Development of a Measurement and Evaluation System for Bed-Making Activity for Self-training

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Abstract. This study proposes a method to automatically measure multiple objects by image processing for constructing a system for nursing trainees of self-training in the skill of bed making. In a previous study, we constructed a system to measure and evaluate trainee performance using three RGB-D (RGB color and depth) sensors. Our previous system had a problem with recognition of equipment such as the bed pad and the sheet because of color change by the light condition, the automatic color correction by the sensors and color variability in one object. In this paper, we used color reduction and cluster selection for equipment recognition. The system reduced the color in images by using k-means clustering and recognized the clusters as separate objects by predetermined thresholds. Compared with the previous method, the recognition accuracy was higher and the accuracy achieved was 70%.

Keywords: image processing, self-training support system.

1 Introduction

With the population aging, the need for well-trained nurses is increasing. It is very important for nursing trainees to learn accurate nursing skills, such as wheelchair transfer and bed making, because performing heavy tasks can cause fatigue or injury not only for patients but also for nurses [1–3]. For efficient and adequate learning, trainees need to practice the skills repeatedly with evaluation and feedback from nursing teachers to correct improper movement. However, nursing trainees are hindered from efficiently learning nursing skills because nursing teachers and instruction time are limited.

V.G. Duffy (Ed.): DHM/HCII 2013, Part I, LNCS 8025, pp. 268–275, 2013.

To overcome this problem, a number of studies have tried to construct a system of self-learning for certain nursing skills [4–8]. Itami *et al.* constructed a system that evaluated the body mechanics of trainees during bed making with angle sensors, goniometers and electromyographs attached on the trainees' body [5]. This system could measure the posture of trainees and could provide them with feedback, showing images of their posture and data from sensors. The authors found some improvement in the trainees' skills by using this system. However, this study focused only on the trainees' movements and not on the objects they manipulated, such as the bed, the sheet, etc. In addition, sensors attached on the trainee's body could hinder the natural and smooth procedure of nursing skills.

Yonetsuji *et al.* constructed a system that evaluated the skill of transferring patients from bed to wheelchair using cameras and markers on the trainee [6]. This system could measure and recognize the states of the trainee, patient and the wheelchair. Matsumura *et al.* constructed a system that measured the movement in transferring patients from bed to wheelchair [7]. This system used RGB-D (RGB color and depth) sensors for the measurement of posture. Using this system, the authors quantified the differences in operation by trainees and teachers.

From the viewpoint of self-training, the previous systems had one problem that has yet to be overcome, namely the automatic evaluation of trainee performance, which should be assessed in the same way as when human teachers do.

Therefore, we developed a system that could automatically measure and evaluate trainee performance by using image processing, focusing on the bed-making procedure [8]. The system was equipped with three RGB-D sensors to automatically recognize the trainees' movements and the state of multiple objects, such as the bed, the bed pad and the sheet. In addition, through consulting nursing teachers and a textbook [9] used in nursing university courses, we determined the criteria to evaluate the trainees' skills involved in bed making, such as body movement and the state of the bed and the sheet. Using these criteria, the system could automatically evaluate trainee performance.

However, in our previous study, a problem arose in recognizing multiple objects, i.e., the bed, the bed pad and the sheet. This low recognition led to low evaluation accuracy of trainee performance. This problem was caused by the lack of stability in color recognition from changes in light conditions and the auto correction of color by the sensors in addition to the color variability in one object. Because the previous system recognized respective objects by predetermined color thresholds for each object, the whole color change of images led to false recognition. Therefore, in this paper, we propose an image processing method to solve the recognition problem. To construct a system that is robust to color change, we used the color reduction method using k-means clustering.

2 Automatic Measurement of Bed-Making Skills

2.1 Skills for Bed Making and Evaluation Points of the Skills

The bed-making procedure was divided into the following skills (Fig. 1) [8]. 1) Place the bed pad on the top right-hand side of the bed (Fig. 1 (a)). 2) Spread the bed pad on the mattress (Fig. 1 (b)). 3) Place a sheet on the top right-hand side of the bed and spread it out in the same way as the bed pad (Fig. 1 (c)). 4) The part of the sheet hanging from the bed is then tucked under the mattress. At this point, the nurse takes the portion of sheet hanging from the corner of the bed and folds it into two triangles (Fig. 1 (d) and (e)). The top point of the triangle should lie on top of the bed, and the bottom of the triangle should extend down the side of the bed. The bottom of the triangle is tucked tightly under the mattress (Fig. 1 (f)) and the top point of the triangle is then turned under the mattress (Fig. 1 (g)). The same procedure (Fig. 1 (f) and (g)) is repeated for the parts of the sheet hanging from the other three corners of the bed. 5) Finally, the edges of the sheet hanging between the corners are tucked tightly under the mattress (Fig. 1 (h)). When working with the sheet, it is important that the nurses keep their feet wide apart and bend their knees to prevent low back pain (Fig. 1 (i)). In addition, to avoid injury from the bed frame, the nurses should keep their palms facing downward while tucking the sheet under the mattress.

To evaluate these skills, we defined eight evaluation points for each skill [8]. The evaluation points are shown in Table 1.

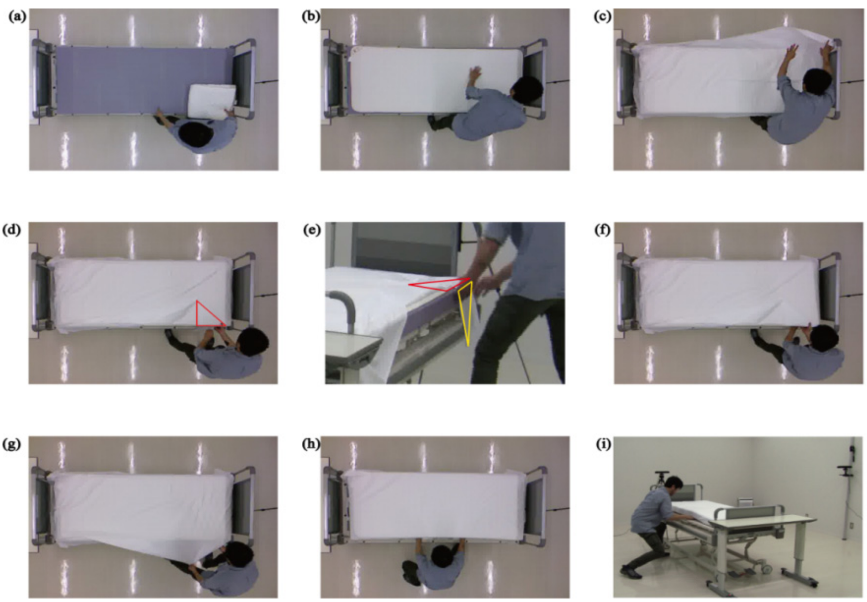

Fig. 1. Bed-making operation

Table 1. Evaluation points. The first two items are related directly to recognition of the bed, the bed pad and the sheet.

ID	Evaluation Points
1	Position of the bed pad and the sheet before spreading them
2	Spreading the sheet on the bed
3	Order of operation used on the sections of sheet hanging from the four corners of the bed
4	Manner of holding the mattress and sheet while manipulating the edge of the sheet
5	Direction of the palms while tucking the edge of the sheet edge under the mattress
6	Direction of pulling the final corner of the sheet
7	Posture while tucking the sheet edge under the mattress
8	Number of creases remaining after completion of the task

2.2 A System for Measuring Bed-Making Skills and a Method of Image Processing

To measure the evaluation points by image processing [8], we decided on measurement items corresponding to each evaluation point. The measurement items were classified into two types: the posture of the nurse and the position and state of the equipment, i.e., the bed pad, the sheet and the bed.

To recognize trainees and objects, we constructed a measurement system including three RGB-D sensors (Kinect; Microsoft) [8] (Fig. 2). A Kinect was hung vertically from the ceiling above the bed to measure the position and the state of the bed pad, sheet, bed and trainee. Two Kinects were placed horizontally to measure the trainee's posture. In addition, to measure the palm direction with the Kinects, the trainees wore two black marks on the inner side of their forearm. The marks were made by black stickers that could be detected by the Kinects.

We used three methods to measure the evaluated items: i) classification of the region of each image, corresponding to the evaluation points by using distance information and color recognition; ii) quantification of trainees' posture using skeleton information from trainees' bodies, provided by the Kinects; and iii) line detection using Hough transform for measuring the number of creases in the sheet.

To evaluate each item, it was necessary to automatically extract specific operations from the whole image. However, the order of some operations in bed making was not fixed. Therefore, we first divided the operations involved into three segments: segmentation I) putting on the bed pad, spreading the sheet; segmentation II) handling the edges of the sheet; and segmentation III) after smoothing the sheet. The order of these segments was fixed.

When the bed pad was recognized but not the sheet, the image was included in segmentation I. When the sheet was recognized and the area of the sheet was smaller than the area of the bed, the image was categorized as segmentation II. When the sheet was recognized and the area of the sheet was larger than the area of the bed, the image was classified as segmentation III.

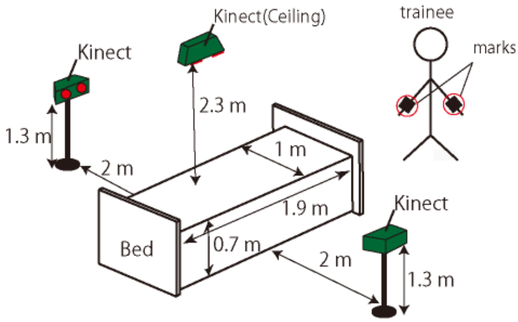

Fig. 2. The measurement system: a set of three Kinects positioned depending on the objects being measured and the range that the sensors can observe

2.3 Improvement in Equipment Recognition

In our previous study [8], we had problems with the color thresholds. These thresholds were used to recognize separately objects such as the bed, the bed pad and the sheet. In the previous study, the thresholds were set manually before the experiment. However, changes in light conditions and color correction by Kinect led to a decrease in recognition rate. In particular, the decrease in the recognition rate of the bed pad and the sheet led to the decrease in the recognition rate of the other evaluation items because the recognition of the bed pad and sheet was related to the division between the three segments. To solve this problem, we developed a new recognition method as follows.

In the first stage, by using depth information from the Kinect on the ceiling, the area of the bed was recognized, which was achieved in the following manner. First, an area within a depth of ± 30 cm of the center of the image was recognized. The center of the image was always included in the area of the bed. Then, based on the four points on the bounds of the area—the highest, lowest, rightmost and leftmost points of the bounds in the image—a rectangular area was created. Finally, 30 pixels were cut off the left, right, top and bottom sides of the rectangular area. The residual area was recognized as the bed area.

In the second stage, the number of colors used for image processing was reduced from 16,777,216 to 16 by k-means clustering. Then, the distance in color space between the color of each cluster and the colors, which was determined in advance manually for the bed pad and the sheet, was calculated. The cluster with the color distance that was nearest to the predetermined color for each object was recognized as the respective object. In addition, the next nearest cluster was also recognized as the object if the distance of the first and second nearest clusters was smaller than the predetermined thresholds. This cluster addition was continued until the distance between the neighboring clusters became larger than the threshold. In addition, to reduce calculation time, the size of each image was reduced from 640×480 to 80×60.

3 Experiment

To examine the validity of the proposed method, we applied the previous [8] and the proposed methods to images of 33 bed-making trials by five nursing students and five caregivers who had not worked as professionals for several years.

In this experiment, we investigated the recognition accuracy of the following four steps of the bed-making process: A) the trainee places the bed pad on the bed (Fig. 3(a)); B) the trainee spreads the pad (Fig. 3(b)); C) the trainee places the sheet on the bed (Fig. 3(c)); and D) the trainee spreads the sheet (Fig. 3(d)). The first and third steps correspond to the first point in Table 1. The second step is set to change the threshold from that of the bed pad to that of the sheet. With the fourth step, the system evaluates item 2 in Table 1.

(a) (b) (c) (d)

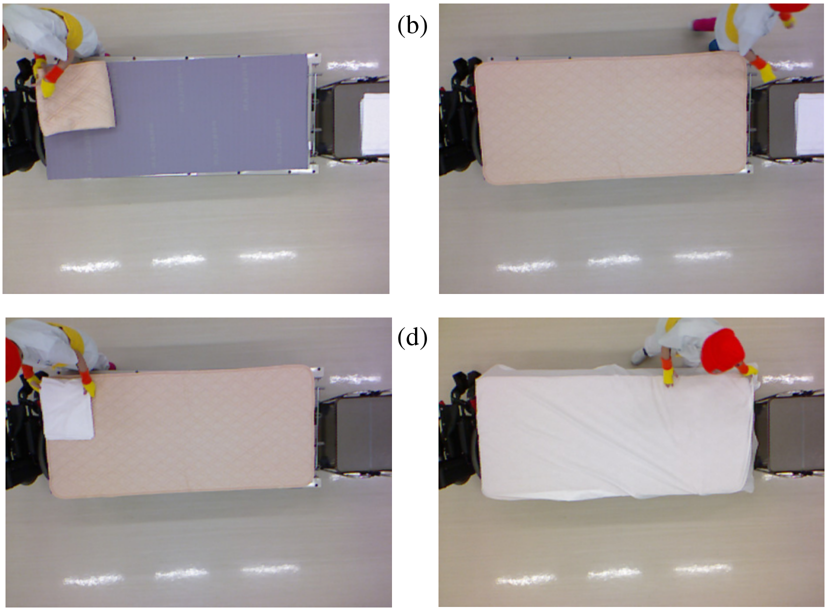

Fig. 3. The state of the bed-making process includes the following steps: (a) The trainee places the bed pad on the bed. (b) The trainee spreads the bed pad. (c) The trainee places the sheet on the bed. (d) The trainee spreads the sheet.

4 Results and Discussion

Figure 4 shows the recognition accuracy of the four steps related to the recognition of the bed, the bed pad and the sheet when using the previous method [8] and the proposed method. For all four steps, the recognition accuracy improved with the proposed method. In particular, the percentage of recognition accuracy of steps 4, spreading the sheet, improved to 78% (from 10% with the previous method) with the proposed method.

This result shows that the proposed method was robust enough to color changes by light conditions and correction by the sensors and to color variability in the area of the equipment.

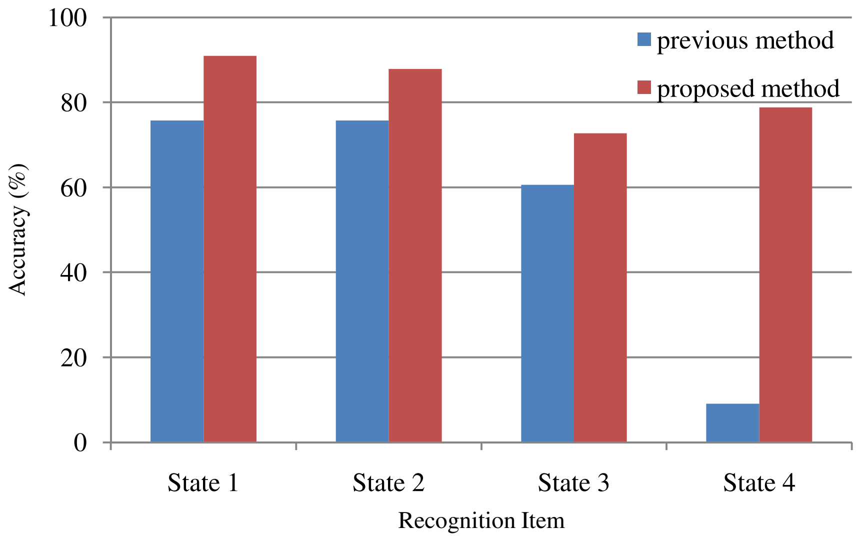

Fig. 4. The percentage of accurate recognition for each step in Fig. 3

5 Conclusion

The purpose of this study was to improve the self-training system of bed making for trainees [8]. In particular, the recognition accuracy of the equipment, namely the bed, the bed pad and the sheet was focused on image processing. To overcome color changes by the light conditions and correction by the sensors and color variability within the same object, we proposed a method to subtract the color by the k-means clustering method and to recognize the clusters as each of the objects by predetermined thresholds. The results show that the recognition accuracy of the proposed method was overall higher than the previous method with an accuracy of over 70%.

Acknowledgment. This work was supported by MEXT/JSPS KAKENHI (23593194, 24300079).

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