Self-Help Training System for Nursing Students to Learn Patient Transfer Skills

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Abstract—This paper describes the construction and evaluation of a self-help skill training system for assisting student nurses in learning skills involving the transfer of patients from beds to wheelchairs. We have proposed a feedback method that is based on a checklist and video demonstrations. To help trainees efficiently check their performance and correct errors, the checklist was prepared with items specific to the performance of tasks related to individual body parts (e.g., the height of the waist). In this system, two Kinect RGB-D sensors were used for measuring the posture of the trainees and patients. An automatic skill evaluation method was used to designate the trainees' performance against each evaluation item as correct or incorrect. Furthermore, the system's operation interface was designed to enable self-operation by trainees. Control tests were performed to measure the training effectiveness of the system. The results of the tests on a control group (n = 5) that used only a textbook and demonstration video but did not receive feedback were compared with those of the experimental group (n = 5) that used the proposed system. The results of both subjective and objective evaluation demonstrated that the experimental group showed greater improvement in performing patient transfer than the control group $(p < 0.05)$.

Index Terms—Computer-assisted instruction, 3D/stereo scene analysis, knowledge acquisition, self-assessment

1 Introduction

Nursing care generally requires nurses to perform complex and tedious tasks frequently and on a daily basis according to the different situations and conditions of patients. Moreover, many of these are heavy physical tasks involving the lifting and moving of patients [1], which present significant risk of injury to both patients and nurses in the event of procedural errors.

According to a previous study [1], patient transfers (involving the lifting and carrying of patients) and other tasks (such as undressing and feeding patients) were performed 26 and 23 times, respectively, on average per nurse during a 4-h shift.

Patient transfer is a complex task that requires skills in many different procedures. These skills involve the application of proper body mechanics (e.g., the proper posture, position, or method of movement of the related body parts) [2], in addition to appropriate preparation of equipment (e.g., appropriate placement of the wheelchair and application of brakes). Patient transfer becomes further complicated as it involves multiple people: one or more nurses and the patient. During each procedure, nurses are required to not only apply proper body mechanics themselves but also help the patients to do so even as they intensely concentrate on latter.

Prior to commencing their hospital careers, nurses are required to complete several courses and training programs at nursing schools to acquire skills that will help them ensure patients' comfort and safety [3], [4] as well as conserve their energy, and prevent fatigue and injuries [2]. However, the present nursing education system does not impart adequate training and effective guidance to students owing to the limited course time and shortage of experienced nursing teachers [5], [6], [7]. As a result, many nurses are unable to master these skills and apply them while performing their nursing duties at hospitals, and thus suffer from occupational diseases [8], [9], particularly low back pain [10], [11], [12]. The incidence of occupational diseases among nurses, which makes many of them retire early [13], [14], is regarded among the main factors responsible for the shortage of nurses [15].

A self-help skill training system capable of automatically monitoring and assessing the performance of nursing students and providing targeted feedback (for enabling them to correct their wrong performance) is expected to significantly improve their nursing skills.

The primary focus of this study was the development of a self-help skill training system for mastering the basic task in nursing education, namely, transferring a patient from the bed to a wheelchair, involving two people: a nurse and a patient. The trainees qualified to use this system are nursing students who have already completed courses in patient transfer and are hence, unlikely to perform procedural errors leading to accidents (e.g., falling down). The system developed in this study was aimed at assisting students in

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further training after class to improve their skill performance (e.g., adjusting the height of the waist properly before helping the patient stand up).

The following is one of the most important requirements for realizing a self-help skill training system for patient transfer:

- The system should provide effective feedback for assisting nursing students in learning a complex nursing task that includes many skills in different procedures. The feedback should be specific to each procedure performed on the related body parts (e.g., posture, position, or method of movement) and should neither distract the attention of students during patient transfer nor interrupt its process.

Previous studies [16], [17], [18] have developed several training programs for improving nurses' skills in patient transfer. Additionally, they have deployed electromyography [19] and the electrogoniometer [20] for evaluating the loading on the lower backs of nurses. However, in these methods, feedback training was either not considered or was conducted manually.

Previous studies have also developed training systems to impart skills in various fields. Several researchers have utilized image-processing technology for monitoring and assessing trainee performance and constructing the training system. In a previous work [21], a real-time posture analysis system based on a depth camera was developed for determining whether a worker's posture is ergonomic or not. In another study [22], motion recognition techniques were used for the construction of a system that imparts single-person aerobic training. Virtual reality (VR) techniques and motion capture technology have been deployed in training systems for dance [23] and Tai Chi [24]. In yet another study [25], a single RGB camera was used to track the trajectory of each trainee's head and evaluate his or her skill in medical teamwork training.

Other researchers have utilized sensors attached to the bodies of trainees for monitoring their performance during the development of training systems. In the previous works utilizing inertial measurement unit sensors, the devices were designed and attached to the bodies of swimmers to monitor their strokes [26] and to trainees' upper limbs for evaluating laparoscopic surgery skills [27]. In another research [28], these sensors were deployed for developing a training system for golfers.

Other researchers have used VR, augmented reality (AR), or special mechanisms to reproduce real-world training conditions. Many studies have utilized VR technology for constructing training systems for imparting medical skills such as laparoscopic surgery [29], radiation therapy [30], tubal surgery [31], and neurosurgery [32]. Furthermore, several researchers have combined haptic systems with VR technology for precisely reproducing real-world conditions toward constructing simulation training systems for surgery skills [33] and dental procedures [34]. VR technology has also been used for developing a tennis training system [35], and in conjunction with motion capture, a system capable of displaying a virtual master for the trainee to follow was also developed [36]. AR technology has been applied for developing a training platform for workers to improve their assembly and maintenance skills [37] whereas mobile robotics has been deployed for assisting trainees in learning dance skills [38] by using a robot to reproduce the information on the position and distance of dance steps. Other previous studies based on robotics developed a robot patient for airway management training [39]. A human-scale direct motion instruction system has also been developed for motion training [40], which provided cable-driven force feedback pertaining to a specific task.

These previous systems were limited to the reproduction of the real-world conditions of tasks, measurement, assessment of trainee performance, or providing template motions and prompts for trainees to mimic, and did not focus on adequate feedback provision to indicate the errors made by trainees or help them rectify their errors.

The feedback methods that did exist in previously-developed training systems, however, did not relate to body mechanics training [32], [33], [34].

The dance training system [23] enabled trainees to follow the dancing motion of a virtual teacher on a screen during the training process and provided the following three types of feedback pertaining to the posture differences between the trainees and the teacher: 1) real-time feedback indicating errors in dance postures, 2) overall score for the accuracy of each body part, and 3) replay of trainee performance by highlighting erroneous body postures in different colors. However, for patient transfer training, the first type of feedback might distract the trainee's attention whereas the remaining two will not directly indicate the erroneously performed procedures. The trainees will be required to manually view all the procedures during the performance replay for identifying their errors. Hence, these types of feedback may not suit patient transfer training as it contains several procedures.

The aim of the research described in this paper is to develop a feedback method and construct a self-help skill training system incorporating that method for efficiently helping nursing students correct their patient-transfer performance errors. A control test was conducted to evaluate the system's performance (e.g., ease of operation, evaluation accuracy) and training effectiveness.

The self-help skill training system consists of three parts: (1) a sensor system comprising Kinect sensors and color markers (which has been proposed in our previous studies) to measure and evaluate the performance of trainees [41], [42]; (2) a feedback method to help trainees check and correct their errors; and (3) an operation interface to enable trainees to operate the system by themselves.

The system provides feedback only after the trainees complete performing all the tasks on patients. Real-time feedback aimed at alerting trainees for avoiding accidents (such as falling down) during the execution of procedures was not considered in this study as the qualified users of this system were nursing students who have already studied patient transfer techniques in class, and are not likely to perform errors leading to accidents. We developed a checklist and video demonstrations to assist trainees in identifying and correcting their errors. The checklist comprises 18 evaluation items compiled based on discussions with teachers and was designed to enable the designation

TABLE 1
Checklist for Evaluating Patient Transfer Skills

Item No.	Description
1	Place the wheelchair at the bedside and adjust the included angle such that it is within 20-30 degree.
2	Place the wheelchair near the patient.
3	Apply the wheelchair brakes.
4	Pull back your right foot while adjusting the patient's sitting position.
5	Place your left foot between the feet of the patient while adjusting the patient's sitting position.
6	Enable the patient to sit on the edge of the bed by rocking the patient's bottom.
7	Adjust the patient's shank posture.
8	Place both arms of the patient on your shoulders.
9	Clutch the lower back of the patient.
10	Pull back your right foot while assisting the patient to stand up.
11	Place your left foot between the feet of the patient while assisting the patient to stand up.
12	Lower your waist before assisting the patient to stand up.
13	Use your left foot as a pivot to assist the patient to turn away from the wheelchair.
14	Help the patient lean forward before sitting down.
15	Lower your waist while assisting the patient to sit down.
16	Grab the patient's forearm with your hand under the patient's armpit.
17	Help the patient to stoop before adjusting the sitting position.
18	Place the patient's feet on the wheelchair's footrests.

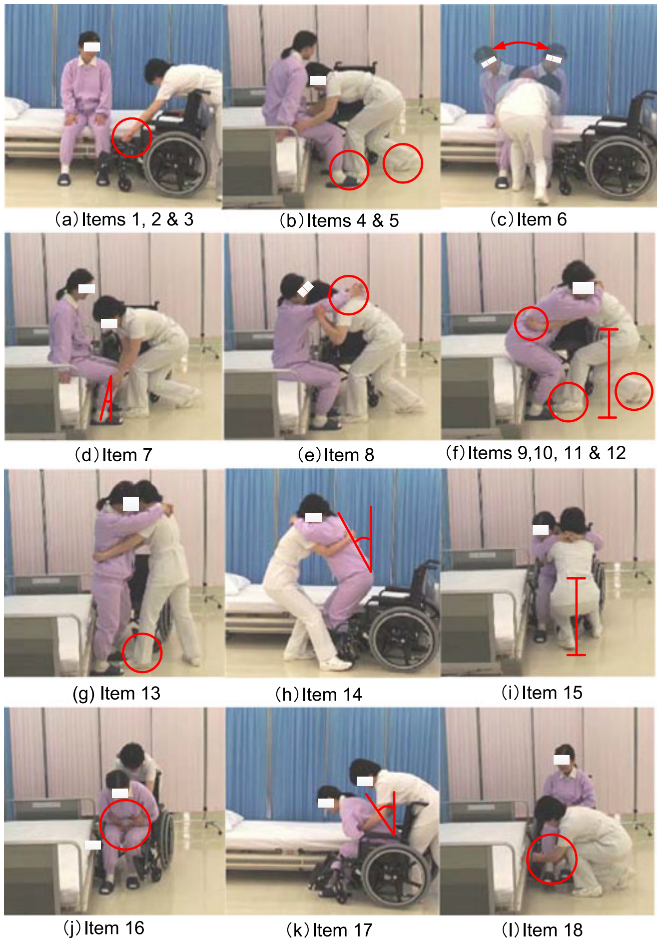

Fig. 1. Checklist items for patient transfer.

of each performed procedure as right or wrong. As each item corresponds to a unique body part (e.g., legs, waist, or hand) the checklist ensures that trainees easily understand exactly which body part's performance needs to be improved. Additionally, the items are listed in the exact order of performance of patient transfer procedures, which enables trainees to directly understand the exact procedure that was performed erroneously. Video demonstrations have already been proved to be effective tools for helping students learn nursing skills [43], [44]. Therefore, corresponding to each checklist item, we prepared a video containing the demonstration of patient transfer by a teacher to help the trainees to compare their performance and correct their errors.

Through this study, we seek to make two main contributions: First, we have pioneered a self-help skill training system that will help nursing trainees improve their skills in patient transfer, which is a complicated and inherently physical task involving at least two people. Second, we have pioneered a method to evaluate the effectiveness of the nursing-skill education imparted by the developed self-help skill training system.

This study extends the scope of our previous study [48] by providing not only new methods based on statistical analysis for evaluating the training effectiveness of the developed system and the subjective feeling of trainees, but also a new way of examining the system's evaluation accuracy and new means for discussing the relationship between training effectiveness and the proposed feedback method.

This paper is structured as follows: Section 2 details the proposed system including the design of the patient transfer checklist, structure of the system, sensor system, skill evaluation method, operation interface, and feedback method. Section 3 describes the experimental setup. Section 4 outlines the results and discusses them in detail, and Section 5 contains our conclusions.

2 System Description

2.1 Checklist for Patient Transfer

Patient transfer is one of the most intensive manual tasks performed frequently by nurses in hospitals and nursing homes [1]. It involves many procedures that require the nurse to apply proper body mechanics (e.g., position, posture, method of movement) [4] to ensure patient comfort and prevent occupational diseases such as low back pain [9], [10], [11]. Nurses also need to place the wheelchair in the appropriate position to shorten the transfer distance and apply the brakes to avoid its sliding.

To comprehensively evaluate the performance of trainees in a patient-transfer process, a checklist was designed (Table 1) based on discussions with teachers of a nursing school. Fig. 1 represents the procedures to be performed during the patient transfer process in terms of the items in the checklist. The checklist contains 18 evaluation items, each referring to a particular skill. The 18 items are listed in the order of performance of various patient transfer procedures.

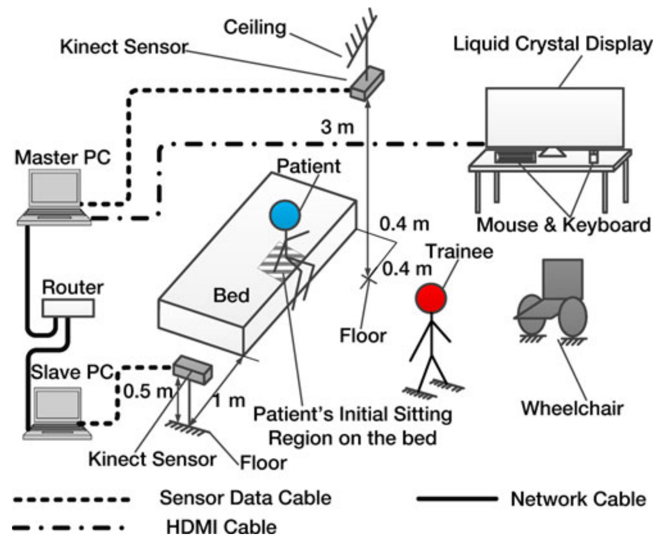

Fig. 2. Hardware of self-help skill training system.

Items 1, 2, and 3 are related to the state of the wheelchair, including its placed position, orientation, and brakes. The remaining items are related to the nurse's or the patient's body parts. The system was designed to sequentially check the accuracy of trainee performance against the checklist items. As each item is related to a unique body part, the trainees are enabled to clearly and quickly check whether they are applying the proper body mechanics and understand the exact procedure that was performed by them wrongly during the transfer process.

2.2 Hardware of Self-Help Skill Training System

Fig. 2 shows the hardware of the self-help skill training system prototype for patient transfer, which comprises a dual-Kinect sensor system, liquid crystal display, wireless mouse, and wireless keyboard.

The dual-Kinect sensor system was designed to capture information on the posture of trainees and patients, and state of the wheelchair [41], [42]. The sensor system contains two Microsoft Kinect sensors, two personal computers (PCs), and a router. One sensor was installed on the ceiling to track the position of the patient's head and measure the wheelchair's posture and the state of the brakes. The second sensor was mounted on the side of the bed to measure the postures of both the trainee and the patient. Two PCs were used in the system because the driver of the Kinect sensor allowed only one PC to be connected with one sensor. The master and slave PCs were connected to the sensors installed on the ceiling and the side of the bed, respectively. Each PC recorded the image data from the Kinect sensor connected to it and both the PCs were connected to a router (communicating via the transmission control protocol/Internet protocol (TCP/IP)) for synchronizing and transferring the image data.

The display, mouse, and keyboard constitute the operation interface for trainees to manipulate the system and view the feedback results.

The posture of the bed and its relative position from the Kinect sensors were determined as shown in Fig. 2 to prevent the sensor placement, and the position of the trainee and patient from affecting the system accuracy. After the system's hardware was set up, it was further calibrated to determine the exact position and posture of the bed on the floor. A set of points on a plane (e.g., the floor) (indicating the spatial position of the object being measured) was collected by the Kinect sensor, after which the least square method [42] was applied to calculate the parameters required for determining the plane.

Furthermore, the patient was asked to sit in a fixed region of the bed (Fig. 2) at the beginning of the patient transfer process to enable the determination of the space range in which the transfer procedures would be performed.

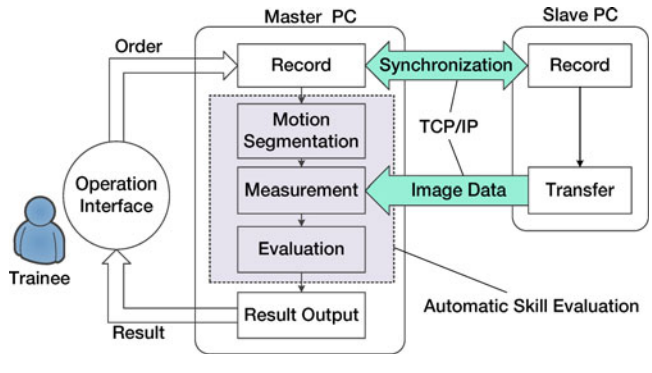

Fig. 3. Framework of self-help skill training system.

2.3 Framework of Self-Help Skill Training System

The framework of the proposed system is shown in Fig. 3. All calculations pertaining to the system were executed by the master PC. The trainees used the operation interface to send orders to the master PC for controlling the system and receiving the feedback results.

In each training sequence, a trainee first used the operation interface to order the master PC to start the process. Subsequently, the master PC commenced the recording of the image data from the ceiling Kinect sensor and simultaneously communicated with the slave PC to synchronize the system time for each PC and to start the latter's recording of the image data from the bedside Kinect sensor. At the end of the training sequence, the trainee used the interface to order the master PC to end the process.

Thereafter, both the PCs stopped recording and the automatic skill evaluation process was commenced (detailed in Section 2.4). The master PC classified the motion sequences and determined the duration of motion for each evaluation item by analyzing the sequence of images from the ceiling Kinect sensor. Subsequently, the measurement process was started, during which the master PC requested the slave PC to transfer the sequence of images from the bedside Kinect sensor for each evaluation item. Finally, the evaluation results for each item were compiled and presented to the trainee via the interface.

2.4 Automatic Skill Evaluation Method for Patient Transfer

To indicate the accuracy of performance of the trainee against each evaluation item, we used our previously developed automatic skill evaluation method [41], [42]. As described in Section 2.1, the evaluation factors and corresponding motions for each item were different. The method, therefore, evaluated skill through the following three steps:

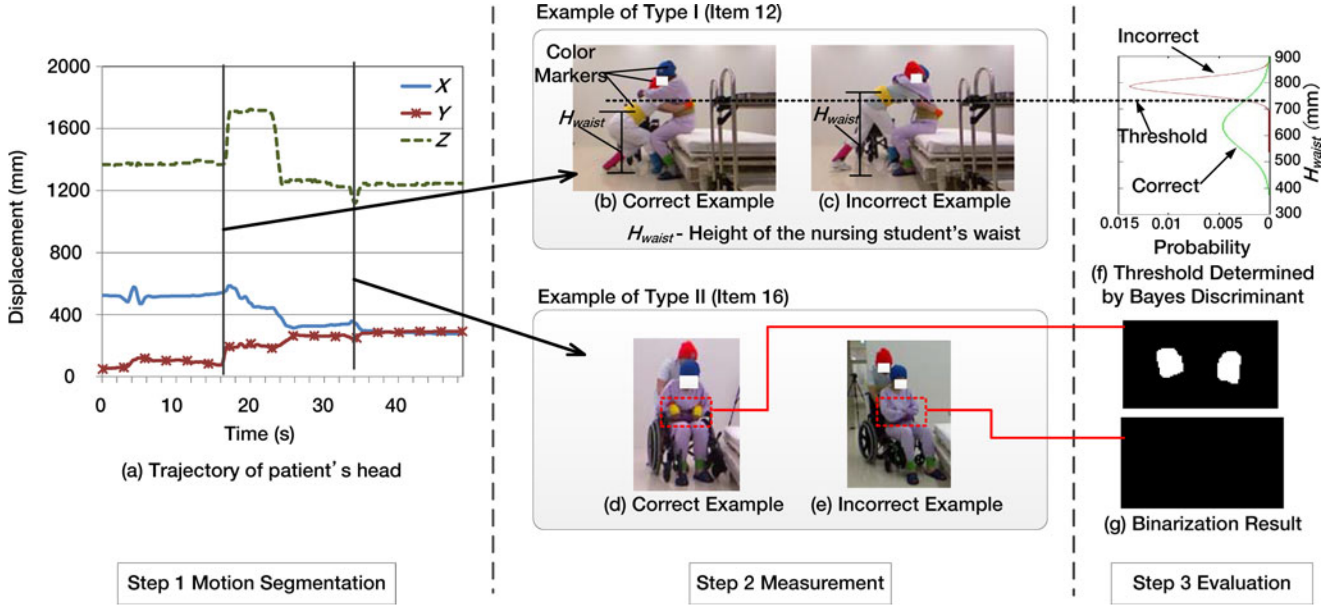

Fig. 4. Automatic skill evaluation method.

(1) motion segmentation, (2) posture measurement, and (3) evaluation (see Fig. 4).

The motion segmentation and posture measurement methods were based on the spatial positions of the body joints. Some existing algorithms provided by the Microsoft software development kit (SDK) [46] and the middleware, NiTE, from OpenNI [47] can be used for programming Kinectz sensors to track human body joints. However, it is impossible for these algorithms to separate the bodies of the trainee and the patient (who are closely interacting during the transfer) and hence, cannot facilitate the provision of specific feedback. Therefore, in our method, we attached several color markers (Fig. 4b) to the bodies of the trainee and patient to identify the positions of their body joints. First, the RGB color images were converted into three single-channel, gray-scale images involving hue, saturation, and value. Each of these images was subsequently converted into a binary image using a preset threshold. The images were then synthesized to obtain the final binary image. Next, the maximum contour of the binary image was traced and its center was regarded as the color marker's pixel position (x, y). The depth d of the color marker was extracted from the same pixel position directly from the corresponding depth image. Finally, using the projection matrix of the Kinect sensor, the location (x, y, d) was transformed into the spatial position (X, Y, Z). Additionally, a median filter was deployed to reduce noise in the body joint trajectory resulting from the noise in the depth data.

Motion segmentation (step 1) was performed by utilizing the feature points (e.g., maximum, minimum, and inflection) of the patient's head trajectories to segment the motion sequence. The feature points of the z-coordinate displacement were used for identifying the starting and ending positions of the patient standing up from the bed, turning, and sitting on the wheelchair. The feature points of the x- and y-coordinate displacements were used for identifying the starting and ending positions of adjusting the patient' posture on the bed and in the wheelchair. In this step, one image sequence was extracted for each evaluation item. The accuracy of segmentation was examined in our previous work [41] and was found to be 96.4 percent.

Posture measurement (step 2) for each item served to measure the relevant posture data such as the body joint's relative distance (items 4, 5, 8, 9, 10, 11, and 16), the relative distance to the floor (items 12, 14, and 15) or the bed (item 7), and the distance of movement (items 6, 13, and 17). The calculation of posture data was based on the spatial positions of the body joints, indicated by X, Y, and Z. Additionally, data on the wheelchair's position and posture (items 1 and 2) were measured using the preset color threshold to determine the minimum bounding rectangle of its cushion [41]. The states of brakes (item 3) were detected using the attached red markers, which became visible only when the brakes were applied [41]. The resolutions for distance and angle measurements achieved using the above methods were 1 cm and 1 degree, respectively.

The evaluation process (step 3) involved the classification of the evaluation items into two types, and performing the evaluation corresponding to each.

The first type involved the items related to the quantitative evaluation indexes. We calculated these indexes in step 2 and thereafter used the thresholds determined in our previous study [42] to designate the trainees' performance as correct or incorrect (see Figs. 4b, 4c, and 4f). The thresholds were, in turn, determined by applying the Bayesian minimum error method to the results of trainees' performance assessment made by an experienced nursing teacher.

The second type involved the items requiring the relevant body joints to be contained within a clearly defined region. We verified the accuracy of trainee performance by detecting whether the relevant body joints were visible inside the required region or not (see Figs. 4d, 4e, and 4g).

2.5 Operation Interface

The operation interface of the system is designed to enable trainees manipulate it themselves. The input devices

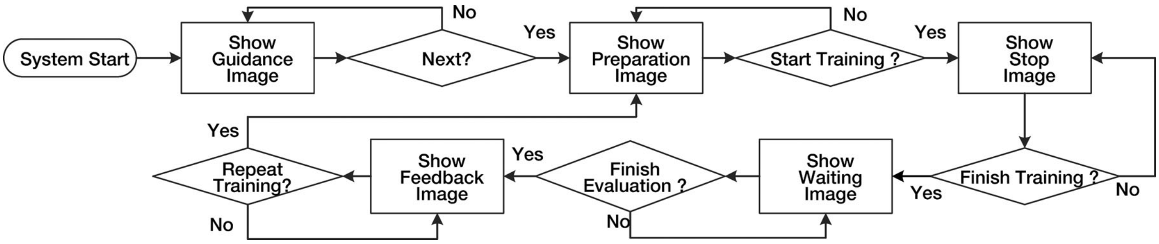

Fig. 5. Flowchart of operation interface.

comprise only a mouse and the "Esc" key. Five different images (guidance, preparation, stop, waiting, and feedback) have been used to indicate the various stages of the system. Different orders, namely, "Next," "Start," "Stop," or "Training Again," were sent by the trainees by using the mouse to click on the various buttons on the interface. Fig. 5 depicts the flowchart of the interface. When the system is started, a Guidance image is shown to describe its operation and introduce the Feedback image. When a trainee completes reading this image, he or she can proceed to click the "Next" button, which will show the Preparation image. Subsequently, when the trainee is ready to start, he or she can click the "Start" button in the Preparation image to order the system to commence the training. The system then shows the Stop image and starts recording the training process in the form of image sequences. Upon the completion of the process, the trainee can return to the screen and click the "Stop" button in the Stop image, upon which the system stops recording, displays the Waiting image, and starts evaluating the trainee's performance. It then displays the Feedback image. If another training session is required, the trainee can click the "Training Again" button on the Feedback image to commence the next training session.

2.6 Feedback Method

During the patient transfer process, nurses need to concentrate on the state of patients to ensure their comfort and prevent them from falling down. Hence, any system feedback should not distract the trainees during the process. To meet this requirement, we designed our system to provide feedback only after the trainee completed the patient transfer process. The feedback method is based on a checklist that includes 18 evaluation items (as listed in Table 1) and demonstration videos. The feedback image (Fig. 6) comprises five parts: (1) the overall result (percentage-complete) for all items to provide the trainees an overview of their performance; (2) results for each evaluation item to help trainees check whether they have performed correctly; (3) a list detailing each item; (4) buttons including (a) a "Full Demo" button to view a demonstration of the entire process, (b) "Chip" buttons to review demonstrations corresponding to each item, and (c) a "Training Again" button to commence the next training section; and (5) a window for displaying the demonstration videos.

The feedback indicates correct and incorrect performance against each item in the checklist, labeled with "OK!" and "Please Check It!" tags, respectively, along with red underlining of the description of the corresponding item.

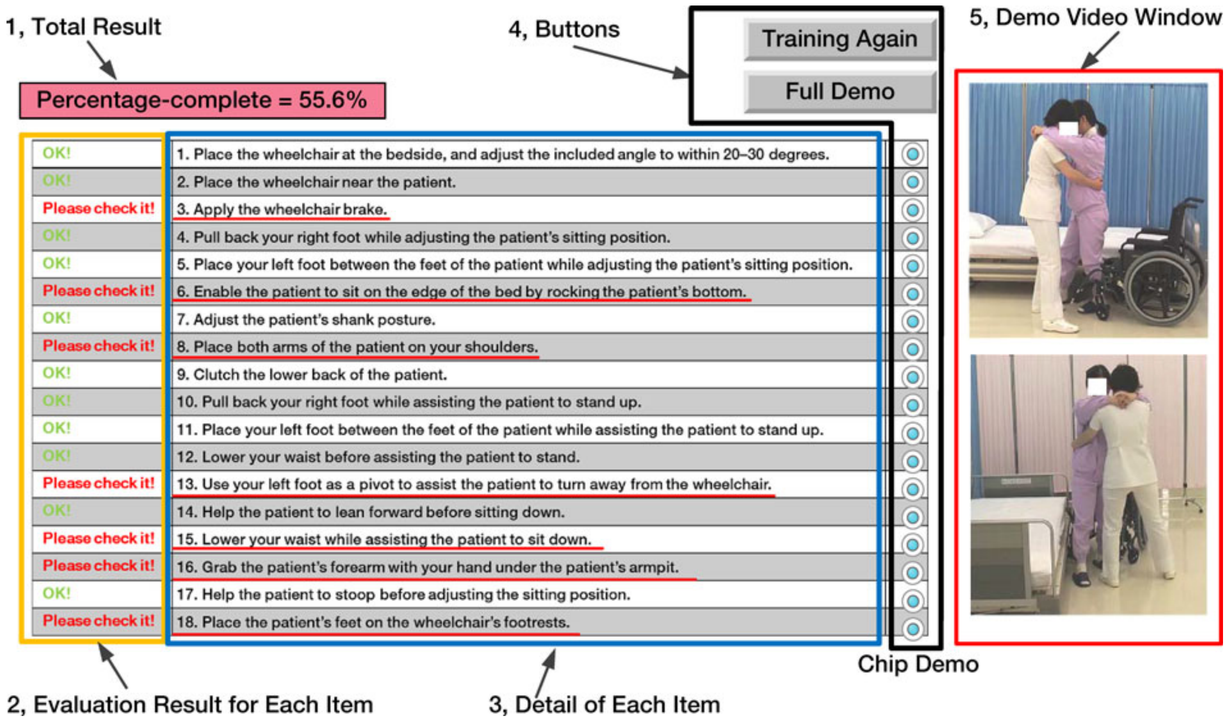

Fig. 6. Example of feedback image.

3 Experiments with Proposed System

3.1 Purpose

The control test was conducted for evaluating the following two parameters:

1) *System performance.*
   - By determining whether the system was capable of being easily operated by the trainees themselves.
   - By determining whether the evaluation accuracy achieved by the system was almost the same as that of the nursing teachers.
2) *Training effectiveness.*
   - By determining whether the system helped the trainees to improve their skills.
   - By determining whether the trainees who used the proposed system could improve their skills more effectively that did those who trained without any feedback.

3.2 Participants

Ten first-year nursing students were employed as trainees for evaluating the proposed system. Although the selected trainees had completed the course in patient transfer, they did not possess any practical experience in transferring patients or operating the proposed system. The trainees were randomly assigned to an experimental group or a control group, each comprising five students.

A healthy woman, 160 cm in height, was employed as the mock patient assumed to be unable to stand on her own but could maintain a standing posture once she had been assisted to her feet. Prior to the experiment, a nursing teacher explained the details of patient transfer to the mock patient to help her better mimic a real patient's performance.

3.3 Procedures

During nursing training, teachers are concerned about helping students learn more number of skills within the limited training time. Therefore, in our control test, we preset the length of the training time for both groups rather than presetting the number of training trials, to examine whether the students who trained using the system's feedback could learn more number of skills than could those who trained without any feedback.

The experimental environment was a training room at the Tokyo Ariake University of Medical and Health Science (TAU), which was set up to simulate a patient's room, and was occupied by only the trainees and the mock patient.

The experiment comprised four stages: (1) learning period, (2) pretest, (3) training, and (4) posttest. First, each group was given 7 min to learn the skills of patient transfer. The length of the learning period, which was determined based on the advice of teachers, was deemed adequate for the trainees to watch the demonstration videos at least twice. The videos included not only a teacher's slow demonstration of the patient transfer procedure but also a detailed interpretation of each skill. The main function of the videos was to help the trainees understand patient transfer procedures and skills. To ensure uniformity in learning conditions, the textbook and demonstration videos from TAU were used as the teaching materials. Next, each group took the pretest and recorded their initial scores. The trainees were then asked to train for patient transfer within 20 min, which was adequate for them to undergo training at least twice. Prior to the training, a nursing teacher explained the operation methods of the proposed system to the trainees in the experimental group for 2 min, which is considered as adequate time considering the simplicity of the proposed system's operation interface. The experimental group trained using the proposed system whereas the conditions for the control group were set to simulate the current situation of self-training of nurses in patient transfer. Although the control group trained without any feedback, they were allowed to use the textbook and demonstration videos freely to review their skills. By comparing the two conditions, we examined whether our proposed system was able to impart any improvement to the current method of training nurses. Finally, the students in both the groups took the posttest and recorded their final scores.

The performances of both groups of trainees in the pretest, training, and posttest stages were recorded as video data to enable the assessment of the system's evaluation accuracy as well as training effectiveness.

3.4 Evaluation Methods

3.4.1 Evaluation of System Operability

No operational assistance was provided to the trainees during the training process to verify whether they were able to successfully operate the proposed system by themselves (e.g., starting the system to evaluate their performances and reviewing the feedback results). We observed the training process by means of a video recording to check for any operation failure during the system operation. Furthermore, the trainees were asked to complete a questionnaire (Section 3.4.5) after the posttest for the purpose of understanding their subjective feeling about the proposed system's operability.

3.4.2 Evaluation of System Accuracy

An experienced nursing teacher was asked to evaluate the training-stage performance of the trainees belonging to the experimental group (using the video data) to verify whether the system could provide the evaluation results with almost the same precision as that of nursing teachers. The teacher designated the performance of each trainee as correct or incorrect against each item in Table 1. The results from the teacher were subsequently compared with those of the system. The rate of coincidence was defined as the evaluation accuracy of the system.

3.4.3 Subjective Evaluation of Training Effectiveness

The nursing teacher also evaluated the pretest and posttest results using the same checklist described in Table 1 (again using the video data). In the same way as the training-stage evaluation, the teacher designated the performance of the trainees against each checklist item as correct or incorrect.

The trainees scored one and zero point for every correct and incorrect item, respectively. The maximum possible score for a trainee was, therefore, 18 points.

We used the evaluation scores obtained from the nursing teacher to check the number of skills the trainees could learn post training, for each group. As described above, the scores for the pretest and posttest stages indicated the number of items correctly performed by trainees. Therefore, to evaluate the effectiveness of training for each group, we defined the following three parameters:

- *Growth*. This was used to measure the improvement in the skill of a trainee after training, calculated using(1):

$$Growth = S_{post} - S_{pre}, \tag{1}$$

  where S_{pre} and S_{post} are the pretest and posttest scores, respectively. The maximum achievable *Growth* is 18, which implies that the trainee wrongly performed every item in the pretest stage and performed all items correctly after training. The minimum achievable *Growth* is –18, which indicates that the trainee performed all items correctly before the training stage but wrongly after training.
- *Progress*: This was used to observe the change in a trainee's error performance after training. In particular, we calculated the number of corrections that the trainee no longer needed after training. *Progress* was calculated using (2):

$$Progress = E_{pre} - E_{both}, \tag{2}$$

  where E_{pre} and E_{both} refer to the numbers of items incorrectly performed by the trainee during pretest, and both pretest and posttest, respectively. The maximum achievable *Progress* is 18, which implies that the trainee wrongly performed every item during pretest and correctly performed all items after training. This scenario implies the same as the maximum *Growth* case. The minimum achievable *Progress* is 0, which implies that the trainee did not make any progress after training, as compared to the performance during pretest.
- *Regress:* This was used to observe the decline in a trainee's correct performance after training. In particular, we calculated the number of items performed correctly in the pretest but incorrectly in the posttest. Regress was calculated using (3):

$$Regress = C_{pre} - C_{both}, \tag{3}$$

  where C_{pre} and C_{both} are the numbers of items performed correctly by the trainee during pretest, and both the pretest and posttest, respectively. The maximum achievable *Regress* is 18, which implies that the trainee performed all items correctly before, but wrongly after training. This scenario implies the same as the minimum *Growth* case. The minimum achievable *Regress* is 0, which implies that the trainee did not make any regress.

The relationship between *Growth*, *Progress*, and *Regress* is represented by (4):

TABLE 2
Quantified Index of Evaluation Items

Index and No.	Meaning	Nos. of Related Items[a]
1. θ_{wheel}	Included angle between the side of the wheelchair and the bed.	1
2. D_{wb}	Distance between the centers of the wheelchair's cushion and bed.	2
3. D_{feet}	Distance between the trainee's left and right ankles	4, 5
4. D_{mov}	Extent of movement of the patient's head along the direction of the longer side of the bed before standing.	6
5. D_{ank}	Distance between the patient's ankle and the side of the bed.	7
6. D_{hand}	Distance between the trainee's hand and the patient's head.	9
7. D_{feet}	Distance between the trainee's left and right ankles.	10, 11
8. H_{Nwstd}	Lowest waist-height of the nurse while assisting the patient to stand up.	12
9. D_{lleg}	Extent of movement of the nurse's left foot while assisting the patient to pivot.	13
10. H_{Phead}	Height of the patient's head before he/she starts to sit down.	14
11. H_{Nwsit}	Lowest waist-height of the nurse while assisting the patient to sit.	15
12. δ_X	Distance of shift in the patient' head in the direction of the wheelchair-center-line while adjusting his/her sitting position in the wheelchair.	17

[a] *Details and numbers of items are defined in* Table 1.

$$Growth = Progress - Regress. \tag{4}$$

3.4.4 Objective Evaluation of Training Effectiveness

Objective evaluation was conducted to check whether the performance of each trainee was close to a teacher's standard performance of patient transfer.

We asked two nursing teachers to transfer a patient from the bed to a wheelchair twice each. Subsequently, we used the proposed system to record and measure their performance and compared the data with those of the trainees for objectively evaluating the skill improvement. For each of the 18 items listed in Table 1, excepting items 3, 8, 16, and 18, we defined quantified indexes (Table 2) and used the proposed system to measure the indexes for calculating the differences between the performances of the trainees and the teachers. The indexes were defined to represent the position, displacement, or posture of the body part pertaining to each item so that they effectively represented trainee performance. The definition of indexes was further based on a discussion with the teachers and the training effectiveness results obtained from our previous studies [41], [42]. For items 3, 8, 16, and 18, quantified indexes were deemed unnecessary as the

TABLE 3
Questionnaire on Subjective Judgment of Trainees

Question	Level (1/2/3/4/5)
Q1: Did you care about the color markers?	1–greatly 5–not at all
Q2: How did you feel about the system's calculation time?	1–too long 5–very short
Q3: How did you feel about the system operation?	1–too difficult 5–very easy
Q4: Were the feedback results easy to understand?	1–not at all 5–very much
Q5: Did you feel that the system was useful?	1–not at all 5–very much
Q6: Did you feel stressed while using the system?	1–not at all 5–very much
Q7: Would you want to use the system in the future?	1–not at all 5–very much

performances of such items are discrete and binary. For example, in item 3, the performance can reflect two situations only: either the wheelchair brakes were applied or not. Additionally, we defined a single index for representing the performances of items 4 and 5 as they were related to the relative position of the trainee's feet. Items 10 and 11 have the same indexes as items 4 and 5 as they refer to the same procedures in the standing and sitting positions, respectively. Thus, the total number of quantified indexes is 12.

We first calculated the mean of the teachers' performance and used it as the standard for quantifying the difference in performance between a trainee and the teachers, expressed as the *Performance difference ratio* in (7). The numerator represented the difference between the trainee's performance and the standard whereas the denominator, which is the baseline, represented the difference in the performances of the teachers (which is a result of their individual differences in performance). A smaller ratio is considered to be better because it indicates that the performance of the trainee is closer to the standard performance of the teachers. The *Performance difference ratio* was calculated using (5)-(7):

$$\overline{Vt}_{itotal} = \frac{1}{nm}\sum_{j=1}^{n}\sum_{k=1}^{m} Vt_{ijk}, \tag{5}$$

$$\overline{Vt_{ij}} = \frac{1}{m}\sum_{k=1}^{m} Vt_{ijk}, \tag{6}$$

$$Performance\ difference\ ratio = \frac{1}{N}\sum_{i=1}^{N}\frac{n\left|Vs_i - \overline{Vt}_{i\ total}\right|}{\sum_{j=1}^{n}\left|\overline{Vt_{ij}} - \overline{Vt}_{i\ total}\right|}, \tag{7}$$

where *i*, *j*, and *k* are the serial numbers of the index, teacher, and performance, respectively, and *N* is the total number of indexes. As discussed above, there were 12 defined indexes and hence, $N = 12$. The variables *n* and *m* refer to the number of teachers and the number of times each teacher performed the patient transfer, respectively. In our experiment, $n = m = 2$. Vs_i and Vt_{ijk} are the values of the *i*th index of the trainee and the *i*th index of the *j*th teacher in the *k*th performance, respectively.

TABLE 4
Confusion Matrix of Systems

		System	
		Erroneous performance	Correct performance
Teacher	Erroneous performance	True Positive 65	False Negative 33
	Correct performance	False Positive 17	True Negative 155

3.4.5 Evaluation of Subjective Feeling of Trainees

Additionally, the students in the experimental group were asked to complete a questionnaire (see Table 3) after the posttest to investigate their subjective feelings about the proposed system. The questionnaire comprised seven five-level questions. Levels 1 and 5 were regarded as the lowest and highest ratings, respectively.

4 Results and Discussion

There was no intervention made or assistance provided to the two groups during the training process. The experimental group underwent training in patient transfer 15 times (at an average of three times per trainee, a maximum of four, and minimum of two times). The control group underwent training 12 times (at an average of 2.4 times per trainee, a maximum of 5, and minimum of 0 times). Zero implies that the trainees only read the textbook and watched the video demonstrations but did not undergo practical training. The number of training sessions was zero for only one trainee in the control group.

4.1 System Operability

Trainees in the experimental group were able to successfully manipulate the proposed system by themselves. The results of the questionnaire (Section 4.4) revealed that all of them considered the system to be easy to operate.

4.2 Accuracy of Skill Evaluation Results of System

The system achieved an accuracy of 81.5 percent in skill evaluation. The experimental group underwent training for a total of 15 times and 18 evaluation items needed to be checked in each training session. Therefore, the number of evaluations made was 270. Table 4 presents the confusion matrix. In this study, the occurrences of erroneous and correct performances were considered as positive and negative, respectively.

4.3 Results of Groups' Subjective Evaluation of Training Effectiveness

To calculate the results of the trainees' subjective evaluation of training effectiveness, the averages of the pretest scores and the values for *Growth*, *Progress*, and *Regress* were calculated. The normality of the data set for each parameter was confirmed using the Shapiro-Wilk test [48], and subsequently, the one tailed t-test was conducted to measure the significant difference (*p*) in the averages (of the various parameters except *Regress*) between the two groups.

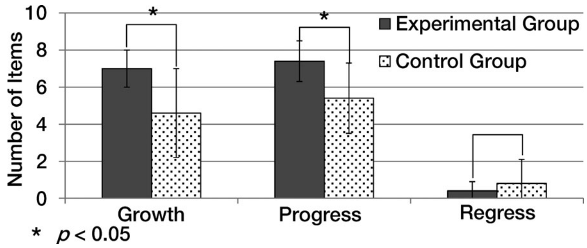

Fig. 7. Average of growth, progress, and regress for each group.

The averages of the pretest scores of the experimental and control groups were 7.8 (SD = 2.8) and 9.0 (SD = 3.7), respectively. The value of p was found to be 0.28, which shows that there was no significant difference in the score levels between the two groups before training.

The average *Growth*, *Progress*, and *Regress* for each group is shown in Fig. 7. The averages of Growth were 7.0 (SD = 1.0) and 4.6 (SD = 2.4), and the average rates of Growth were 90 and 51 percent, for the experimental and control groups, respectively. The value of p for Growth was found to be 0.037.

The averages of *Progress* were 7.4 (SD = 1.1) and 5.4 (SD = 1.9) for the experimental and control groups, respectively, and the value of p was found to be 0.042.

The averages of *Regress* were 0.4 (SD = 0.5) and 0.8 (SD = 1.3) in the experimental and control groups, respectively. Since the data set for *Regress* did not come from a normal distribution, the Mann-Whitney u-test [49] was conducted and no significant difference in *Regress* between the two groups was found ($p = 0.42$).

4.4 Results of Groups' Objective Evaluation of Training Effectiveness

A comparison of the performances of the teacher and the trainees' during pretest is summarized in Table 5. We collected the index data for both groups and calculated the average. Furthermore, we estimated the confidence interval for each index as 95 percent.

Fig. 8 depicts the average of the *Performance difference ratio* (defined in Section 3.4.4) values for each group during the pretest and posttest stages. This ratio indicates the extent of difference between the performances of the trainees and the teachers. A lower ratio is considered favorable. In this case, the significant difference was determined between the averages of the ratios during pretest and posttest separately for each group through the one tailed t-test, after confirming the normality of the data set of each parameter using the Shapiro-Wilk test.

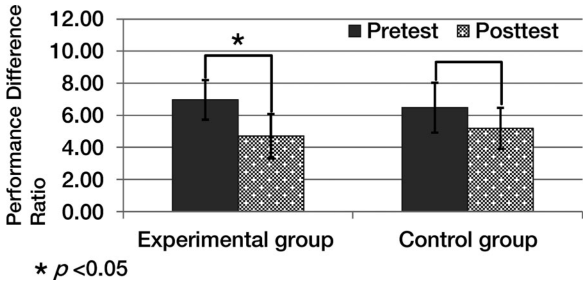

Fig. 8. Average of *Performance difference ratio* values for each group.

The average *Performance difference ratio* for the experimental group during pretest was 6.96 (SD = 1.23), which reduced to 4.70 (SD = 1.38) during posttest. The value of p between the average ratios during pretest and posttest for this group was found to be 0.019.

The average *Performance difference ratio* for the control group was 6.47 (SD = 1.55) during pretest, which reduced to 5.18 (SD = 1.28) during posttest. No significant difference was found between the averages ratios during pretest and posttest for the control group ($p = 0.084$).

TABLE 5
Comparison of Performances of Teacher and Trainees during Pretest

Index	Teacher	Trainees [a]	[95% CI] [b]
1. θ_{wheel} (°)	26.0	20.0	[8.0, 32.0]
2. D_{wb} (cm)	102.8	112.7	[108.3,117.1]
3. D_{feet} (cm)	56.2	−9.2	[−36.3, 17.9]
4. D_{mov} (cm)	14.6	9.4	[4.9, 13.9]
5. D_{ank} (cm)	12.9	9.5	[6.6, 12.4]
6. D_{hand} (cm)	52.7	50.9	[46.7, 55.1]
7. D_{feet} (cm)	57.2	0.2	[−25.3, 25.7]
8. H_{Nwstd} (cm)	67.1	70.5	[63.8, 77.2]
9. D_{lleg} (cm)	29.8	52.0	[37.9, 66.1]
10. H_{Phead} (cm)	154.0	164.9	[163.0, 166.8]
11. H_{Nwsit} (cm)	58.0	71.8	[63.9, 79.7]
12. δ_X (cm)	32.4	7.4	[3.3, 11.5]

[a] *Number of trainees in pretest: 10 (Experimental group: 5, Control group: 5).*
[b] *CI: confidence interval.*

4.5 Questionnaire Results

All trainees in the experimental group (n = 5) completed the questionnaire. The average level for each question is shown in Fig. 9. The results indicate a high average level for trainees' views on the system's operation, feedback method, and training effectiveness. Additionally, the trainees expressed their willingness to use the proposed system in their education. The results reveal almost middle average levels for trainees' feelings about the color markers and stress (2.8 and 3.6, respectively), and a low average level (2.2) for trainees' feeling about the calculation time.

4.6 Discussion

The experimental results demonstrate that the proposed self-help skill training system was (a) capable of being manipulated by the trainees themselves and (b) successful in providing feedback to help them in improving their performance. The results of Table 5 revealed that the system's measurement accuracy is enough to clearly show the difference of performance between the trainees and the teachers. The system's evaluation accuracy was examined by

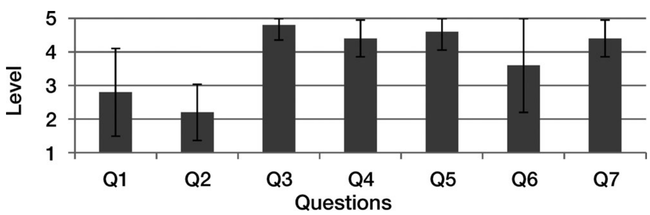

Fig. 9. Average levels of questionnaire results.

comparing its results with those of the teacher and was found to be 81.5 percent. Any error in its evaluation was mainly due to the existence of critical states, in which the student's performance is almost right or almost wrong. For items that are related to the quantified index and evaluated using the threshold, the critical states occur when the values of the indexes are close to the threshold. For items that require the placement of a relevant body joint in a desired region, the critical states occur when the joints are located around the boundary of the region. In such cases, it would be difficult for even the teachers to determine whether a trainee's performance is correct or incorrect and their answers might vary. Consequently, the system's evaluation results might be different from those of the teachers. The tracking errors caused by the noise in the depth data also affect the system accuracy. Most of the noise was effectively removed by the median filter, leaving a small amount that could have affected the measurement of the moving distance of the body joints (items 6 and 13). This noise was found to cause the calculated distance to be larger than the actual distance, allowing the possibility for error in judgment by the system. Furthermore, the placement of the sensor and the positions of trainees and patients are also likely to affect the system accuracy. However, these effects were minimal as the former issue was fixed through calibration.

With the achieved accuracy level, the training effectiveness of the proposed system was proved by comparing it with that of a control group trained without feedback. Both the subjective and objective evaluation results indicated that trainees who used the proposed system were capable of acquiring better skills and their performances are likely to be closer to the standard performance of the teachers.

The significance trend ($p < 0.1$) between the two groups for *Growth* and *Progress* was found using the two-tailed t-test whereas the one-tailed t-test (which hypothesized that the experimental group performed better than the control group) yielded a $p < 0.05$ for both *Growth* and *Progress*. As the effectiveness of feedback was confirmed in a previous work [23], we regarded the result of one-tailed t-test acceptable. Moreover, the differences in *Growth* and *Progress* between the two groups were over 34 and 27 percent, respectively. These results indicate that the trainees who used the system could acquire better skills than those who trained without any feedback. *Regress* was observed in both the groups, albeit very minimal (<1), which implies that no negative effects were caused by the training methods of both groups.

The decrease in the *Performance difference ratio* found in the objective evaluation results indicates that the trainees of both groups performed almost similarly to the teacher's standard performance. The average *Performance difference ratio* in the experimental group decreased by a much greater extent than it did in the control group. Furthermore, in both the one- and two-tailed tests, a significant difference was found between the pretest and posttest results in the experimental group, whereas it was not observed in the control group. These results reveal that the trainees who used the proposed system's feedback mechanism could correct their errors in performance more effectively than did those who trained without any feedback. Using the proposed system, the performance of a trainee could be effectively made to closely match the teachers' standard performance.

The improved training effectiveness can be attributed to assistance provided by the system's feedback mechanism to the trainees in drawing greater attention to their performance errors and correcting them by reviewing the demo videos. This is in contrast to the control group trainees' review of the textbook and demo videos without guidance, thereby easily ignoring their errors.

The overall *Regress* observed was small for both groups. In the experimental group, two trainees recorded a single *Regress* and the remaining three, none. The observation was not significantly different from that of the control group, implying that the system's adverse effect on the trainees' performance was small, although an error in judgment could have occurred, possibly because the system did not directly instruct the trainees on the method of correct performance (e.g., by indicating that the height of the waist should have been much higher or much lower) but rather only identified the performance as incorrect, leaving them to review the teacher's demo of the corresponding procedure and learn by comparison.

The results of the questionnaire revealed that the system was easy to operate by the trainees themselves, and that the feedback was both easy to understand and useful. The levels of feeling of stress and about the color markers were close to the middle level. The subjective feelings pertaining to these two questions were neutral. The average level of the subjective feeling about the system's calculation time (140 s) was 2.2 ($SD = 0.8$), which indicates that the trainees felt that the calculation time was long. Some trainees felt that the calculation time was too long because they performed patient transfer very slowly, which caused the image data set to expand and thereby increased the calculation time. The subjective feeling was also partly because the system did not provide any input to trainees during calculation and the waiting time could have caused a perception of long calculation time.

In our future work, we intend to extend the self-help training system to other areas of nursing training. Using more than two Kinect sensors will be considered for other training tasks that require the participation of more than one nursing student, (e.g., for transferring a patient from the bed to a stretcher). Furthermore, the possibility of providing (a) more detailed feedback results (e.g., using a numerical score to rate students' performance to help them more easily understand the difference between their performance and the teacher's standard performance) and (b) means for enabling the trainees to better utilize their waiting time when the system is engaged in calculating the results (e.g., by imparting some useful information to trainees through demonstration videos) will also be considered in future works.

5 Conclusion

In this study, a self-help skill training system for assisting nursing students in improving their skills in transferring a patient from the bed to a wheelchair was proposed. The system was designed for self-operation by trainees. In the system, color markers and two Kinect RGB-D sensors are used for measuring the postures of the trainee and the patient. The system can also automatically designate a trainee's performance as correct or incorrect for each evaluation item representing a particular task in the patient transfer process. From the tests conducted, the system achieved a skill evaluation accuracy of 81.5 percent on average, compared to that achieved by a teacher. The system allows nursing students to view their evaluation results via a feedback image, which includes a checklist and demonstration videos.

We demonstrated the proposed system's training effectiveness through a control test. The average *Growth* of the trainees in the experimental group (who trained using the proposed system) was 1.5 times that of those in the control group (who trained without any feedback). The value of p was smaller than 0.05. Moreover, the results demonstrated that the system was capable of helping trainees to achieve a performance level closer to a teacher's standard performance. The results of the questionnaire revealed that the trainees found the proposed system easy to operate and its feedback both easy to understand and useful.

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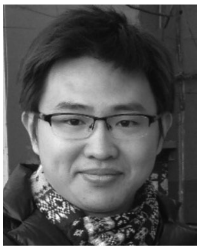

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