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Lifting Assist Device for Transfer in Cooperation with Caregivers

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Abstract. To promote good health and well-being is one of the Sustainable Development Goals (SDGs) drawn by the United Nations. To this end, the development of assistive devices is important to improve the quality of life for both caregivers and patients. This study aims to provide support in transfer assist, which is known to be strenuous work in the care environment. In this study, a concept of a lifting assist device for transfer that is able to adjust the patient's posture according to the intention of the caregiver is proposed. The device can reduce both physical and mental burden of caregivers and patients. The main components of the device are motors, load cells and wires. The device can be operated by the values of the tension force of wires. Since the proposed device has a simple structure, its system is easy to use and inexpensive such that it can be widely introduced, which can contribute to the realization of the SDGs. Two subject experiments including the threshold determination experiment and the transfer simulation experiment were conducted using a fabricated full-scale prototype. In the first experiment, the intention detection strategy based on the change of the tension force of wires was determined, and was applied to the prototype. In the second experiment, it was confirmed that the proposed intention detection method worked well and the upper body posture changed appropriately during the lifting process.

Keywords: SDG3, Robotics and mechatronics, Assist device, Transfer, Lifting process, Human cooperating system, Intention detection, Posture adjustment

1 Introduction

The 17 Sustainable Development Goals (SDGs) were adopted by the United Nations in 2015 [1]. Global aging has been becoming a more severe problem, and it has led to the lack of nursing workforce. It is crucial to install assistive devices to solve this problem in line with SDG3, which aims to ensure healthy lives and promote well-being for all ages.

Transferring a patient from one place to another, such as from a bed to a wheelchair, is one of the most strenuous nursing tasks for caregivers in the nursing field [2].

As Occupational Safety and Health Administration (OSHA) guidelines dictate how to transfer and how to choose the appropriate device depend on the patient's symptoms [3]. The lifting process of transferring severe patients is especially hard because they cannot move their remaining functions by themselves, and caregivers have to lift their whole body to transfer. Due to heavy work, the policy that caregivers should not lift patients called "No Lifting Policy" was suggested and use of transfer assist devices is strongly recommended [4]. On the other hand, it is important for the patients to feel at ease and comfortable with the devices because a patient is transferred frequently everyday and that is deeply involved in their quality of life including the improvement of psychological awareness and health [5]. Thus, the development of transfer assist devices helps both caregivers and patients to be more comfortable and healthy.

Recently, lifting assist devices such as mobile floor lifts and ceiling lifts are widely used for severely disabled patients [6]. A sling seat is placed under the patient and wires connect the seat to the device, then the patient wrapped by the seat is lifted. These lifts are superior to other assistive devices in the aspect that they can reduce caregivers' burden with a relatively low cost, short operation time and easier usage than other devices with a similar function [7]. However, when using a lifting assist device, the patient's position is higher than the case without any device, which is called human assistance. Because of this, the patient might sway in the air when the caregiver's hands leave the patient due to remote controller operation [8]. Such an unstable status may cause the patient to feel anxious and unsafe. Furthermore, the patient runs the risk of injury or tipping over from hitting the bed, the wall or the lifting device. Because of these problems, the installation rate of lifting assist devices is still low and human assistance is often chosen [9].

Hirakata General Hospital for Developmental Disorders is a welfare facility where many patients have severe disabilities which include conditions with limb deformities and limitations in joint motions. Caregivers do transfer assistance frequently between a bed and a wheelchair during the day for daily living and rehabilitation. In this process, caregivers in this facility use mobile floor lifts or transfer by human assistance. A characteristic of conventional lifts is that the patient's lifting posture is fixed in a certain orientation due to the device structure whose sling seat wires gather at one hung point. Caregivers are concerned that unreasonable postures, outside the range of motion of patient's joints, may cause them pain. Compared with mobile floor lifts, human assistance is preferred as caregivers can adjust the upper body posture of the patients by observing their movements and feedbacks, such as facial expressions, during the lifting process. Since the caregiver directly touches the patient, it also makes the patient feel relieved. Hence, reflecting the caregiver's intention in operating the device is also considered essential to enable the caregiver to change the position and posture of the patient freely by observing the patient's expression.

To solve the problem of preventing swaying, a mobile floor lift that can be operated by a power assist system, with no remote-controlled operation, has already been developed [10]. Using this device, the caregiver applied force to the patient directly and the device was able to detect the caregiver's intention depending on the tension force. However, the patient's posture during lifting was determined uniquely so it is difficult to use this device for severely disabled patients.

Therefore, the purpose of this study is to develop a cooperative lifting assist device that can reflect the caregiver's intention and change the patient's posture during lifting. This will reduce the burden on both the caregivers and the patients during transfer and improve comfort for patients with severe disabilities who have not been using existing lifts. Based on this concept, the structure of the full-scale device and the results of subject experiments conducted with the device is described.

2 Method

2.1 Proposed concept of lifting assist device

Considering the care environment in Hirakata General Hospital for Developmental Disorders as a case study, the case where a caregiver who lifts a patient from a bed to a wheelchair was the focus of this paper. Figure 1(a) shows a situation where a caregiver operates the proposed device to lift a patient. A sling seat is placed under the patient to hold the whole body. The patient's weight is supported by two wires connected to the seat near the waist and shoulder of the patient. The caregiver touches the back sides of the patient's shoulder and knees with both arms.

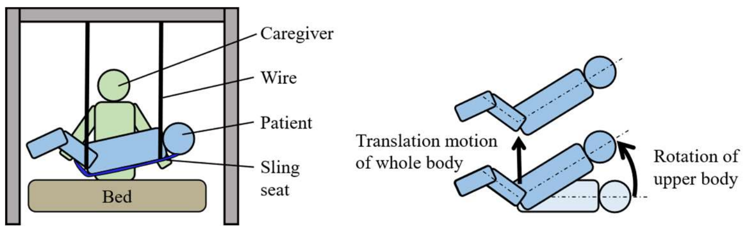
During the lifting process, two motion patterns for controlling the patient's position and posture are proposed, including the whole body's translational motion and the upper body's rotation, as shown in Figure 1(b). To do these movements, three intentions of the caregiver shown in Figure 1(c) are considered necessary to be separately detected during operation, which are defined as *static*, *whole* and *up*. *Static* represents the intention to keep the patient's current position and orientation; *Whole* represents the intention to move upward the patient's whole body; *Up* represents the intention to raise the patient's upper body.

Once the caregiver applies force to the patient with intention, the tension values should change accordingly. Detection of the caregiver's intention will be done by the measured tension force of the two wires. Based on the detected intention, desired motion is given as a reference to the controller of the device, and wires are wound up by each motor. This concept of intention detection using wire tension values was investigated by experiments with a fabricated one-third scale prototype [11]. In this paper, this concept is applied to the full-scale device.

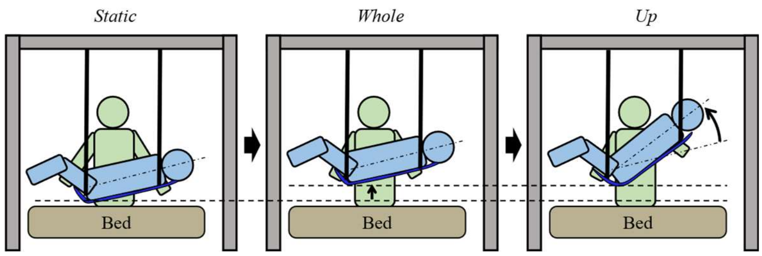
2.2 Experiments with full-scale prototype

Structure of the fabricated full-scale prototype. A full-scale device was designed, whose composition and photo are shown in Figures 2(a) and 2(b). A sling seat is laid under a dummy, whose height and mass are 165 cm, 43 kg, respectively. The dummy is lifted with two wires, denoted as I and II, whose tension values are T_1 and T_2, respectively.

Movable pulleys are connected directly below load cells I and II. Each of them measures the tension of the corresponding wire. Wire I' is connected to the sling seat near the dummy's waist, and wire II' is connected to the sling seat near the dummy's shoulder, and each of tension values T_1' and T_2' are the same as $T_1/2$ and $T_2/2$ because of movable pulleys. Wires I and II are wound up by changing the angles of motors I and II, θ_1 and θ_2, respectively. Three LED lights are set to the device frame to instruct the subject which intention should be thought of during the experiment. The hip position d and the orientation angle θ_p of the dummy shown in Figure 2(a) are measured.



(a) Device composition (b) Two motions for patient's body control



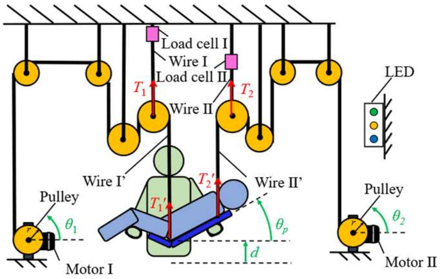
(c) Three intentions considered for device operation

Fig. 1. Proposed concept of lifting assist device

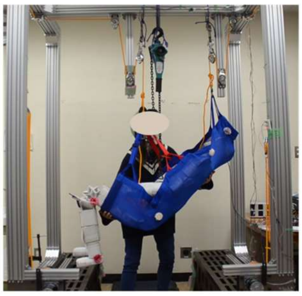
Intention detection method for operating the device. The proposed operation flow for intention detection is shown in Figure 2(c). To determine the values used in Conditions I and II, two subject experiments were conducted, which are discussed in the following section.

It was assumed that when the intention is *static*, the subject only applies small forces to the dummy. Both T_1 and T_2 should have relatively large values compared with the case of *up* and *whole* because the dummy is mainly supported with the wires. Based on this assumption, $T_1 + T_2$ was used as a measure for discriminating between *static* and the other two intentions. As to discriminate between the *up* and *whole* intentions, it is assumed that the ratio R calculated by Eq. (1) should be effective. It is assumed that the smaller the R value is, the stronger the intention to lift the upper body.

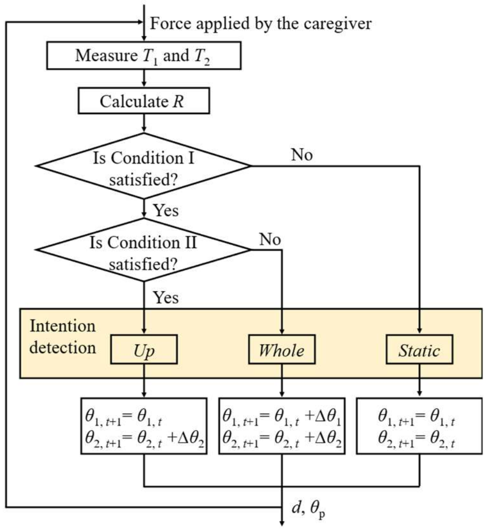
$$R = \frac{T_2}{T_1 + T_2} \times 100\ \% \quad (1)$$



(a) Structure of the proposed full-scale prototype



(b) Fabricated full-scale prototype



(c) Flow for detecting the intentions

Fig. 2. Full-scale prototype based on the proposed concept.

Experiment methods for evaluating intention detection. Two experiments were conducted, including the threshold determination experiment and the transfer simulation experiment.

The threshold determination experiment aims to investigate the appropriate methods used for determining the subject's intention. In this experiment, the subject applied force on the dummy continuously with *static*, *up* and *whole* intentions each time. The dummy's upper posture is changed slowly during the experiment by changing θ_2 due to be measured different values of T_1 and T_2 in each upper posture regardless of the intentions. Then, T_1 and T_2 in different intention conditions are measured, respectively.

Based on these measured data collected in the threshold determination experiment, each subject's decision criteria and thresholds are determined to detect the subject's intention in the later transfer simulation experiment.

In the transfer simulation experiment, intentions that the subject should think of are instructed by lightening each LED: in the order of *up* → *static* → *whole* → *static* for three sets. Subjects applies force as guided by the LED. If the device can detect subject's intention correctly, motors I and II are moved respectively as shown in Figure 2(c). During this experiment, the results of the intention detected by the device are recorded. The proposed strategy flow of intention detection is evaluated by checking the consistency rate between the instructed intention and the detected intention.

3 Results and discussions

Figures 3(a) and 3(b) show the values of the total tension $T_1 + T_2$, the ratio value R in each of θ_2 and determined thresholds of them to discriminate the intentions of subject #1 as an example. It is found that the collected data of four subjects showed a similar tendency in both $T_1 + T_2$ and R. In Figure 3(a), the data shows a gap between *static* and the other two intentions. Hence, the condition to discriminate the intention *static* was determined as a linear function of $(\theta_2 - \theta_1)$ in Eq. (2) with the threshold shown in the right side of the equation. The condition to discriminate between the intention *up* and *whole* was determined as a linear function of $(\theta_2 - \theta_1)$ in Eq. (3) with the threshold shown in the right side of the equation.

Condition I for discrimination of *static* from others:

$$T_1 + T_2 \leq \frac{(p_{S,up} + p_{S,whole}) + 2p_{S,static}}{4} \cdot (\theta_2 - \theta_1) + \frac{(q_{S,up} + q_{S,whole}) + 2q_{S,static}}{4} \quad (2)$$

Condition II for discrimination between *up* and *whole:*

$$R \leq \frac{(p_{R,up} + p_{R,whole})}{2} \cdot (\theta_2 - \theta_1) + \frac{(q_{R,up} + q_{R,whole})}{2} \quad (3)$$

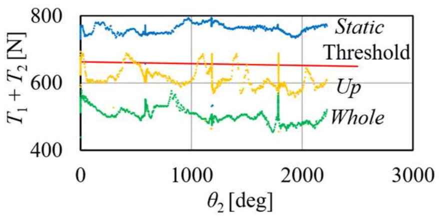
$p_{S,static}$, $p_{S,up}$ and $p_{S,whol}$ are the slopes of the approximate straight-line calculated based on each data in Figure 3(a). $q_{S,static}$, $q_{S,up}$ and $q_{S,whole}$ are the intercepts of the same line. The subscripts S and R represent the data for the sum of T_1 and T_2, and R defined with (1), respectively. The subscripts *static*, *up* and *whole* represent each intention condition, respectively. Equations (2) and (3) are the decision conditions for discriminating each intention adopted in the flow shown in Figure 2(c).

Each threshold for $T_1 + T_2$ and R for four subjects was summarized in Figures 3(c) and (d). It is interesting to note that the data from all four subjects showed similar threshold tendency, which suggests that different users may share and use devices with a common discrimination condition.

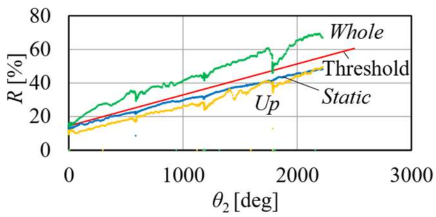
Figure 4(a) shows the results of subject #1's intention (indication by LED) and the intention detected by the device obtained in the transfer simulation experiment. The experimental time was 72 seconds. It was found that the device successfully detected the caregiver's intentions with a high consistency. The consistency rate for subjects #1-4 was 88.4%, 86.6%, 78.9% and 80.8%, respectively. The average consistency rate of the four subjects was 83.7%.

The inconsistencies in intention detection are expected to be mainly caused by the delay between the timing for giving the instructions by the LED and the timing of subject's actual reaction to start to apply force on the dummy. This delay will not occur in the real use situation because there is no delay time between the thinking of the intention and the application of force by the caregiver. Also, this delay problem can be reduced by accelerating the response time of the device, as this will allow the subjects to feel that the device is more responsive to the force applied.

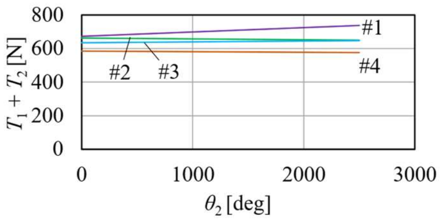
Figure 4(b) shows the position d and the orientation angle θ_p of the dummy that were measured from the positions of markers attached to the dummy. By correctly identifying the subject's intention based on the values of tension force, the appropriate motion of the dummy was performed.



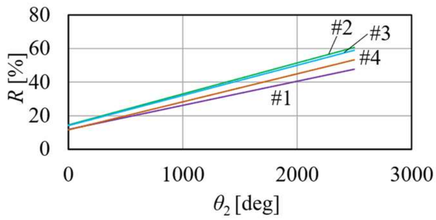
(a) Tension values $T_1 + T_2$ of subject #1



(b) Ratio values R of subject #1

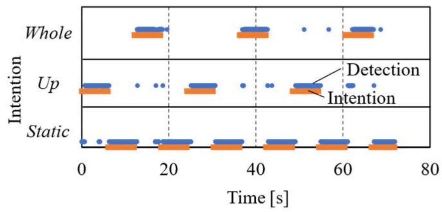


(c) Determined threshold values $T_1 + T_2$ of all subjects

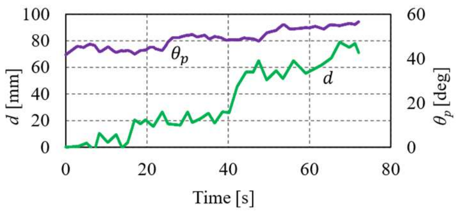


(d) Determined threshold values R of all subjects

Fig. 3. Results of threshold determination experiment in each rotation angles of the θ_2



(a) Detected intentions of subject #1



(b) Transition of d and θ_p of subject #1

Fig. 4. Results of transfer simulation experiment

4 Conclusion

A full-scale device was fabricated based on the proposed concept of a lifting assist device that detects the caregiver's intention based on the tension force of wires and adjusts the patient's posture during the lifting process. Two subject experiments, including the threshold determination and the transfer simulation experiments, were conducted to confirm that the proposed strategy functioned appropriately for intention detection. In the first experiment, it was confirmed that the appropriate thresholds were determined for detecting each caregiver's intentions and each threshold of all subjects showed a similar tendency, which indicates that unified detection thresholds may be applied. In the second experiment, it was confirmed that the device detected the intentions of the subjects according to the threshold determined above and the dummy's position and posture were controlled appropriately. Further subject experiments will be carried out to investigate user-independent characteristics of intention detection and improve the comfort of the operation system with the full-scale device.

This study aimed to develop transfer devices that can improve the quality of life for caregivers and patients. Since our proposed device has a simple structure, it can also provide insights that can lead to more widespread use of transfer devices in the lifting process, which can contribute to realizing the SDGs.

Acknowledgement. The subject experiments conducted in this study followed the Ethical Guidelines for Life Science and Medical Research Involving Human Subjects and have been approved by the Ethics Review Committee of Tokyo Institute of Technology (No. 2022251).

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