describe the concepts and features of our system in Section III. The key technologies of our simulator and the evaluation results are described in Section IV. An application for a teacher to lecture about auscultation was developed. It is introduced in Section V. The questionnaires for students who set up and used our system and for practicing nurses are shown in Section VI. The key points are summarized in Section VII.

II. Related works

Many kinds of patient simulators have been developed and provided as medical and nursing training tools [2][3][4][5][7][9]. Because we propose a new type of simulator for practicing auscultation, we first discuss existing auscultation simulators, which are divided into three groups: the humanoid model type, the virtual reality type and the hybrid type.

A. Humanoid model type

Kyoto Kagaku Co., Ltd. provides the Lung Sound Auscultation Trainer (LSAT) [2], shown in Figure 1, for respiratory auscultation. There are several small speakers inside a mannequin. Disease sounds are recorded from real patients. This simulator also works for cardiac auscultation by changing from respiratory sounds to cardiac sounds. Sakamoto Model Corporation provides the Sakamoto auscultation simulator [4]. This simulator also works for both respiratory and cardiac auscultation. Sakamoto provides a transparent cover for this simulator, as shown in Figure 2, to illustrate correct stethoscope locations.

Figure 1. Lung Sound Auscultation Trainer (LSAT) by Kyoko Kagaku

Figure 2. Transparent chest cover, by Sakamoto Model, to illustrate correct stethoscope locations

Although the above two simulators are focused on the upper body, they simulate disease sounds, not the motion of the upper body. And also, they cannot detect where a stethoscope is placed on. Each price is too expensive to buy a few of them.

On the other hand, the SimMan® 3G [4] by Laerdal is an advanced patient simulator that can simulate the characteristics of a real patient, including the blood pressure, heart beat, chest motion, and so on. It is too expensive, however, for a general nursing school to buy.

B. Virtual reality type

Zadow, et al. developed the SimMed system for medical education [9]. By using an interactive multi-touch tabletop to display a simulated patient, as shown in Figure 3, they have created an immersive environment that supports a large variety of learning scenarios. The simulated patient can show skin changes and be animated to show realistic bodily and facial movements. By its nature, the setup allows scenarios to be repeated easily and to be changed and configured dynamically.

SimMed is substantially lower in cost than a full-scale humanoid simulator. It has many functions, however, and is still too expensive for most nursing schools. Moreover, while students can touch the virtual patient on a display, they cannot physically feel the motion of the virtual patient.

Figure 3. The SimMed system

C. Hybrid type

Cardionics provides the SimScope WiFi Hybrid Simulator™ [8]. As shown in Figure 4, a specific stethoscope has a Bluetooth earphone mounted to hear disease sounds from a PC, and patches are attached on a body to decide the locations for auscultation practices. Therefore, a person who attaches patches on a body has to know the correct locations for each practice. Students have difficulty practicing auscultation by themselves.

Figure 4. SimScope WiFi™ The Hybrid Simulator$_{TM}$ by Cardionics

III. System concept

As a matter of course, the introduction cost is adequate for the number of students in a nursing school. Among the nursing skills that students have to learn are the recognition of different sounds between different kinds of diseases and the knowledge about placing correct points and order for locating a stethoscope on a body. In the case of respiratory auscultation, students have to listen to respiratory sounds for more than one cycle. Moreover, the learning progress for every student is consolidated on a cloud server. Therefore, an auscultation practice system requires the following issues:

- Low system cost.
- Simulating real disease sounds at different points on the body.
- Showing correct points for locating a stethoscope on an operation display.
- Judging whether or not a stethoscope is located on shown points.
- Judging whether or not a stethoscope is fixed on a body for more than one respiratory cycle.
- Logs that students practice are stored on a cloud server.

Our practice system comprises a cloud server, terminal equipment, and a PC for a teacher. The terminal equipment and PC for a teacher are connected to the cloud server through the Internet as shown in Figure 5. With the terminal equipment in our system, shown in Figure 6, the students themselves can act as patients instead of having mannequins act as patients—much like in Cardionics's hybrid simulator—to achieve low cost. The stethoscope locations and forward and backward movement of a body during breathing are measured with KINECT. The students can hear disease sounds generated by a PC through earphones. The sound volume for each point is different for locating a stethoscope, as with a real patient. Therefore, a specific stethoscope and patches are not needed. These also enable low system cost.

Log data for a student practicing with terminal equipment are sent to the cloud server and stored. Such stored data are managed in the cloud server. A teacher can access the cloud server and can look at a list of learning progress reports for each student.

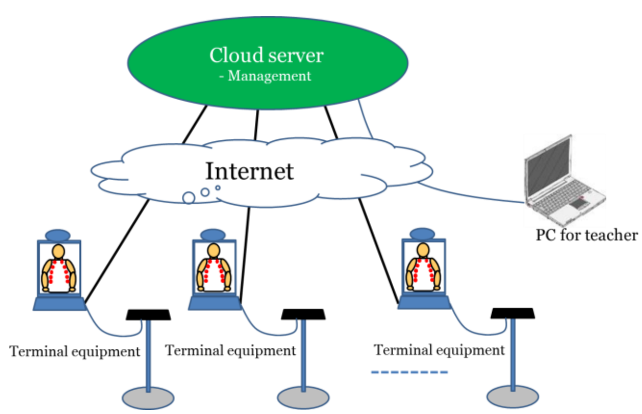


Figure 5. System configuration of our proposed system

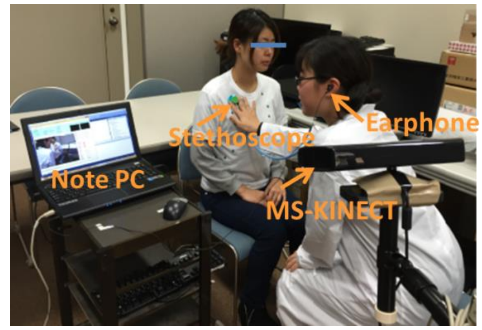


Figure 6. Terminal equipment in our proposed system

IV. Detection Technologies

The following capabilities are necessary to implement our auscultation practice tool:

- Tracing a stethoscope.
- Detecting a stethoscope's location.
- Detecting whether or not a stethoscope is placed properly on a body.
- Automatically adjusting correct points for locating a stethoscope on a body according to body size.

Also, detecting the inhalation and expiration during respiration is desired.

Because KINECT automatically generates position data for a stethoscope while it is traced, we examined each of these four issues except the second one.

A. *Tracing a stethoscope*

Three candidate tracing methods are shape tracing, color tracing and the AR marker. Since a stethoscope is held by hand, the shape of a stethoscope as viewed through a video camera changes over time. And, size of AR marker on a stethoscope would be too small to detect it with KINECT. Therefore, we chose the color tracing, rather than shape tracing or AR marker. The process of color tracing is shown schematically in Figure 7. Video data from the BGR (Blue, Green, and Red) 32 output of KINECT is converted to HSV (Hue, Saturation, and Value) color data. First, the traced object, i.e., a stethoscope, is pointed, and its hue histogram is generated and stored. Then, masking data are generated for each frame from the HSV data, the minimum saturation, and the maximum and minimum brightness.

The video data for practice is also converted to HSV data, and target areas are separated with the masking data. Noise, including the hue data of the target area, is reduced by a median filter. The output data from the median filter is then traced by the cvCamShift function of Open CV [10]. Since cvCamShift sometimes outputs incorrect data, the hue histogram for the output data is repeatedly compared with the pre-stored hue histogram. When these histograms are equivalent, the color tracing is successful.

We used an experiment to select a target color from among seven choices: "red", "green", "light blue", "yellow", "yellow-green", "pink", and "orange". We used KINECT v1 and examined whether it could detect only a target color. We show the resulting data for the top three colors in Figure 8. "Yellow-green" had the best performance, with no portions having the target color except the target. “Light blue” also performed well, but since the color of a stethoscope tube is “light blue”, that was detected. In the case of “yellow”, dots of the same color appeared in the bottom-left region of the image. The other colors exhibited more dots of the same color or had a smaller target size. Hence, we chose “yellow-green” as the target color for our experiments.

The aforementioned processing enables obtaining the x_0 and y_0 axis of a stethoscope on a video image window of KINECT. The size of the video image window and the size of the 3D window in KINECT are the same. Therefore, the length z_0 between KINECT and the location (x_0, y_0) can be obtained to assign (x_0, y_0) to the 3D window as shown in Figure 9. This means that the location (x_0, y_0, z_0) can always be obtained.

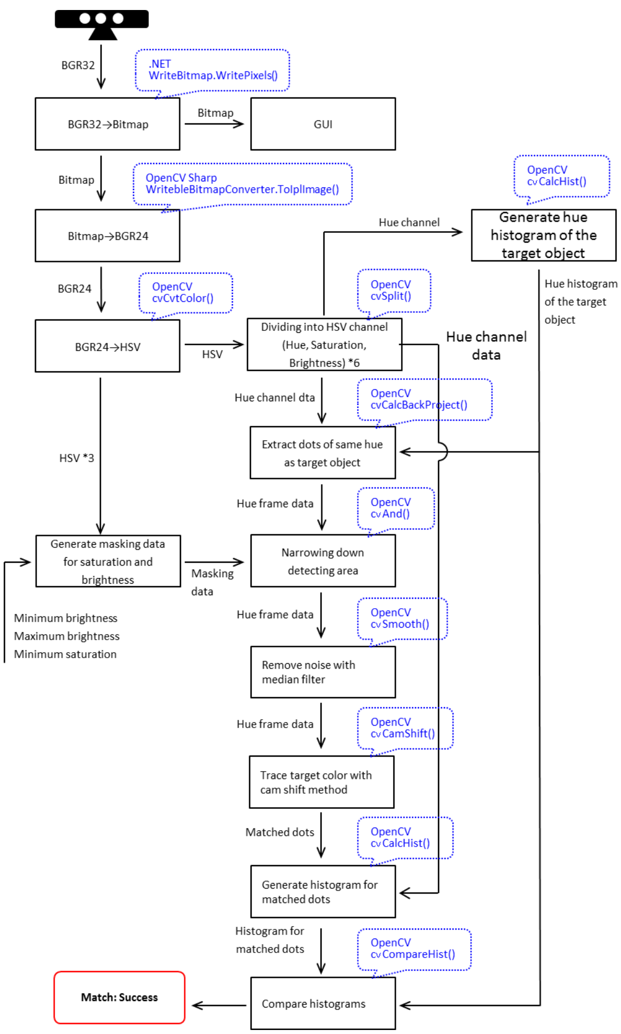


Figure 7. Process of color tracing

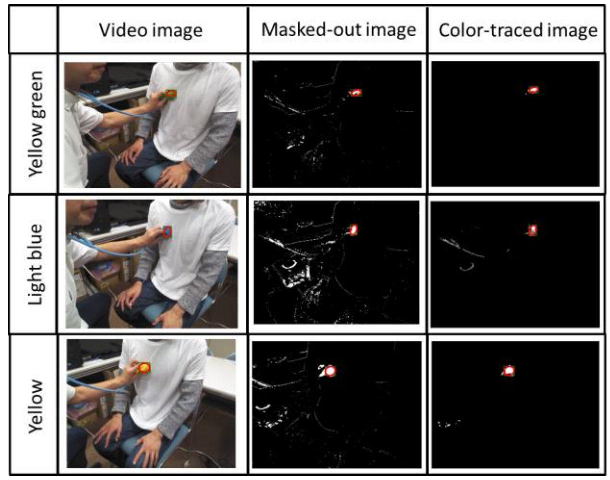


Figure 8. Experiment for deciding a target color

The KINECT camera should be tilted horizontally because the z0 is the shortest length between the flat surface of a KINECT camera and the flat surface going through the measuring point parallel to the surface of the KINECT camera. Also, we recommend the KINECT camera be positioned at about shoulder height.

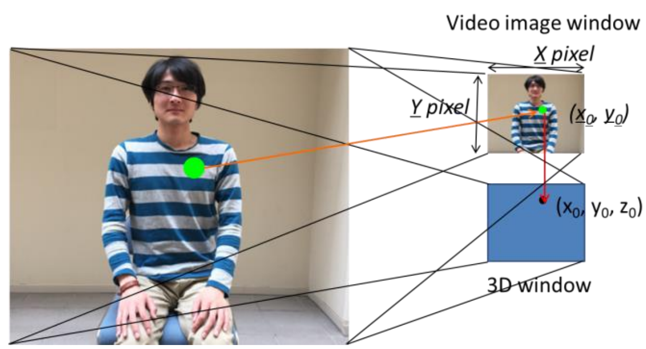


Figure 9. Relationship between video image window and 3D window in KINECT

B. *Detecting whether a stethoscope is placed on a body*

At this time, we think determining whether or not a stethoscope is placed exactly on a body is unnecessary, so we do not use any sensors on the stethoscope. Instead, we estimate the stethoscope is located on a body, where a stethoscope is placed and fixed within distance S from a body surface for T seconds, as shown in Figure 10. In this figure, L_{bs} is the length between the shoulder and a KINECT, and L_d is the threshold length to determine a stethoscope placed on the body. We used S = 10 cm, and T = 0.3 second to achieve balance between certainty and fast recognition. If stricter detection were required, we could change these parameters. Before measuring length L_{st} between a stethoscope and a KINECT, we determine whether or not the stethoscope is within the outline of a body by using a pre-installed program on a KINECT to get an outline.

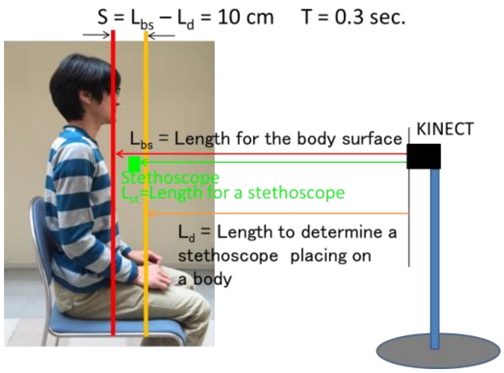


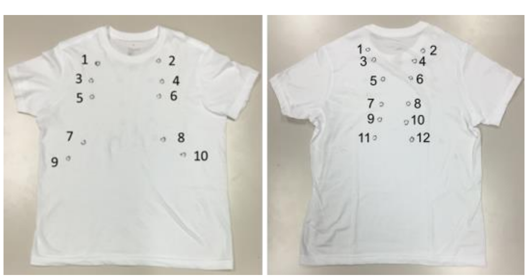
Figure 10. Scheme to estimate whether a stethoscope is placed on the body

We experimentally examined whether or not this method was useful. We started to develop a prototype system by the KINECT v1. However, as described in the next sub-section, the KINECT v1 could not detect the respiration well. Therefore, we redevelop the system by the KINECT v2. The data for the front body were measured by the KINECT v1, and the data for the back body were measure by the KINECT v2. A student acting as a patient wore a white T-shirt with dots marking correct stethoscope locations; a student acting as a nurse placed a stethoscope on these marked dots. We marked 10 dots on a front of T-shirt and 12 dots on the back as shown in Figure 11. These points are decided on the auscultation practice manual. The participants were five male students and five female students for the front body, and three male students and two female students for the back body. Since we think that there is not difference between male and female for the back body, we reduce the number of patients. The experimental results are listed in Table I.

The system sometimes missed when the stethoscope was placed at certain points (points 8, 9, 10) of the front body. As seen from Figure 6, a stethoscope placed on one of these points would sometimes be shadowed from KINECT, especially for women, because these points were below the breasts. The other hand, there are not big sagging on a T-shirt in the back body as shown in Figure 12. Therefore, the system detected a stethoscope was placed on a T-shirt perfectly for every participant.

These are possible solutions to improve detection rate for the front body:

- Switch from a T-shirt to clothing with a tighter fit.
- Attach some dimensional markers to the stethoscope.



(a) Front view (b) Back view

Figure 11. T-shirt with dots marking stethoscope locations

Figure 12. Scene of experiment for the back body

TABLE I. COUNT OF DETECTING A STETHOSCOPE PLACED ON A BODY

(1) Front body

Point #	1	2	3	4	5
Male (5)	5	5	5	5	5
Female (5)	5	5	5	5	5
Point #	7	8	9	10	11
Male (5)	5	5	5	5	3
Female (5)	5	5	4	3	2

* Measured by KINECT v1

(2) Back body

Point #	1	2	3	4	5	6
Male (3)	3	3	3	3	3	3
Female (2)	2	2	2	2	2	2
Point #	7	8	9	10	11	12
Male (3)	3	3	3	3	3	3
Female(2)	2	2	2	2	2	2

* Measured by KINECT v2

C. *Detecting the inhalation and expiration in respiration*

Burba et al. used chest motion to detect breathing [11]. They found that detecting the motion of the front body was possible, but they did not describe detecting respiration from the back body. However, practicing auscultation makes it desirable to detect the inhalation and expiration from the back body if feasible.

In our previous study, we found a KINECT v1 could detect the inhalation and expiration from the front body. However, mistakes sometimes occurred in detecting the inhalation and expiration for the front body, and the output data for some measurement points had extraordinary values.

In this section, first, we describe the difference between KINECT v1 and v2 in detecting respiration for the front body. Then, detecting respiration for the back body is described.

1) *Difference between KINECT v1 and v2 in detecting respiration for the front body*

Since there are two main types of breathing: chest respiration and abdominal respiration, we select six points for measuring movement of the chest and abdomen in this experiment, as shown in Figure 13. Since the stethoscope location is not always fixed, we do not consider it in this experiment. The upper three measuring points are the inner junctions of five vertical lines equally dividing the space between both shoulders into four regions and a horizontal line halfway between the height of the center of the spine and the average height of both shoulders. The lower three measuring points are the inner junctions of the above-mentioned vertical lines and a horizontal line through the hip center. We adopt the same direction of more than 4 points as the resultant direction.

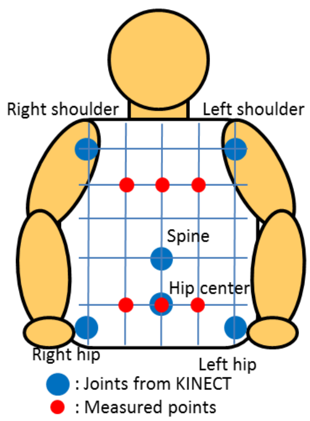


Figure 13. Measuring points for breathing motion

We designed our system to detect the changes from expiration to inhalation and vice versa as quickly as possible. Since there were small but rapid changes in the output data, we used a moving average of 30 samples, with a sampling period of 10 ms. We then have specified that when the sampling data continued to increase 3 times, the breathing mode was expiration; and when the sampling data continued to decrease 3 times, the breathing mode was inhalation.

We measured the number of inhalation and expiration in breathing and their periods with our proposed system, and compared the results with other data obtained by participants keying the up and down arrow keys on a keyboard.

The experimental results were shown in Table II. We measured them for two KINECTs that are K-1 and K-2. Both of them were the same model. At first, we measured for many participants with K-1. Our system counted more and more breaths than did keying for most participants. Data shown in Table II were some of them. In addition, the output data for some measuring points had extraordinary values, as shown in Figure 14 (2). We changed K-1 to K-2 to clear the reason of this problem. Our system with K-2 could count more accurately than that with K-1. However, our system counted fewer breaths than did keying for participant D. And, the extraordinary values were sometimes measured with K-2, too. As shown in Figure 14 (1), our system detected changes in breathing with a delay of about 1 sec. relative to keying when breathings were correctly detected. The measured delay is bigger than we expected.

TABLE II. NUMBER OF BREATHS IN KINECT V1

	Participant	Keying		Proposed system	
		Inhalation	Expiration	Inhalation	Expiration
K-1	A	12	12	16	16
	B	10	10	39	39
	C	14	14	15	15
K-2	C	11	11	11	11
	D	10	10	7	7
	E	15	15	15	15

We think this false detection is derived from the aforementioned extraordinary output data. Also, we estimate the extraordinary output would be derived from a sagging T-shirt and the depth measuring algorithm, which is the random pattern scheme [8]. The random pattern algorithm would be affected from fluctuations of sagging T-shirts as movement from breathing.

We re-programmed the proposed system to KINECT v2; its depth measuring algorithm is the time of flight (TOF) [8]. We experimentally examined the false-detection rate and detection delay for the re-programmed system. The experimental results were shown in Table III and Table IV. The participants were eight male students and four female students. They did not wear our prepared small white T-shirt, but their own clothes. One false detection occurred in about ten breaths for three participants, even though they wore a relatively loose shirt or sweater.

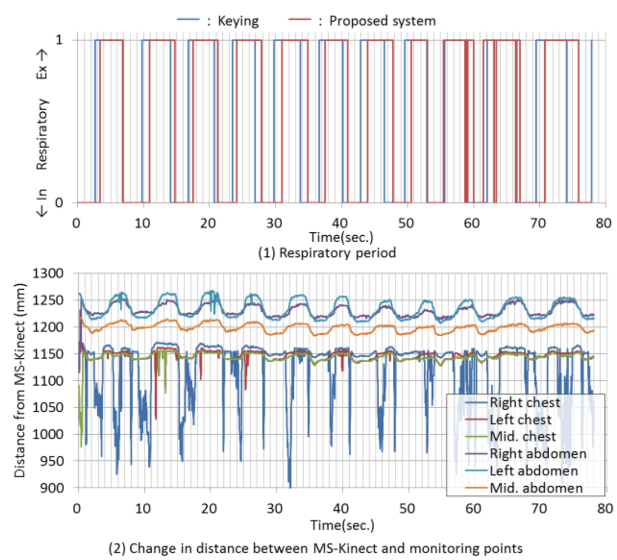


Figure 14. (1) Respiratory period, and (2) change in distance between KINECT v1 and measuring points

Table III. Number of Breaths and detection delay in KINECT v2

No.	Participants	Sex	Keying		Proposed system		Delay time (sec.)		Angle to KINECT Clothes
			Inhalation	Expiration	Inhalation	Expiration	Inhalation	Expiration	
1	A	M	9	9	9	9	0.31	0.70	-Right in front -Y-shirt
2	B	M	10	10	10	10	0.36	0.41	-Left 40° -T-shirt
3	B	M	15	15	15	15	0.26	0.43	-Left 40° -T-shirt
4	B	M	21	21	21	21	0.36	0.40	-Left 40° -Naked
5	C	F	9	9	10	10	0.17	0.37	-Left 40° -Shirt
6	D	F	10	10	10	10	0.71	0.65	-Left 40° -Shirt
7	E	F	10	10	10	10	0.62	0.95	-Left 40° -Shirt
8	F	M	10	10	10	10	0.36	0.48	-Left 40° -T-shirt
9	G	M	10	10	10	10	0.28	0.77	-Left 40° -T-shirt
10	H	M	10	10	9	9	0.80	1.21	-Left 40° -T-shirt
11	I	M	10	10	10	10	0.95	0.95	-Left 40° -T-shirt
12	J	F	10	10	9	9	1.47	0.50	-Left 40° -Sweater

TABLE IV. AVERAGE NUMBER OF BREATHS AND DETECTION DELAY IN TABLE III

		Male	Female
False-Detection	Inhalation	0.01	0.05
	Expiration	0.01	0.05
Detection delay (sec)	Inhalation	0.46	0.74
	Expiration	0.67	0.62

Table IV showed the average of the false detection rate and detection delay. We think the false detection rate was low enough for the auscultation practicing system. However, some measured detection delays were longer than 1 second. We have to improve the detection scheme for inhalation and expiration so that shorter detection delays occur and a high detection rate is possible. The other hand, since the proposed system can start to measure movement of upper body just after recognized a student playing a patient, it is possible to avoid this problem by detecting respiration cycle before a stethoscope placing on a body.

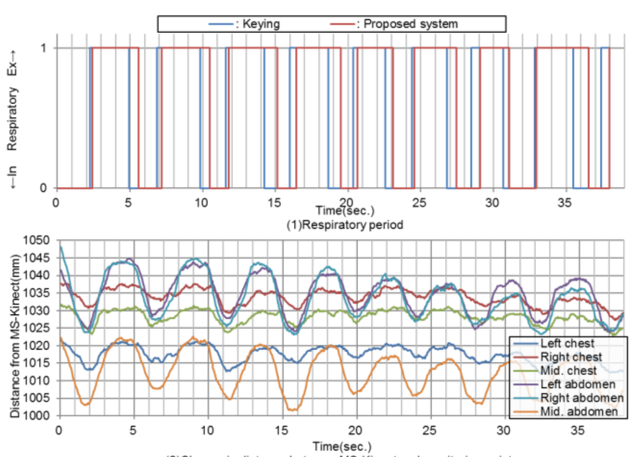


Figure 15. (1) Respiratory period, and (2) change in distance between KINECT v2 and measuring points

As for the high detection rate, KINECT v2 did not find any extraordinary values for every participant, as shown in Figure 15. Because Figure 15 (2) is an example of abdominal respiration, the measured values for every abdominal measurement point varied widely and clearly. No extraordinary values are evident in this figure.

We could not clarify the reason for the extraordinary outputs found by KINECT v1 from these experiments. However, we will develop our system using KINECT v2 in the future.

2) Detecting respiration for the back body

We tried to utilize the previously described program to detect the inhalation and expiration during respiration for the back body. We noticed that the detection results for the back body were opposite to those for the front body in pre-experiment. When a participant breathed in, our system recognized it as expiration. Also, we noticed that the motion of the back body was different from that of the front body. Hence, we measured the motions of both shoulders in addition to the previously described six points for 13 participants. Five of them were female.

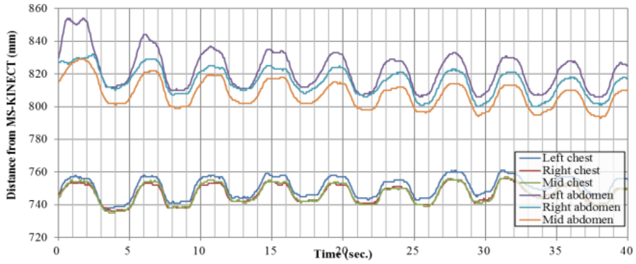
There were many participants who beyond our expectation. The measured data values for only two of the thirteen participants varied clearly and widely enough to detect the inhalation and expiration in both the chest and abdomen. Also, we could not get enough data to detect them for other participants. Most clearly changed data corresponded to the breathing shown in Figure 16, and less than optimal data are shown in Figure 17 and Figure 18.

We noted the following issues from these measured data:

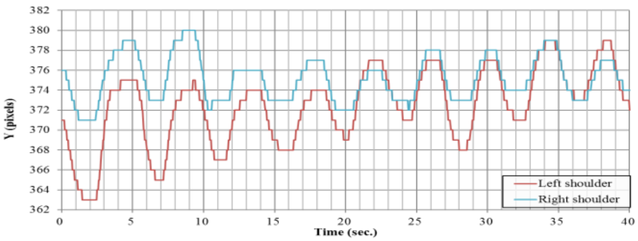
- All measured data on the back chest changed to less than the data on the abdomen.
- In the case of abdominal respiration, the shoulders almost never move up and down.

Measurement points on which data clearly changed depended on the person. For example, for both Participant A in Figure 16 and B in Figure 17, the shoulders moved up and down for chest respiration. The other hand, the shoulders of Participant C in Figure 18 did not move.

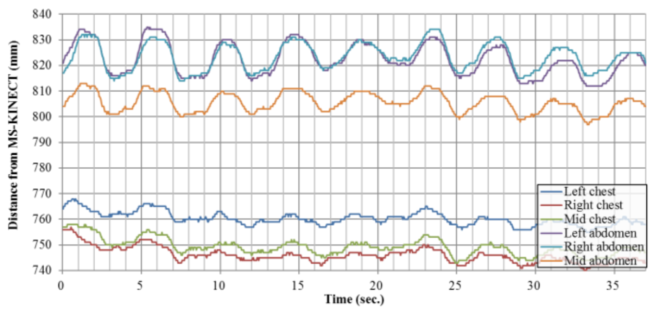
However, we do not think that this issue is serious problem. The reason we would like to detect motion of upper body derived from respiration is that we think a student playing a nurse feels unnatural when sounds of expiration or inhalation do not synchronize with movement of the upper body. When there is not any movement of a back body, there is not any synchronization between respiration sounds and motion of back body. Therefore, a student playing a nurse would not care for the replay timing of respiration sounds, when a back body did not move. In prototype system, when the system detects motion of back body, respiration sounds are replayed to synchronize with movement of a back body: when the system cannot detect them, respiration sounds are automatically replayed with respiration cycle measured for a front body.



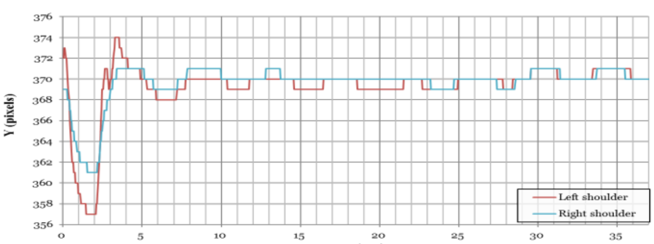
(1) Chest respiration (Back body)



(2) Chest respiration (Shoulder)

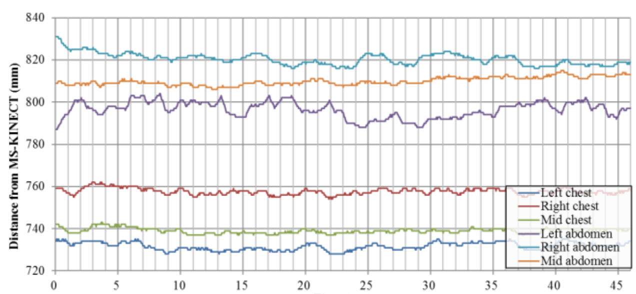


(3) Abdominal respiration (Back body)

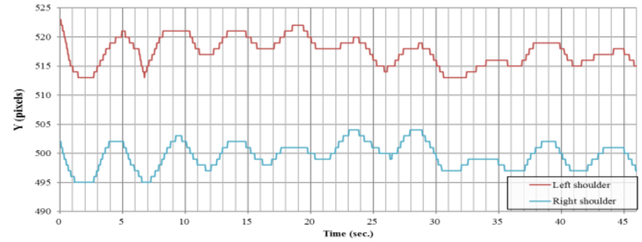


(4) Abdominal respiration (Shoulder)

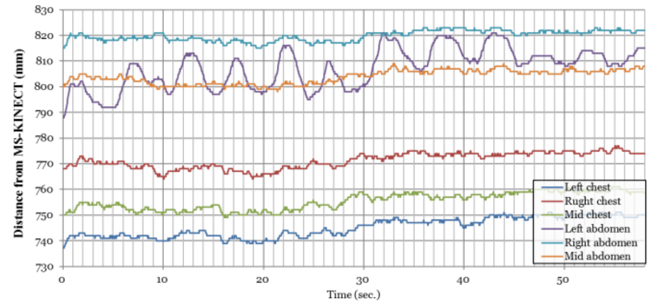
Figure 16. Example of clearly motion in the back body
Participant A, Sex: Male, Cloth: Prepared T-shirt



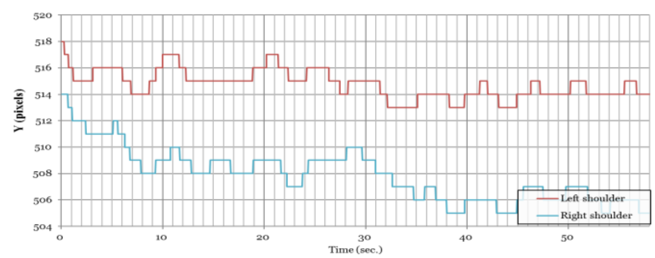
(1) Chest respiration (Back body)



(2) Chest respiration (Shoulder)

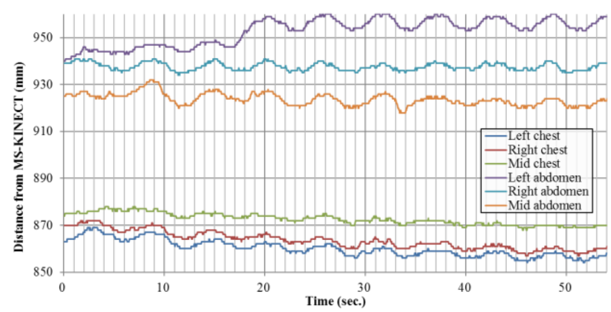


(3) Abdominal respiration (Back body)

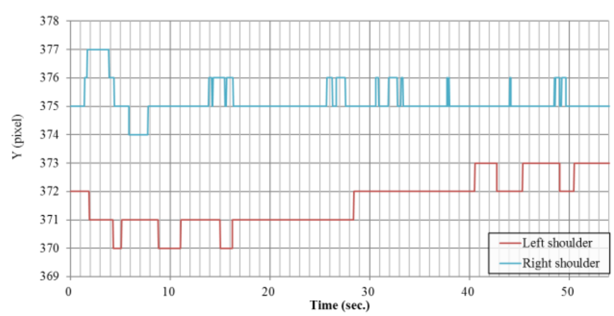


(4) Abdominal respiration (Shoulder)

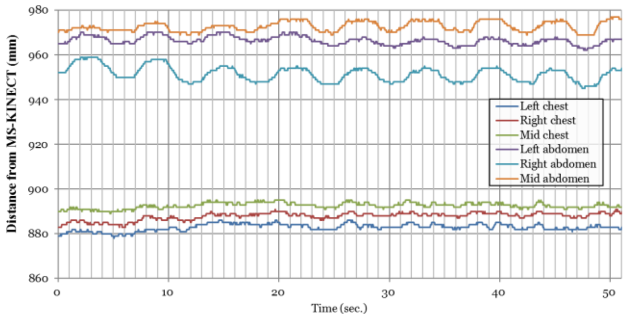
Figure 17. Example of unclearly motion in the back body (1)
Participant B, Sex: Female, Cloth: Her own loose shirt



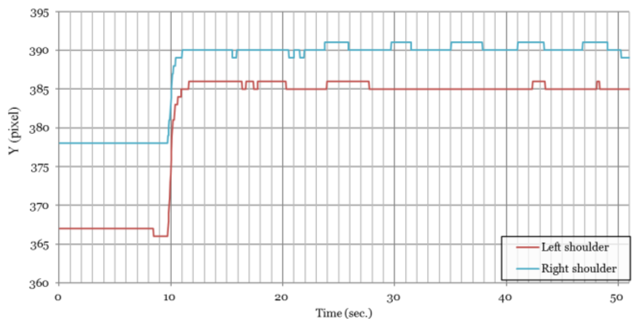
(1) Chest respiration (Back body)



(2) Chest respiration (shoulder)



(3) Abdominal respiration (Back body)



(4) Abdominal respiration (Shoulder)

Figure 18. Example of unclearly motion in the back body (2)
Participant C, Sex: Male, Cloth: Prepared T- shirt

D. *Automatically adjusting according to body size*

The correct points for placing a stethoscope depend on the size of the body; they differ a little between men and women. Also, their X and Y values vary according to the distance between a student playing a patient and a KINECT. Therefore, we estimate correct positions for placing a stethoscope with respect to the positions of both shoulder joints and both hip joints.

Two sets of correct position data and the positions of both shoulders and both hips are measured and stored as standard man and woman data. Since the origin of the output of KINECT's depth camera is at the upper left, it is difficult to compare body sizes among people. Therefore, for each person we reset the origin to the junction of a horizontal line connecting the average right and left hip heights and a vertical line passing through the midpoint between the right and left hip heights. Here, we assume that a person is sitting upright, and that the human body is a little unsymmetrical. The result of resetting the origin for each person is illustrated in Figure 19.

The estimated left-side (X_{LE}, Y_{LE}) and right-side (X_{RE}, Y_{RE}) locations are calculated with the following equations by using the above stored standard locations and the measured positions of both shoulders and both hips:

$$X_{LE} = X_{LS} * X_{mls}/X_{sls} \quad , \qquad (1)$$
$$Y_{LE} = Y_{LS} * Y_{mls}/Y_{sls} \quad , \qquad (2)$$
$$X_{RE} = - X_{RS} * X_{mrs}/X_{srs} \quad , \qquad (3)$$
$$Y_{RE} = Y_{RS} * Y_{mrs}/Y_{srs} \quad , \qquad (4)$$

where

(X_{LS}, Y_{LS}) is the left-side standard location,
(X_{sls}, Y_{sls}) is the standard left shoulder position,
(X_{srs}, Y_{srs}) is the standard right shoulder positon,
(X_{pls}, Y_{pls}) is the measured left shoulder position of the patient, and
(X_{prs}, Y_{prs}) is the measured right shoulder positon of the patient.

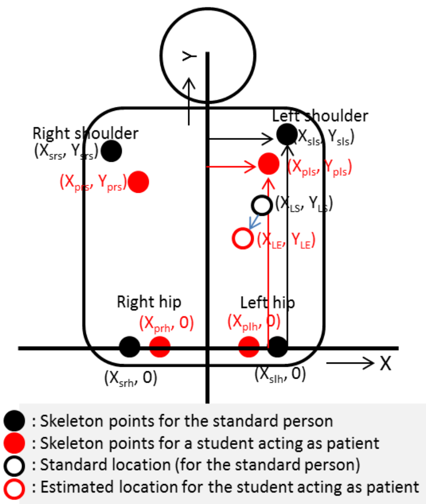


Figure 19. Illustration of adjusting locations for body size

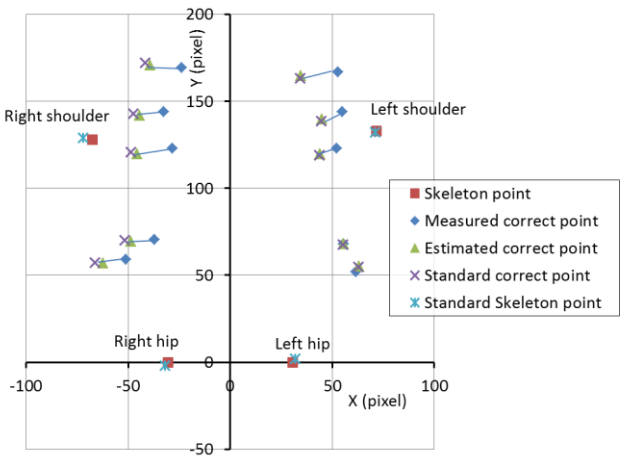
We measured the ten points marked on a T-shirt and skeleton data for three men and three women to validate the proposed automatically adjusting algorithm. Each man wore the same T-shirt like that in Figure 11.

Since the T-shirt was relatively small, it should have closely fit each person, and we predicted the marked points should have adjusted to each person correctly. After selecting one man and one woman each as the standard, we estimated correct points a stethoscope placing by using the above equations and the data for the standard person.

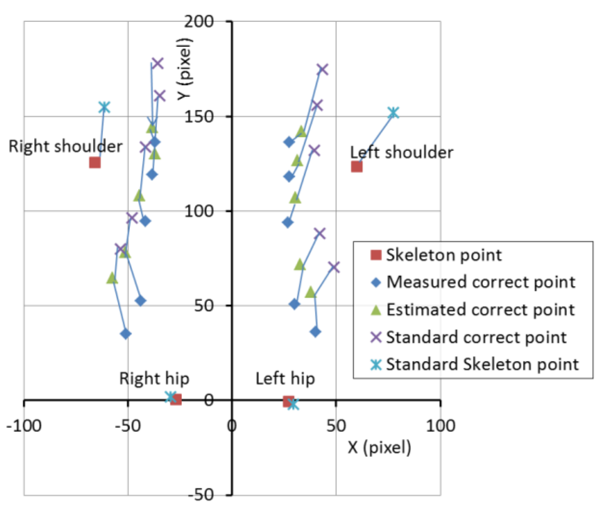
TABLE V. COMPARISON BETWEEN MEASURED AND ESTIMATED LOCATIONS

Location		Male-1		Male-2		Female-1		Female-2	
		X	Y	X	Y	X	Y	X	Y
2	measured	28	136	46	157	53	167	52	157
	estimated	33	142	42	154	35	164	36	155
4	measured	28	118	43	140	55	144	53	133
	estimated	32	127	40	137	45	140	46	131
6	measured	27	94	44	118	52	123	50	107
	estimated	31	107	39	116	44	120	45	113
8	measured	30	51	43	78	55	68	50	59
	estimated	33	72	41	77	56	68	57	64
10	measured	40	36	49	59	62	52	65	54
	estimated	38	57	48	62	63	55	65	52

Since there was not big difference between left-side data and right-side data, we showed only the left-side data in Table V. The location relationships between measured and estimated correct points for a female and male participant are shown in Figure 19. In these figures, shoulder points and correct points a stethoscope placing for a standard person, and shoulder point and estimated and measured correct points a stethoscope placing for other participants are presented.



(1) Female-1



(2) Male-1

Figure 20. Example of measured and estimated correct points

Data unit in Figure 20 was not the millimeter, but the pixel. In these figures, 10 pixels corresponded roughly to 4 cm. Differences between estimated and measured positions depend on participants and measuring points. Maximum difference was about 8 cm. In case of Figure 20 (1), shoulder and hip positions of Female-1 were the same as those of a standard participant. Therefore, estimated correct positions of Female-1 were the same as those of a standard participant. However, locations of measured points were different from location of estimated ones in Y axis. The reason for this difference must be that each person did not wear the T-shirt symmetrically in the horizontal direction. In case of Figure 20 (2), differences between estimated and measured Y values were bigger for lower points, because the T-shirt was less elastic in the vertical direction.

We think the above experiment does not appropriate to evaluate the proposed estimation scheme for adjusting locations to different body sizes after experimenting. We try to devise an appropriate scheme to evaluate this technology.

V. Application

As we described already, every necessary technology to implement a practical auscultation practice system has been achieved. Therefore, we developed a simple application for a teacher to explain practicing auscultation for the lungs.

Our co-authors in the nursing course showed the following functions:

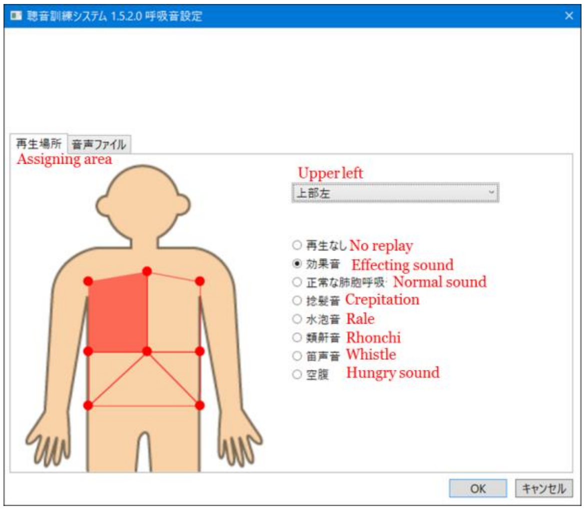
- Dividing the upper body: The lungs and the abdomen were divided, and the right and left lungs were divided up and down at the pit of the stomach level.
- Assigning sounds: An appropriate sound was assigned to each divided area for teaching content.

We developed two programs:

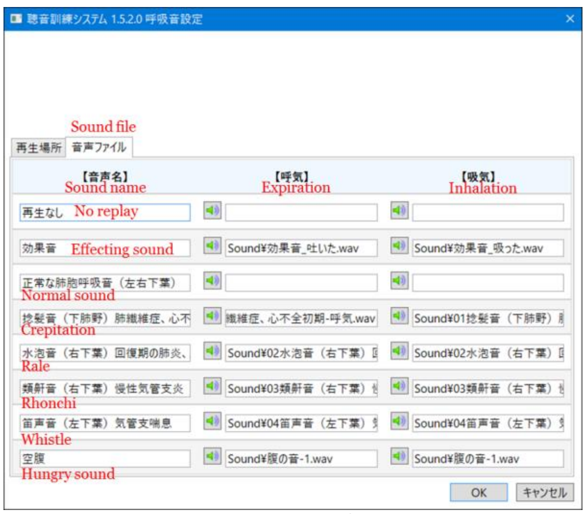
- Sound assigning program: This program assigns a sound to each area, dividing the upper body into five areas.
- Auscultation teaching program: This program detects on which area a stethoscope should be placed, and it replays a sound assigned to that area.

Figure 21 (1) shows the operation window to assign a sound file to each divided area. The front upper body was divided into five areas. The upper three points are the location on both shoulders and the bottom of the throat that was obtained from the Microsoft skeleton program. The pit of the stomach was also obtained from the Microsoft skeleton program. The abdomen is the isosceles right triangle whose top is the pit of the stomach. First, a teacher selects an area. Then, he or she selects a sound by clicking the right radio buttons according to the taught content. Disease sounds are managed using the operation window shown in Figure 21 (2). Because the disease sounds were different for the expiration and inhalation, both of them were prepared. Prepared sound files were assigned to expiration and inhalation for each disease.

Figure 22 shows an example window of the developed teaching program. When a stethoscope is placed on various areas, the area on which the stethoscope is placed changes yellow.



(1) Assigning sound



(2) Management of sounds

Figure 21. Operation window to assign a sound to divided body area

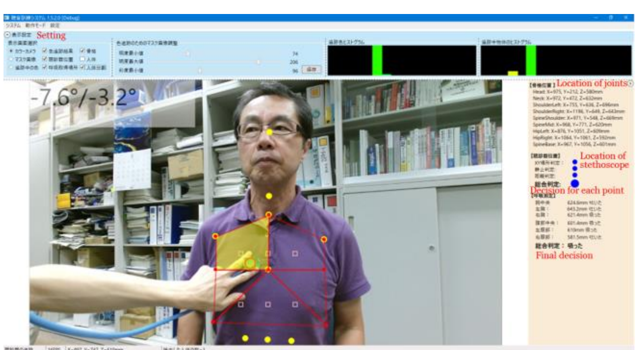


Figure 22. Operation window of the auscultation teaching program

VI. EVALUATION

We think our system is useful for not only students in medical and nursing schools but also for practicing nurses to continue their learning. Hence, we asked nursing students and practicing nurses to test whether or not our system was useful for them. Unfortunately, we did not ask medical students. For this questionnaire, we used the first prototype for which a student heard one sound when a stethoscope was placed on anyplace of the upper body, not the second prototype written in Section V.

A. *Nursing course student*

We asked six nursing students who took physical assessment including practicing auscultation. The questions asked of them and the results are as follows;

Q1: Could you set up this system by yourself?
Yes: 6, No: 0

Q2: Did you hear both a normal sound and a disease sound when you placed a stethoscope on the body?
Yes: 5, No: 1

Q3: Did you hear sounds prior to placing a stethoscope on the body?
Yes: 5, No: 1

Q4: Which simulator is more useful to practice auscultation, the existing mannequin or our system?
Equal: 2, Our system: 4, Mannequin: 0

Q5: Would you like to use this system to practice auscultation?
Yes: 6, No: 0

Their comments were as follows:

(1) Disease sounds can be learned in addition to learning communication with patients.
(2) Imagining a practical patient is easy.
(3) Learning is possible while practicing auscultation naturally.
(4) I'm very interested in this system, because it could utilize a wide range of applications.
(5) I feel the timing of the replayed sounds was a little different from that in real situations.
(6) I feel the replayed sounds were a little different from those in real life, because I could not hear the heartbeats.

On the basis of the answers for Q3 and comments for (5), we redesigned the replay timing of sounds so that they could be heard naturally.

B. *Practicing nurse*

We asked the following questions to 50 practicing nurses. Their age composition is shown in Figure 23. Most of them had several years of experience.

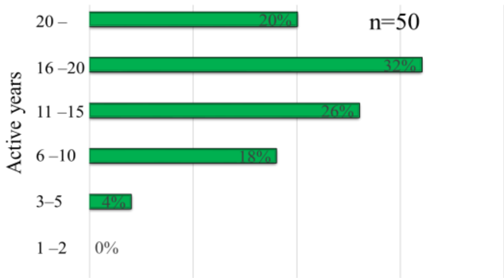
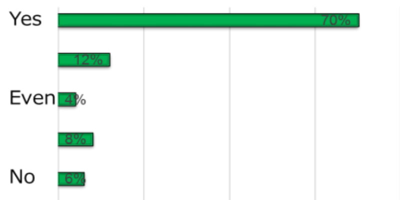
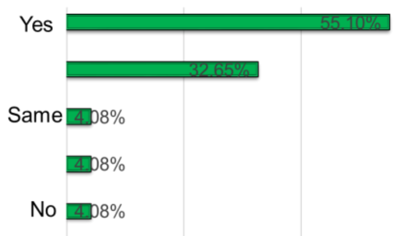


Figure 23. Age composition of questionnaires to active nurses

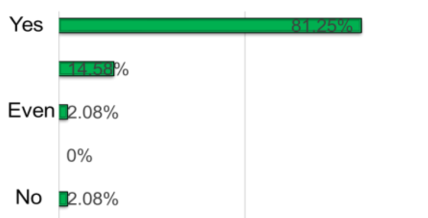
Q1: Are you interested in this system?



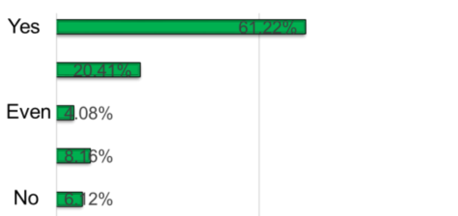
Q2: Does our system imitate real clinical situations?



Q3: Is it useful for a student to learn auscultation?



Q4: Is it useful for a practicing nurse to learn auscultation?



Most of them evaluated our system highly for both nursing students and practicing nurses to learn auscultation. Also, most of them thought our system imitates real clinical situations.

VII. CONCLUSION

We proposed a new auscultation practice system for medical and nursing students. In this system, students themselves play the role of a patient instead of a humanoid model, and the locations for stethoscope placement on the body are measured with KINECT. Therefore, this practice system has low cost. In addition, the system can judge whether or not stethoscope locations are correct. Practicing students hear disease sounds, synchronized with the movement of breathing, through earphones or a speaker.

We developed a prototype system and evaluated it experimentally. The results showed that our system could perfectly detect stethoscope placement on a body, except for three lower points, and that it could detect respiratory changes. Also, it perfectly detected the inhalation and expiration during respiration for the front body. However, the detection delay for respiratory changes was slightly larger than expected. We found that most people breathed without any movement on their back body.

We asked nursing students and practicing nurses to test whether or not our system was useful for them. The results of a questionnaire showed that our system was useful for them to learn auscultation. However, some of them felt the replay timing of sounds was a little different from that in real situations.

We think that it is possible to solve or avoid such problems; and plan to provide production service in a future.

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