DRC0021

Gesture based interface of robot arm "Udero" for upper limb dysfunction

Tomoya Ichikawa[1], Ken'ichi Yano[1,*], Ryota Sakamoto[2], Shintaro Shimada[3], Tsutomu Shimada[3], and Panya Minyong [4]

[1] Dept. of Mechanical Engineering, Mie University, 1577 Kurimamachiya-cho, Tsu-city, Mie, 514-8507, Japan
[2] Mie University Hospital, 2-174 Edobashi, Tsu City, 514-8507, Japan
[3] Technotools Corporation, Masuya Bldg. 4F, 2106-5, Higashi-Naganuma, Inagi-city, Tokyo, 206-0802, Japan
[4] Rajamangala University of Technology Thanyaburi, 39 Muh 1 Rangsit-Nakhonnayok Rd., Klong Hok, Thanyaburi, Pathumthani 12110, Thailand

* Corresponding Author: yanolab@robot.mach.mie-u.ac.jp

Abstract. Many physically disabled people who cannot freely move their extremities are forced to travel by electric wheelchairs or become bedridden. To assist them, we have developed a 7-DOF robot arm called "Udero", which has a versatile design that allows attachment to either wheelchairs or bedsides. Position control use PID control and is implemented with both an automatic control mode and a manual control mode. However, with manual operation using a joystick, there is a problem that the arm takes time to reach a target. Therefore, we propose an operation system with 3-D motion of the hand using an infrared camera. Finally, we demonstrated effectiveness by a comparison experiment between the joystick and proposed method.

1. Introduction

About 50% of handicapped people in Japan have a physical disability [1]. People with upper limb dysfunction such as cervical cord injury (CCI) are often forced to live in a wheelchair, and experience difficulties with the actions of everyday life, such as "grabbing objects in front", "opening doors" and "moving objects falling on the floor". They therefore, we need help in performing such actions. Welfare robot arms that support the lives of people with upper limb dysfunction have been attracting serious attention. Users learn to operate the welfare robot arms, which are attached to an electric wheelchair or bedside, instead of their own arms, as shown in figure 1. If people with upper limb dysfunction can freely manipulate the robot arm, it is possible to perform various daily activities without further support, thus improving quality of life.

Several welfare robot arms are currently in the research and development process [2-4]. For example, conventional robotic arms for welfare include the iARM by Exact Dynamics, JACO^2 by Kinova Robotics and RAPUDA by the National Institute of Advanced Industrial Science and Technology. In general, these can be operated using a keypad or a joystick. However, since there are many buttons on the keypad, it is difficult to memorize the layout. In addition, it is necessary to switch operation modes frequently when using a joystick. For these reasons, daily operations using the robot arm can take time and burden the operator [5]. In order to solve these problems, we aim to develop an interface that can operate the robot arm quickly, without switching operation modes and requiring many buttons.

First, we describe the details of the robot arm developed in this research and explain the composition of the system. Next, we propose a new robot arm manipulation method. Finally, we perform comparative experiments between conventional interfaces and the proposed method to demonstrate the effectiveness of this research.

Figure 1. Robot arm attached to electric wheelchair.

2. The developed robot arm

Table 1 lists the basic specifications of the seven degree-of-freedom (7-DOF) robot arm "Udero" developed in this research. Udero has a compact root part that can be attached to an electric wheelchair. In addition, since its structure becomes thinner from the root to the finger like a human arm and hand, it is designed to work well in familiar surroundings.

Table 1. Specifications of the robot arm.

DOF	4(Arm) + 3(Wrist) + 1(Hand)
Max. Reach	885 [mm]
Max. Total weight	6.0 [kg]
Max. Payload	1.0 [kg]
Max. Speed	200 [mm/s]

2.1 Joint structure of robot arm

The robot arm has a structure in which adjacent joint axes are orthogonal to each other. The seven joints of the robot arm are called J_1 to J_7 in order from the root. Also, we can use orthogonal joints from J_1 to J_3 and J_5 to J_7 to resemble ball joints $J_{1,2,3}$ and $J_{5,6,7}$. If these joints are compared to the human arm, $J_{1,2,3}$, J_4 and $J_{5,6,7}$ are equivalent to the shoulder, elbow and wrist joints, respectively. As shown in figure 2, the movable region of each joint has a wider range of motion than the human body in regions where physical interference does not occur. The length of each link is designed with reference to the length of human hands, forearms and upper limbs [6], and the lengths of $J_{1,2,3}$, J_4, and $J_{5,6,7}$ from the tip of the hand are 190 mm, 470 mm and 750 mm, respectively. The total length is 850 mm. Also, since the device must be able to lift a cup onto the table at the hand, the payload amount is 1 kg at the maximum reach.

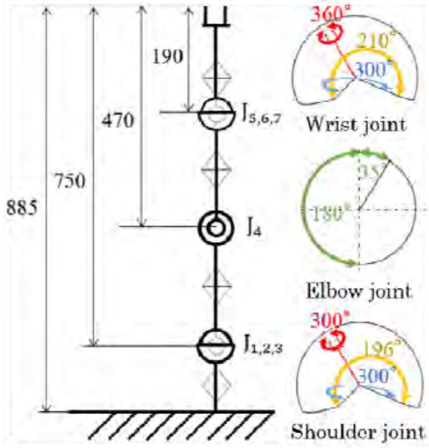
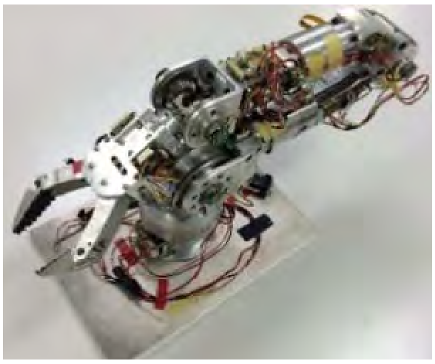


Figure 2. Structure of the robot arm.

2.2 Folding structure considering size reduction and design

In the case where the upper arm link and forearm link of the robot arm are on the same straight line, since the elbow joint has a rotation axis orthogonal to the two links, the links tend to interfere with each other and the range of motion becomes small. Therefore, an offset is provided between the upper arm link and the forearm link so that the elbow joint can be bent 180 degrees. Figure 3 shows the developed robot arm. As may be seen in the figure, with the offset, it is not only possible to fold the robot arm compactly, but also to pick up items located directly underneath it.

(a) Unfolding state.



(b) Folding state.

Figure 3. 7-DOF robot arm “Udero”.

2.3 Basic control method

In order to calculate the angle of each joint we use inverse kinematics from the current hand position to the target. PID control is used to control each joint.

There are two modes of operation method. The first is an automatic control mode that moves based on a pre-generated trajectory. The second is a manual control mode operated by input from the interface. Since various actions are required to support individuals with upper limb dysfunction, we focus on the problems with manual operation in this research.

3. Development of gesture based interface system

To solve the problem of long operation time, we develop an interface that does not require many buttons or switching of operation modes. In this research, we focus on people who cannot move their fingers, as in CCI with upper limb dysfunction. Therefore, we use an infrared camera for the interface, which does not require fingers movements. It is designed to operate the robot arm according to the movement of the operator's hand. For the infrared camera, we used Leap Motion, which can recognize the 3-dimensional (3-D) position of the fingertip or hand joint by a maximum of 0.01 mm, in figure 4.

Figure 4. Leap Motion used as an infrared camera.

We perform position control of the robot hand using the above interface. As the operation system, a threshold ε is taken with respect to the deviation $|X_{Li} - X_{L0}|$ between the coordinates X_{Li} of the current palm and the initial coordinate X_{L0} of the palm read by the Leap Motion. When the deviation is $|X_{Li} - X_{L0}| > \varepsilon$, the target coordinate of the robot hand is represented as equation (1).

$$X_r = X_p + X_v v dt \tag{1}$$

Here, X_p is the current coordinate of the robot hand, which changes with displacement $X_v v dt$; v is the moving speed of the robot hand, which varies between 0.05-0.08 m/s depending on the norm of the deviation; and dt is the sampling time. X_v is the direction vector of the normalized deviation and is represented as equation (2).

$$X_v = \frac{X_{Li} - X_{L0}}{|X_{Li} - X_{L0}|} \tag{2}$$

Also, when the deviation is $|X_{Li} - X_{L0}| \leq \varepsilon$, the target coordinate of the robot hand is represented as equation (3).

$$X_r = X_p \tag{3}$$

At this time, the position of the wrist of the robot arm does not change. When the robot arm is stationary, it is possible to open and close the hand. In order to allow people with CCI to operate the robot arm, the motion of the arm must correspond to their possible movements. In this study, we detect the angle between the vector perpendicular to the palm and the z-axis of the reference coordinate system, read from the infrared camera. As shown in figure 5(b), the inclination angle of the hand corresponds to the opening and closing operations of the robot hand.

(a) Position operation. (b) Opening and closing.

Figure 5. Image of proposed gesture interface.

4. Comparative operation experiment

4.1 Experimental Outline

In order to verify the effectiveness of the gesture interface system, we conducted experiments comparing the joystick and buttons operation to the Leap Motion operation. The experimental task was an operation to transport a cup from point A to point B three times for each interface. Point A was located 250 mm forward from the base of the robot arm and 160 mm to the left; point B was 100 mm forward of the point A, 300 mm to the right, and 150 mm above. The experimental procedures were as follows.

1. Exercises using Leap Motion
2. Experiment with Leap Motion
3. Exercises using joystick and buttons
4. Experiment with joystick and buttons

Participants in the experiment were three healthy persons (two male, one female). The experimental environment for the interface is shown in figures 6 and 7. As may be seen in figures, subjects operated the system from a position where the robot arm could not reach, for safety.

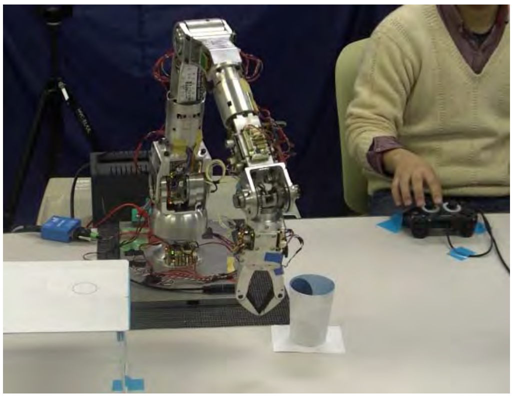


Figure 6. Experimental setup of joystick and button.

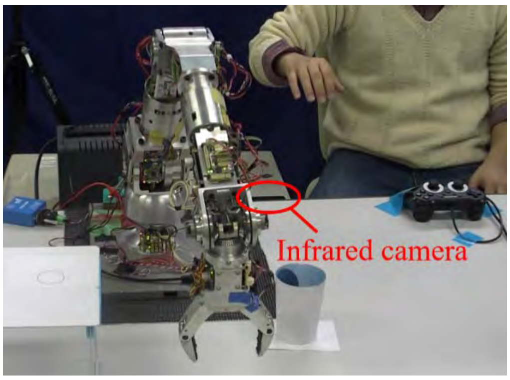


Figure 7. Experimental setup of infrared camera operation.

4.2 Experimental result

Figures 8 and 9 present the experimental results of the operation using the joystick and button, and the Leap Motion. As shown in figure 8, the average times for each subject's operation were 22.6 s, 20.6 s and 22.6 s. Subjects were unable to achieve the operation in less than 20 s. On the other hand, in figure 9, the average time of operation for each subject was 18.3 s, 17.6 s, 14.0 s, all less than 20 s. These results confirmed that the operation time was reduced in all subjects by using the proposed operation method. In the operation using the joystick and button, it was necessary to switch between the up and down operations and the horizontal operation of the hand. However, in the proposed method, since the robot arm is operated by the hand movement of the operator, it is possible to manipulate the robot arm three-dimensionally. Therefore, the operator can easily recognize the operation of the robot arm. This is considered to be one of the reasons why operation time was shortened. In addition, we compared the number of operations required to operate the joystick and button and the infrared camera. Here, the number of operations is defined as the number of times it is necessary to switch the movement of the robot arm. In the case of the joystick and button, the number of operations corresponds to the number of times the hand had to leave the interface. In the case of the operation by the infrared camera, it corresponds to the number of times that the deviation between the current coordinates of the palm and the initial coordinates becomes smaller than the threshold value. Table 2 shows the number of operations using the joystick and buttons, and Table 3 the number of operations using the infrared camera. Data in the tables confirm that the number of operations to achieve the goal was reduced in all subjects with the proposed method. From this, it can be considered that the operation time was shortened, since the number of operations was reduced. From the results of this study, it is considered that the proposed manipulation method leads to a reduction in operation time, and suggests adaptation to upper limb dysfunction can be expected.

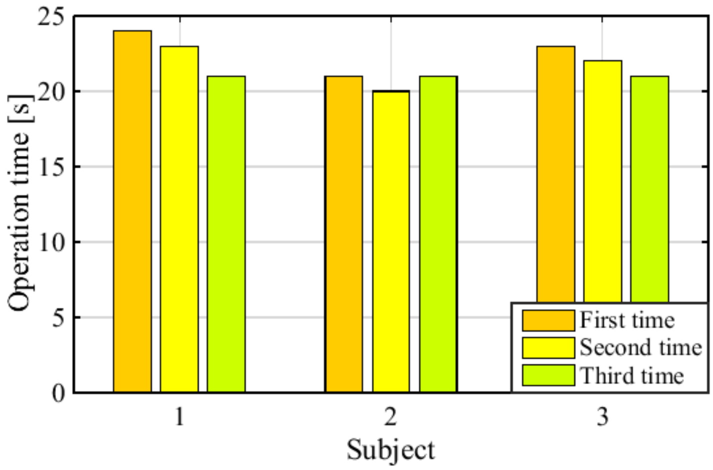


Figure 8. Operation time with joystick and button.

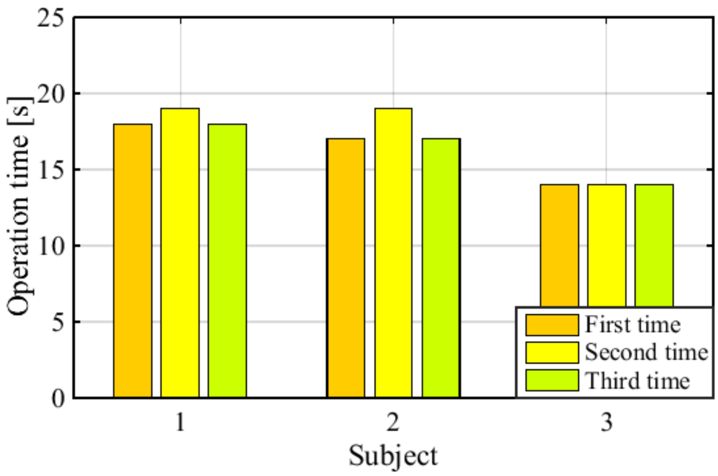


Figure 9. Operation time with Leap Motion.

Table 2. Number of operations with joystick and button.

	First	Second	Third	Average
Subject 1	11	14	10	11.7
Subject 2	11	11	12	11.3
Subject 3	15	14	12	13.7

Table 3. Number of operations with Leap Motion.

	First	Second	Third	Average
Subject 1	9	8	9	8.7
Subject 2	8	7	8	7.7
Subject 3	5	5	5	5.0

5. Conclusion

People with upper limb dysfunction such as CCI need various forms of support in their daily lives. Welfare robot arms are one possible from of support that has been attracting attention. However, existing interfaces, require frequent switching of operation modes and manipulation of many buttons, which takes time to operate. Therefore, it is difficult to smoothly incorporate the robot arm into daily life routines. In this research, in order to shorten operation time, we developed an interface that does not require operations with multiple buttons or switching operation modes. We proposed a manipulation method by 3-D motion of the hand, read by an infrared camera. We then conducted an experiment to compare the joystick and button operation with the proposed operation. The experiments confirmed a reduction in operation time and in number of operations, and showed the effectiveness of this research approach. In future research, we plan to conduct comparative experiments with the system on cervical spinal cord injured persons.

References

[1] Ministry of Health, Labor and Welfare, Survey on the difficulty of living in Heisei 23 (Survey on actual condition of children and others at home), Japan (2013).

[2] Hairong Jiang, Ting Zhang, Juan P. Wachs and Bradley S. Duerstock (2016), Enhanced control of a wheelchair-mounted robotic manipulator using 3-D vision and multimodal interaction, Computer Vision and Image Understanding, vol.149, August 2016, pp. 21 – 31.

[3] Sebastian Schröer, Ingo Killmann, Barbara Frank, Martin Völker, Lukas Fiederer, Tonio Ball and Wolfram Burgard (2015), An Autonomous Robotic Assistant for Drinking, 2015 IEEE International Conference on Robotics and Automation, Washington, USA.

[4] Won-Kyung Song, Heyoung Lee and Zeungnam Bien (1999), KARES: Intelligent wheelchair-mounted robotic arm system using vision and force sensor, Robotics and Autonomous Systems, vol.28, July 1999, pp.83 – 94.

[5] Takashi Fuzawa (2015), The User Evaluation of Robotic manupilator: The Difficulty of Integrating New Technology into Daily Life, The 30th Japanese Conference on the Advancement of Assistive and Rehabilitation Technology in OKINAWA, Japan.

[6] National Institute of Advanced Industrial Science and Technology Digital Human Research Center (1991-1992), Human body dimension database, *Statistic Data*, URL: https://www.dh.aist.go.jp/database/index.php.ja, accessed on 06/02/2017