International Journal of Innovative Computing, Information and Control
Volume **15**, Number **6**, December **2019**

ICIC International ©2019 ISSN 1349-4198
pp. 2109–2118

TRIAL DEVELOPMENT OF NURSING CARE ROBOT MOVING BY INTUITIVE HAND MOTION

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Received April 2019; revised August 2019

Abstract. *In Japan, the aging problem is increasingly becoming serious, and it seems that we cannot avoid this problem for the future society. The quality of life of an aging person who needs nursing care must be increased, and this is an important problem in the fields of medical care and welfare. Thus, the need for nursing care increases year by year, and a nursing care robot is one solution to these needs. Here, we develop a controllable, movable and low cost nursing care robot by only operator's hand motion and perform an evaluation to verify its effectiveness. The results of this evaluation showed that the participants felt that they cannot operate the robot the way they wanted at first; however, they gradually got used to its operation and were able to eventually operate it the way they wanted. Our developed system was evaluated to have an above-average score; however, as regards the robot's arm, some participants felt that it was hard to control it using the developed controller. As for the tank-like robot, five out of six participants felt that they could not operate the tank robot the way they want. Thus, we need to improve the usability on the basis of the experiment results.*
Keywords: Nursing care robot, Robot arm, Controller, Usability

1. **Introduction.** The aging problem in Japan is increasingly becoming serious, and it seems that we cannot avoid this problem for the future society. As of September 15, 2017, a total of 35,140,000 people from the Japanese population were elderly people, aged 65 or above. This number accounts for 27.7% of the total population. The old-age dependency ratio is obtained by dividing the population of aged over 65 by the working-age population (aged 15-64). The old-age dependency ratio increased from 45.2% in 2016 to 46.3% in 2017 [1]. According to the National Institute of Population and Social Security Research, the elderly dependency ratio will be 78.4% in 2060 [2].

The quality of life of an aging person who requires nursing care must be increased, and this is an important problem in the fields of medical care and welfare. Thus, the need for nursing care increases year by year, and a nursing care robot is one solution to these needs. Many care workers handle the nursing job; however, the number of aging people is increasing year after year, while the total population of Japan is decreasing. Thus, the lack of care worker personnel constitutes a serious problem, which needs to be solved as soon as possible [3]. Single-person households are also on the rise in Japan. Living alone is no longer a phenomenon peculiar to young people. The number of elderly people living

DOI: 10.24507/ijicic.15.06.2109

alone after losing their spouses or unmarried senior males living on their own is rapidly growing [4].

Thus, in the future, many aging people will need to take care of themselves. However, this is quite hard for them; hence, having a robot to take personal care of them is helpful. In this study, we develop a nursing care robot to help solve this problem. For aging people, especially those who have weak legs or are bedridden, walking to objects that they want to bring and walking back with these objects is quite hard work. Hence, a nursing care robot should be developed and effectively used in order to reduce their burden. They should be able to quite easily control this robot to bring them anything without them moving, which can be helpful for them. A previous study presented a type of single-body multifunctional personal care robot and a motion control method for the robot to navigate the indoor environment and manipulate intended objects [5]. Besides this study, there is a lot of study about developing nursing care robot; however, we think the way of controlling the robot should be considered and, in general, it is desirable for the user to operate easily. Thus, we also developed an interface to operate this nursing robot easily and intuitively. In general, various interfaces can be used to move robots (e.g., joysticks [6], mouses [7], or biosignals [8]). However, here, we developed a glove-like controller that detects the arm's motion, because the intuitive operation is essential for older people and complex operation is demotivating for using the robot. Considering the above-mentioned points, we here describe the development of a nursing care robot, evaluate it, and verify its effectiveness. This robot consists of parts made by a 3D printer and a few Arduino and Raspberry Pi components, as well as various sensors, and is characterized by its low cost and lightweight. The remainder of this paper is organized as follows. Section 2 comprehensively explains the development of the nursing care robot. Section 3 describes the evaluation experiment of this developed nursing care robot and describes the results. Section 4 discusses the experimental results. Section 5 summarizes the main findings of this research, with a brief consideration for future studies.

2. **Development of Nursing Care Robot and Its Component.** Our nursing care robot consists of two parts: a robot arm, which does not move, and a tank-like robot. In order to move the robot arm, the arm is mounted on the tank-like robot. Both the robot arm and the tank-like robot are intuitively controllable. Figure 1 shows the system dialog of the developed nursing care robot.

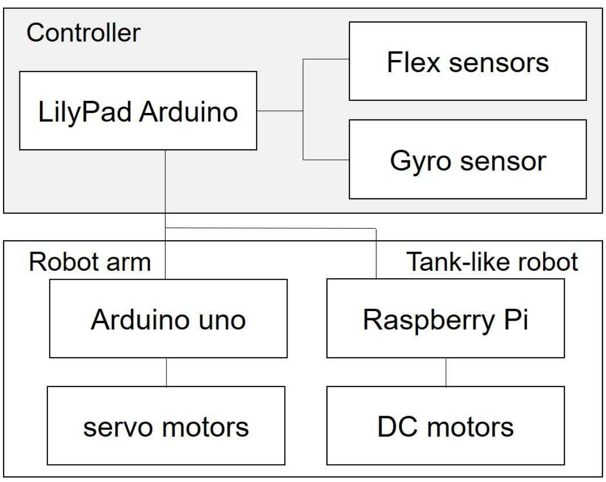

Figure 1. The system dialog of developed nursing care robot

2.1. **Development of the robot arm.** The robot arm was created using a 3D printer (Zortrax M200; Zortrax, Olsztyn, Poland) and comprises several parts. Each part was designed and printed using a 3D printer separately. These parts were then assembled to make the robot arm, which was then mounted with five servo motors so that it can be rotated and stretched. Arduino uno is mounted in this robot arm. Arduino uno received the signal from the controller (explained in 2.3) and controlled the movement of servo motor. We calculated the safety ratio of the robot arm to verify whether the arm has sufficient strength.

Figure 2 shows a simple model where the tip hand of the robot arm is lifting an object. We considered the movement of the robot arm to follow a three-degree-of-freedom system. In Figure 2, each suffix in T_1, T_2 and T_3 denotes the torque of each joint (unit: kgf·cm); M_1 and M_2 are the masses of the servo motors mounted at each joint (unit: kg); l_1, l_2 and l_3 denote the length of each arm between the joints; m_1, m_2 and m_3 are the mass of each joint (unit: kg); and F denotes the force in the y-axis direction when the hand of the robot arm is lifting an object; θ_1, θ_2 and θ_3 are the angles of O and joint A, joint A and B, joint B and arm from x-axis, respectively.

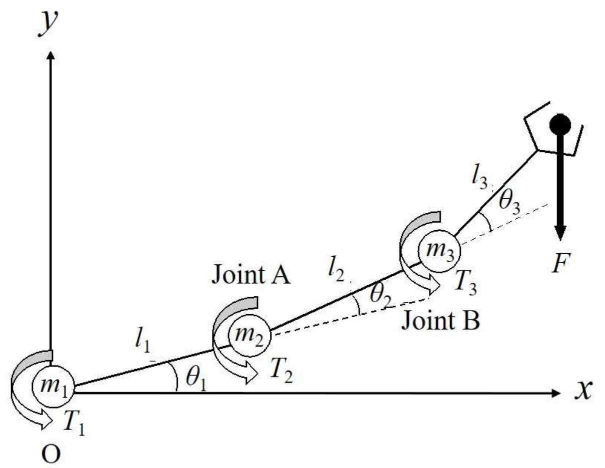

FIGURE 2. Simple model when the tip of the hand of the robot arm lifts an object

T_1, T_2 and T_3 are expressed as follows:

$$T_1 = \frac{1}{2}(2M_1 + m_1)gl_1 \cos\theta_1 + T_2, \tag{1}$$

$$T_2 = \frac{1}{2}(2M_2 + m_2)gl_2 \cos(\theta_1 + \theta_2) + T_3, \tag{2}$$

$$T_3 = \frac{1}{2}(2F + m_3 g)l_3 \cos(\theta_1 + \theta_2 + \theta_3). \tag{3}$$

In addition, the formulae of safety ratio of the robot arm are expressed as follows:

$$f_1 = \frac{Tq(M_1)}{T_1}, \tag{4}$$

$$f_2 = \frac{Tq(M_1)}{T_2}, \tag{5}$$

$$f_3 = \frac{Tq(M_2)}{T_3}. \tag{6}$$

where, $Tq(M_1)$, $Tq(M_2)$ and $Tq(M_3)$ denote the torque of each servo motor.

Table 1. Specifications of the servo motors

	Mass [kg]	Maximum torque [kgf·cm]
Motor at joint A	3.0	4.5×10^{-2}
Motor at joint B	2.5	9.0×10^{-3}

Table 2. Length of each part of the robot arm (unit: m)

l_1	l_2	l_3
4.70×10^{-3}	6.45×10^{-3}	15.0×10^{-2}

Table 3. Mass of each part of the robot arm (unit: kg)

m_1	m_2	m_3
4.70×10^{-2}	1.70×10^{-2}	5.4×10^{-2}

Next, we calculated the maximum torque of the robot arm. We assumed that the hand of the robot arm is not lifting anything; thus, $F = 0$, and $\theta_1 = \theta_2 = \theta_3 = 0$ when the torque of the robot arm is maximum. Tables 1-3 present the robot's specifications. Table 1 shows the names and the maximum torques of the servo motors used for this robot arm, Table 2 lists the length of each part (arm and hand) of the robot arm, and Table 3 presents the mass of each part of the robot arm. We decided the motor and the length of each part arbitrary considering total size and ease to carry. We substituted the above values into Equation (3) and obtained the following:

$$T_3 = \frac{1}{2} \times (2 \times 0 + 0.054 \times 9.8) \times 15 \times \cos(0 + 0 + 0) = 3.97. \tag{7}$$

We substituted Equation (7) and the above values into Equation (2) and obtained the following:

$$T_2 = \frac{1}{2} \times (2 \times 0.009 + 0.017) \times 9.8 \times 6.45 \times \cos(0 + 0) + T_3 = 5.08. \tag{8}$$

Finally, we substituted Equation (8) and the above values into Equation (1) and obtained the following:

$$T_1 = \frac{1}{2} \times (2 \times 0.045 + 0.047) \times 9.8 \times 4.7 \times \cos 0 + T_2 = 8.23. \tag{9}$$

Here, we define f_1, f_2 and f_3 as the safety ratio at each joint, which are obtained as follows:

$$f_1 = \frac{Tq(M_1)}{T_1} = \frac{3.0 \times 9.8}{8.23} = 3.57, \tag{10}$$

$$f_2 = \frac{Tq(M_1)}{T_2} = \frac{3.0 \times 9.8}{5.08} = 5.79, \tag{11}$$

$$f_3 = \frac{Tq(M_2)}{T_3} = \frac{2.5 \times 9.8}{3.97} = 6.17. \tag{12}$$

We defined herein the threshold of the safety ratio as 3 according to [7]. Thus, the safety ratio of the developed robot arm at all joints was over 3. Moreover, the stiffness of the developed robot arm was efficient.

Figure 3 shows an outline of the designed and developed robot arm considering the above points.

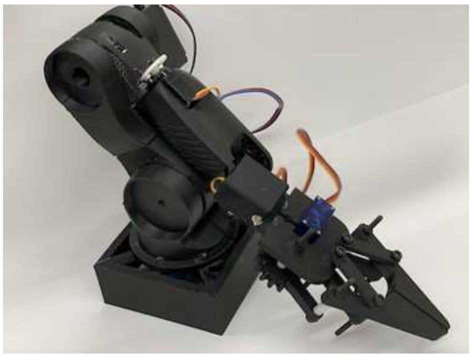

FIGURE 3. Outline of the designed and developed robot arm

2.2. **Development of mobile robot.** We next developed a mobile robot on which the developed robot arm moves. The driving performance and balance in driving are considered in developing. Figure 4 shows an outline of the developed tank-like robot created using the 3D printer (Zortrax M200; Zortrax) based on a basic tank-construction kit (Tamiya, Inc., Shizuoka, Japan). This tank-like robot can move using a DC motor; thus, the DC motor and the Raspberry Pi mounted on this robot must be controlled.

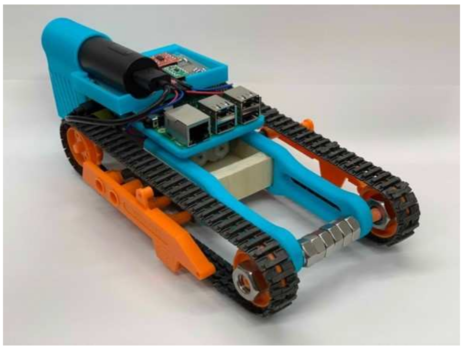

FIGURE 4. Outline of the designed tank-like robot

A motor driver was connected to the GPIO of the Raspberry Pi, which was used to control two DC motors. The two DC motors rotate clockwise when the robot goes forward and counterclockwise when the robot goes backward. When the robot turns left, the left-side DC motor rotates clockwise and the right-side DC motor rotates counterclockwise. When the robot turns right, the right-side DC motor rotates clockwise and the left-side DC motor rotates counterclockwise.

2.3. **Development of the interface for operating the robot arm and the tank-like robot.** As regards intuitive and various movements, we applied palm and finger motion for the robot arm's movement because the developed robot arm was designed to be able to stretch, twist, and grasp. In relation to this, the already existing controllers with a button and a joystick seem to be inadequate because they force a complicated operation for their users, and they are desirable to operate based on the user's intuition.

We then adopted the motion of the middle, ring, and pinky fingers for stretching the arms. We attached servo motors at each joint for rotation. The developed robot arm simultaneously stretches if the operator stretches the middle, ring, and pinky fingers [Figure 5(a)]. Next, we adopted the motion of bending the thumb for twisting the hand of the robot arm [Figure 5(b)]. Finally, we adopted the motion of attaching the index

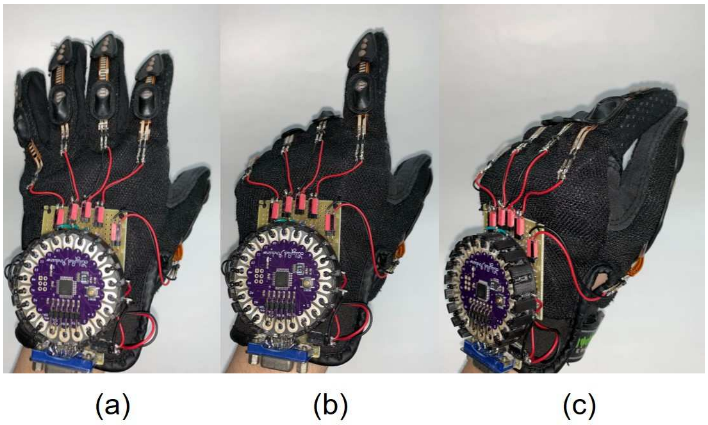

Figure 5. Motions adopted by the developed controller: (a) stretching arms, (b) twisting the hand of the robot arm, and (c) grasping something by hand

finger and thumb for grasping something by hand. This motion does not conflict with the motion for stretching arms [Figure 5(c)].

We used a glove with flex sensors attached on each finger to detect the motion of the fingers. Thus, five flex sensors were attached on each finger of the glove. Each flex sensor and gyro sensor was connected to a LilyPad Arduino, which is attached to the glove controller. An outline of the glove controller is shown in Figure 6.

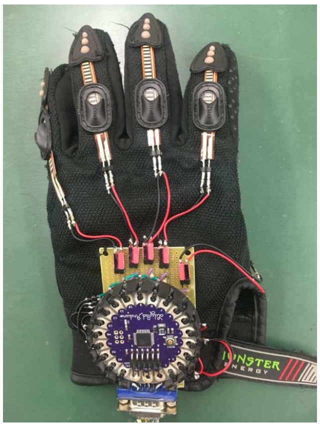

Figure 6. Outline of the designed controller

Next, we considered the movement of the tank-like robot by this glove controller. A gyro sensor attached to the glove controller was used to control the tank-like robot. We defined the reference position: the tank-like robot was in a stationary state when the palm was parallel to the floor. The tank-like robot goes forward when the palm is tilted up and backward when the palm is tilted down. In addition, it turns left when the palm is tilted left and right when the palm is tilted right. Figure 7 shows the controlling image.

3. **Experiment.** Here, we evaluate the usability of the developed robot arm and the tank-like robot. Six participants joined this experiment.

First, the participants operated the developed robot arm and the total time for the robot operation was calculated. Each participant was taught to stretch and shorten the robot arm using the controller. Figure 8(a) shows the robot arm being stretched (initial

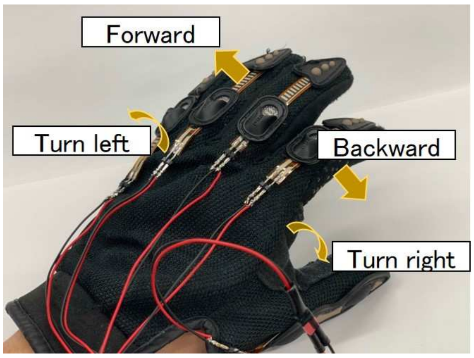

FIGURE 7. Controlling image of the tank-like robot

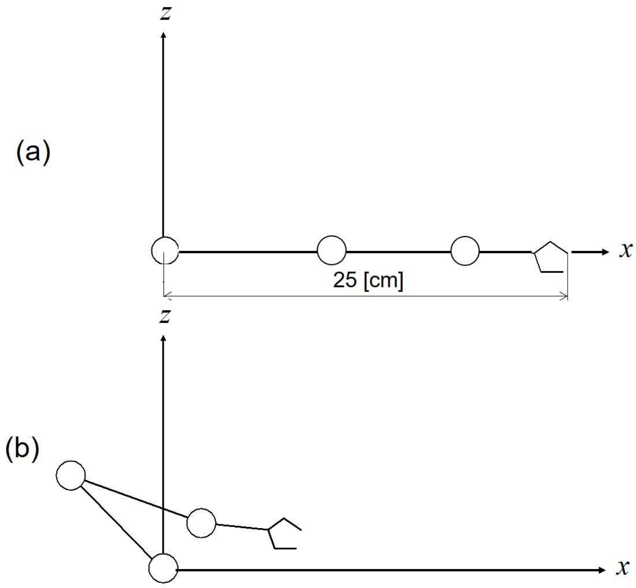

FIGURE 8. Outline of the experiment of the robot arm: (a) stretched, (b) shortened

condition), and Figure 8(b) shows a shortened robot arm. Each participant did this 10 times.

Next, the participants operated the developed tank-like robot, and the total time for the robot operation was calculated. Each participant was taught to move the tank-like robot from the start position to the goal position (Figure 9), and each participant performed this 10 times.

Finally, each participant was asked the following: "Could operate as you think (Q1)," "Got used to operation (Q2)," and "Easy to control by developed controller (Q3)" after each experiment finished. Each participant scored each questionnaire on the following basis: worst = 1 point; average (neither good nor bad) = 3 points; and best = 5 points.

Figure 10 shows an actual photo for the experiment and Figure 10(a) is an actual photo of the robot arm experiment, whereas Figure 10(b) depicts the tank-like robot experiment. Figure 11 presents the experimental results, where Figure 11(a) illustrates the result of the robot arm and Figure 11(b) shows that of the tank-like robot. Figure 11 exhibits the average operating time of the six subjects (bar = one standard deviation (SD) of the operating time). Figure 12 depicts the questionnaire results, where Figure 12(a) shows the questionnaire results regarding the robot arm and Figure 12(b) presents those regarding

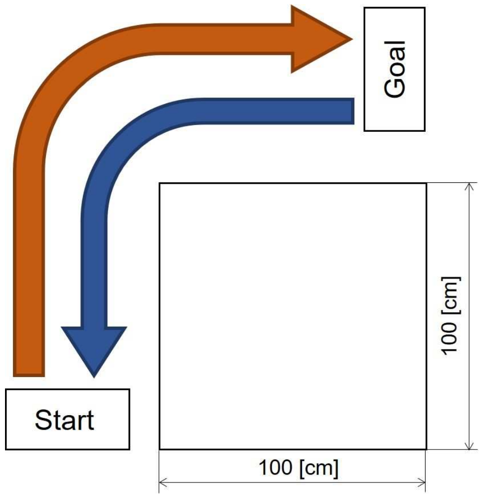

FIGURE 9. Outline of the experiment of the tank-like robot, where each participant makes the tank-like robot move from the "Start" point to the "Goal" point and then back from the "Goal" point to the "Start" point using the developed controller

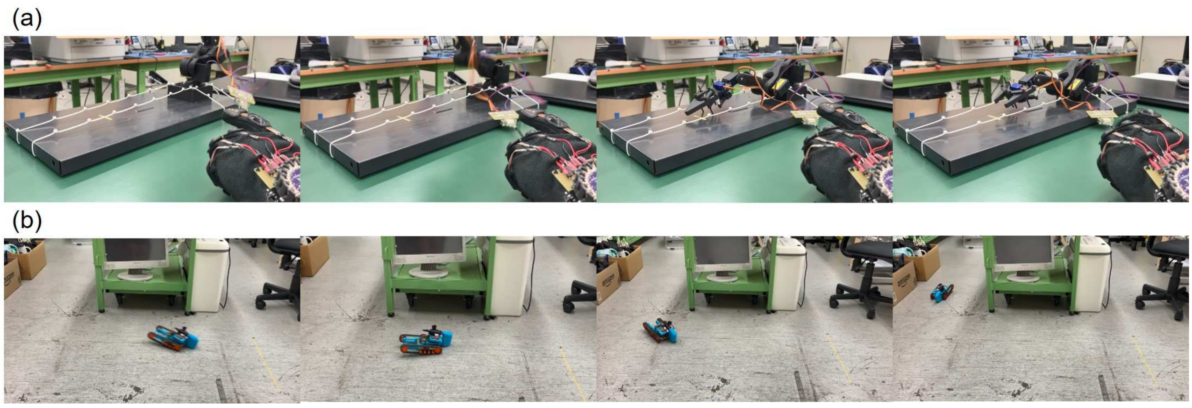

FIGURE 10. Actual photo of the evaluation experiment of the (a) robot arm and the (b) tank-like robot

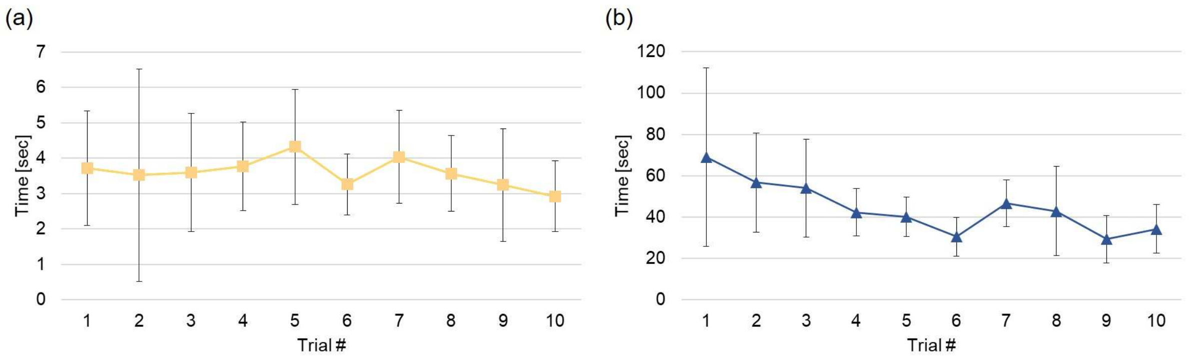

FIGURE 11. Average operation time and one SD of the (a) robot arm and the (b) tank-like robot. The horizontal axis denotes the trial number, whereas the vertical axis denotes the operation time.

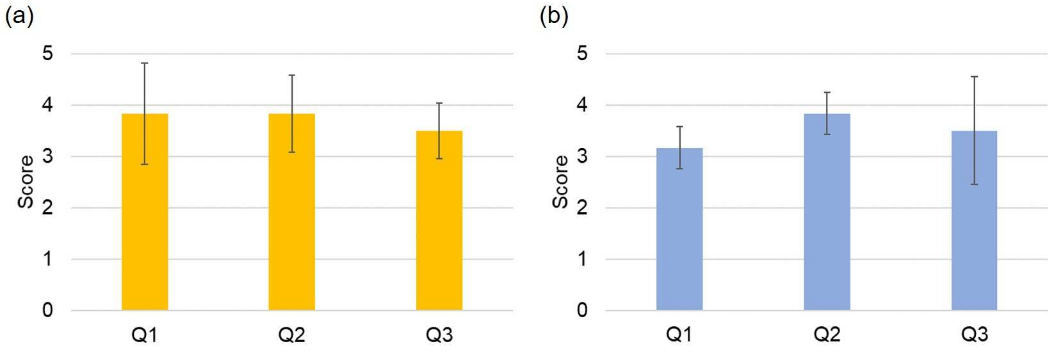

FIGURE 12. Average score and one SD of the (a) robot arm and the (b) tank-like robot. The horizontal axis denotes the questionnaires, whereas the vertical axis denotes the scores.

the tank-like robot. The average score of the six subjects is also shown in the same figure (bar = one SD of the score).

4. **Consideration.** First, we considered the operation time of the robot arm. Figure 11(a) shows that the operation time was gradually shortened, and one SD of the operation time became smaller. This result shows that the participants gradually got used to operating the robot, and the variance of each participant's operation time became smaller. Thus, the difference of the operation time between each participant seemed to be suppressed.

Figure 11(b) illustrates that the case of the tank-like robot was the same as this. The participants might have felt that they cannot operate the robot the way they wanted at first; however, they gradually got used to its operation and were able to eventually operate it the way they wanted.

Second, we considered the questionnaires about the developed robot. Figure 12 shows that the score in the questionnaires was over three points, establishing the notion that our developed system had an above-average score. The score of Q2 was the highest in both cases of the robot arm and the tank-like robot. In other words, the participants got used to the operation of both the robot arm and the tank-like robot. This result supports the result of the operation time. In contrast, the scores of Q1 and Q3 were lower than that of Q2 in both cases. Q3 had the lowest score in the case of the robot arm, whereas Q1 had the lowest score in the case of the tank-like robot. As for the robot arm, some participants felt that it was hard to control it using the developed controller. One of the reasons for this was that we did not design the robot arm control, and the gear and the motor were directly connected. If we had designed the control and introduced a lag system (e.g., a first-order lag system), the participants might have felt that they can easily control the robot arm. As for the tank-like robot, five out of six participants rated 3 points. They felt that they could not operate the tank robot the way they wanted. One of the reasons for this seemed to be the control system design, which was the same as that of the robot arm. The other reason was the controller's interface design. Thus, as for the tank-like robot, its usability can be improved if the controller's interface design is improved.

In Figures 11(a) and 11(b), the operation time at trial #6 is relatively shorter than other trials. The reason is not clarified; however, the operation time of two participants is almost as half as that of the previous trial. They accustomed to operating the robots and they could operate more smoothly than they think at trial #6 coincidentally. Thus, the operation time at trial #6 might get to be, totally, relatively short.

5. **Conclusion.** In this study, we presented and evaluated a nursing care robot that can move and grasp things by hand motion only. The experiment showed that the participants felt that they cannot operate the robot the way they wanted at first; however, they gradually got used to the operation and were able to eventually operate it the way they wanted. The questionnaires illustrated that our developed system had an above-average score; however, as for the robot arm, some participants felt that it was hard to control it using the developed controller. As for the tank-like robot, five out of six participants felt that they could not operate the tank robot the way they wanted. In this experiment, we could acquire only six participants' data; thus we may not secure adequacy of the result from the point of the number of participants. However, we think we could find the modification point of this nursing care robot.

In the future, we will revise and improve the developed robots' usability according to the experiment results. Especially, the interface of the controller and control design should be improved. As for control of the robot arm, a lag system will be introduced and the control system will be designed in order to realize the movement according to the user's intention. As for control of the tank-like robot, the motion besides tilting up and down of palm should be considered, for example, the movement like circular motion of palm.

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