

Study on the Lower Garments Dressing and Undressing Portable Support System for Independent Daily Toilet Activity*

N. Miyazaki, A. Uehara, H. Kawamoto, Y. Sankai, *Member, IEEE*

Abstract—Independent excretion is crucial for maintaining self-worth among individuals. Toilet care significantly reduces the quality of life for care receivers while imposing physical and mental burdens on caregivers. Even if care receivers can move to toilets using a walker independently, they often require assistance with dressing and undressing their lower garments, such as trousers and underwear. A walker that assists with dressing and undressing lower garments could not only safely increase opportunities for independent walking to prevent disuse in any place, but it could also reduce the burden of caregivers. The purpose of this study is to develop the lower garments dressing and undressing portable support system attached to a walker and used by the care-receiver with independent gait function to support their daily toilet activity with dignity. In addition, we confirmed the basic performance of independent dressing and undressing using the basic experiment. The system comprised three units: the weight support, lower garment stretching, and lower garment up-and-down units. The weight support unit assisted the user in walking and maintaining a standing posture. The lower garment stretching unit comprised the lazy tong mechanism, which stretches the waistband of the lower garments on hooks by extending the mechanism to perform friction-based holding and reduce friction between the skin and lower garments during dressing and undressing. The lower garment up-and-down unit raises and lowers the lower garments, which are held by the lower garment stretching unit. The lower garment stretching unit and up-and-down unit were attached to both sides of the weight support unit. We conducted a basic experiment involving a series of dressing and undressing movements in the toilet with one of the authors of this study to confirm the basic performance of the system. Consequently, the system was able to dress and undress the lower garments up to the target height without removing them. In conclusion, we confirmed that the system had the basic performance to support for dressing and undressing the lower garments in the toilet.

I. INTRODUCTION

The global population is aging, increasing the need for long-term care [1]. People requiring long-term care, known as care receivers, have difficulty with activities of daily living

*This study includes the results of Cross-ministerial Strategic Innovation Promotion Program (SIP) 3rd Phase, "Expansion of fundamental technologies and development of rules promoting social implementation to expand HCPS Human-Collaborative Robotics" promoted by Council for Science, Technology and Innovation(CSTI), Cabinet Office, Government of Japan. (Project Management Agency: New Energy and Industrial Technology Development Organization (NEDO), Project Code: JPJ012494, HCPS: Human-Cyber-Physical Space)

N. Miyazaki is with Department of Intelligent and Mechanical Interaction System, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, 305-8577, Japan. (corresponding author to provide e-mail: miyazaki@golem.iit.tsukuba.ac.jp).

A. Uehara, H. Kawamoto, and Y. Sankai are with Faculty of Engineering, Information, and Systems and Center of Cybernics Research, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, 305-8577, Japan (e-mail: {uehara, kawamoto, sankai}@golem.iit.tsukuba.ac.jp).

(ADL), such as toileting and eating, and may require assistance. In particular, toileting is an ADL that is strongly related to human dignity; being unable to use the toilet alone can cause embarrassment and lead to a stressful experience for individuals [2][3]. Moreover, the need for caregivers to provide excretory care causes a decline in the quality of life of care receivers. Excretion care is also a task that places a heavy physical and mental burden on caregivers [4][5]. Therefore, independent daily toilet activity is essential for reducing the burden on both caregivers and care receivers.

Toilet activity for excretion consists of several steps, such as moving to and from the toilet; dressing and undressing the lower garments, including trousers and underwear; sitting and standing on the toilet seat; urinating and defecating; and wiping the bottom. In particular, dressing and undressing the lower garments is often difficult for care receivers to perform independently [6] because it requires simultaneous postural control involving trunk bending to grasp the lower garments, center of gravity control, and weight support in a mid-back posture, as well as grasping the lower garments and raising and lowering the lower garments along the legs. Even care receivers with residual cognitive and physical abilities to walk using a walker are often prevented from toileting independently owing to difficulties in dressing and undressing their lower garments without wobbling [7]. Supporting lower garment dressing and undressing associated with toilet excretion to achieve independent daily toilet activities.

In excretion care, caregivers generally accompany the care receivers to ensure safety. In such cases, owing to a lack of caregivers and busy schedules, over assistance may occur to finish care quickly [7], and walking may be replaced by a wheelchair, even for care receivers who still have the ability to walk, leading to loss of walking opportunities and disuse of the muscle groups associated with gait. Toilet activity support is important to prevent this by encouraging walking, which uses the remaining physical abilities.

Yamazaki et al. [8] proposed a dressing assistance method using a humanoid robot. However, they did not provide assistance during undressing. Hagiwara et al. [9] and Kameyama [10] developed devices for assisting in dressing and undressing lower garments that could be installed in toilets by combining a robotic arm. Although they successfully assisted in undressing, they had difficulty in dressing assistance because of the insufficient grasping force of the end effector. In addition, the devices required space for installation in the toilet, and the environment in which they could be used was limited. In nursing homes, several toilets exist, and even care receivers who excrete in the toilet during the day may use portable toilets at night [11], making it impractical to install devices in advance. In particular, because portable toilets are installed in the living room, for example, near bedding,

installing dressing and undressing support equipment in the vicinity of these toilets can squeeze the space in the living room and impede ADL. However, to the best of our knowledge, no portable assistive devices for dressing and undressing exist that need not be installed in the environment.

Therefore, a system that realizes independent daily toilet activities for care receivers requires the following elements.

1. A function to assist in dressing and undressing the lower garments.
2. A configuration to facilitate toileting by walking.
3. No requirement to install it in the environment, and it can be portable.
4. Independently usable by the care receiver without the need for a caregiver.

The purpose of this study is to develop a lower garments dressing and undressing portable support system attached to a walker for a care receiver with an independent gait function to support daily toilet activities with dignity. Additionally, we confirm the basic performance of the system for dressing and undressing support in the toilet through basic experiments.

II. MATERIALS AND METHODS

In general, in dressing and undressing a care receiver who still has the physical ability to walk with a walker and maintain a standing posture, the caregiver raises and lowers the lower garments while the care receiver holds the handrail and maintains a standing posture. The developed system raises and lowers the lower garments while the care receiver maintains a standing posture in the toilet. The system is configured to work as a walker when moving around and be placed close to the side of the toilet bowl during toileting.

A. System Configuration

In this study, we assumed that the user of the developed system was a care receiver and that the system assisted the user in dressing and undressing lower garments in the toilet independently. Fig. 1 shows the configuration of the lower garment dressing and undressing support system. The system comprised three units: weight support, lower garment stretching, and lower garment up-and-down units. The weight support unit assisted the user in walking and maintaining a standing position. The lower garment-stretching unit grasped the waist of the lower garment. The lower garment up-and-down unit raised and lowered the lower garments.

B. Weight support unit

The weight support unit must assist the user in walking and maintaining a standing posture while dressing and undressing, irrespective of the physique of the user. We selected a walker (TY160L-NW-1, Nissin Medical Devices Co., Ltd., Japan) as the weight support unit, which was designed with human body dimensions in mind and could assist in walking and maintaining a standing posture.

C. Lower garment stretching unit

The lower garment stretching unit must grasp the lower garments irrespective of the physique of the user and the size

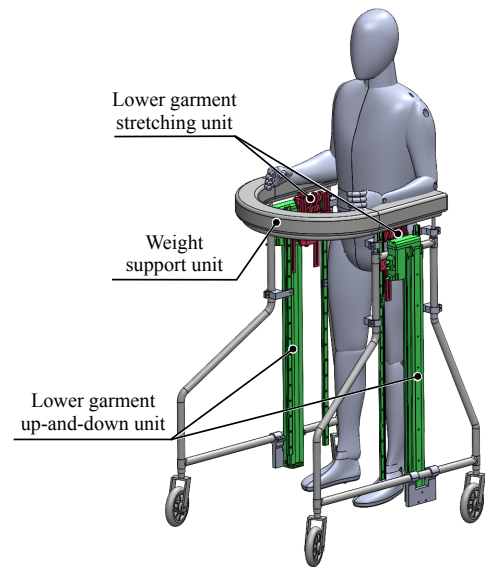


Figure 1. Overview of the lower garments dressing/undressing support system

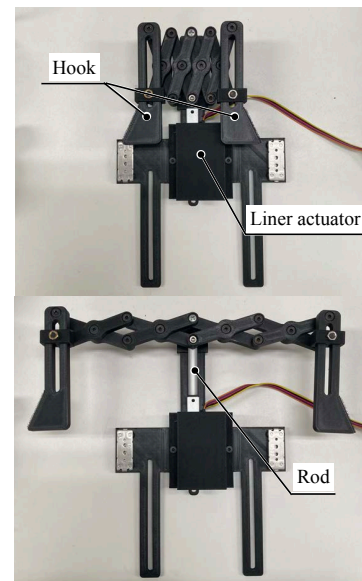


Figure 2. Overview of the lower garment stretching unit

of the lower garments to be worn. In many cases, the user wears nursing care products, such as urine leakage pads, inside the underwear [12]; therefore, sufficient space must be ensured to adjust the position when dressing the user after excretion. In nursing homes, elastic-waisted lower garments are often used in both trousers and underwear for ease of dressing and undressing. The unit stretches the elastic waist of the lower garment in four directions to grasp the lower garments using the tension of the elastic and reduce friction between the skin and lower garments.

When grasping lower garments using elastic tension, adjusting the amount of stretching based on the physique of the user and the size of the lower garments is necessary. We proposed a lower garment stretching unit that comprised a hook for stretching the elastic waist attached to a lazy tong mechanism used for a magic hand to design a compact and lightweight unit

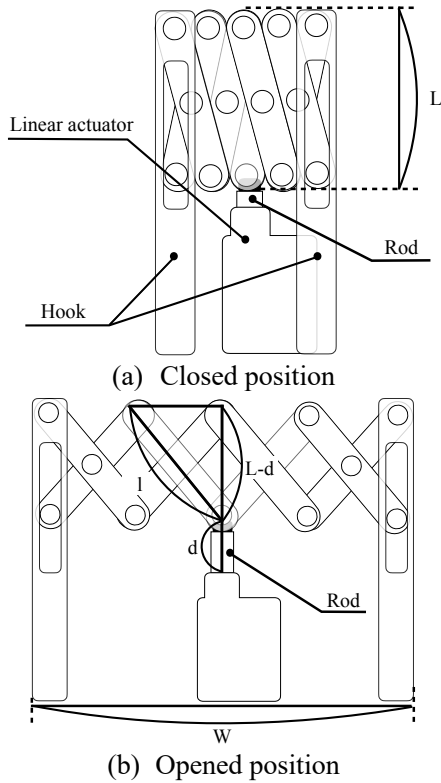


Figure 3. Geometric model of the lower garment stretching unit

that does not interfere with walking.

Fig. 2 shows the lower garment stretching unit. The mechanism was deployed and retracted by extending and retracting the rod of a linear actuator. Fig. 3 shows a schematic of this mechanism. The extension width W of the lower garment stretching unit can be expressed by Equation (1) using the theorem of three squares, where L denotes the distance between the rod and mechanism fixing point during contraction, as shown in Fig. 3(a), d denotes the stroke of the rod, and l denotes the link length, as shown in Fig. 3(b).

$$W = 4\sqrt{l^2 - (L - d)^2} \quad (1)$$

Equation (1) indicates that the length of the lower garment stretching unit in the stretching direction can be adjusted by varying the stroke of the linear actuator rod. By setting L to 70 mm, l to 75 mm, and the maximum stroke d_{max} of the rod to 50 mm, the width could be adjusted in the range from a minimum value of 174.0 mm to a maximum value of 272.0 mm in the statistics of buttock thickness diameter in elderly people [13]. The lower garment stretching unit extended to a width of 289 mm, which was greater than the maximum buttock thickness diameter in elderly people. This feature enabled the user to dress and undress lower garments without being caught on their knees or other protrusions, even if the user moved back and forth slightly. In a simple experiment in which the waist of a pair of nursing pants was stretched with a force gauge attached to the moving part of the lazy tong mechanism, a thrust force of 240 N was required for the mechanism. An actuator (P16 linear actuator; Actonix Motion Devices Inc., Canada) with a thrust of 240 N was used. The maximum stroke speed of the actuator was 4.8 mm/s, allowing the unit to stretch

its elastic waist in approximately 10 s. This was considered an acceptable time for toilet use.

When in use, the stretching width W was set in advance based on the buttock thickness diameter of the user. The user hung the elastic waist of the lower garments on the hooks of the lower garment stretching units on both sides, and the units stretched the lower garments by deploying the mechanisms of the units by operating a switch.

D. Lower garment up-and-down unit

The lower garment up-and-down unit raised and lowered the garments held by the lower garment stretching unit. The waist height of the lower garments must be appropriate to ensure that no obstructions exist to sitting on or standing up from the toilet seat or moving from the toilet afterward. The unit lowered the waist of the lower garments below the popliteal fossa and raised them to the lower iliac crest when undressing and dressing (Fig. 4).

As the difference between the 97.5% tile values of the iliac crest height and the central patella height dimensions [13] of an elderly person was 550.5 mm, we selected an electric slider (EZS series, Oriental Motor Co., Ltd., Japan) with a movement range of 700 mm. As shown in Fig. 5, the lower garment up-and-down unit moved the lower garment stretching unit up and down linearly. When in use, the required movement length of the lower garments was set in advance based on the physique of the user, and the lower garments, which were held by the lower garment stretching unit, were raised and lowered using a switch operation. The operating speed was set to 100 mm/s to ensure user safety. This allowed the unit to complete the dressing and undressing of the lower garment in approximately 5 s, which was considered an acceptable time for use in the toilet.

E. System Integration

Fig. 6 shows a schematic of the operation in each phase. The flow in the toilet using the developed system is as follows:

Phase 1: The user attaches the lower garments to the hooks of the lower garment stretching units.

Phase 2: The lower garment stretching units stretch both sides of the waist of the lower garments.

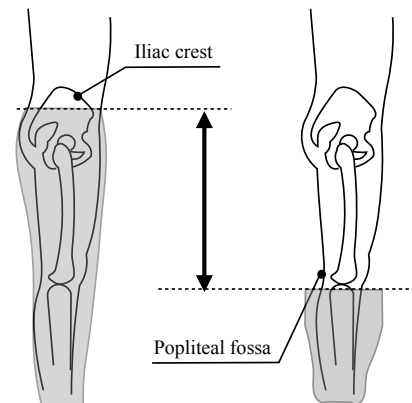


Figure 4. Lifting position of wearing by using the system

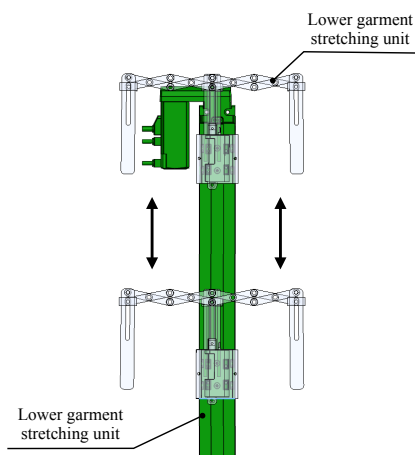


Figure 5. Overview of movement of the lower garment up-and-down unit

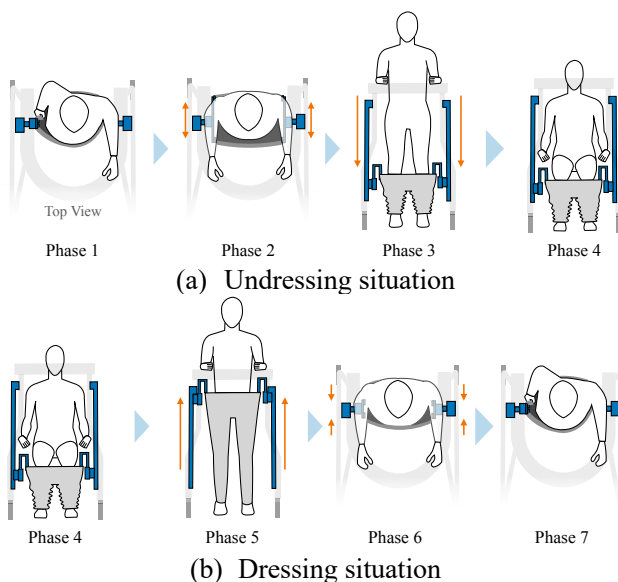


Figure 6. Overview of dressing/undressing using the developed system

Phase 3: The user undresses the lower garment using up-and-down units.

Phase 4: Seating on the toilet seat, excretion, wiping, and flushing.

Phase 5: Standing up from the toilet seat and dressing with the lower garment up-and-down unit.

Phase 6: Closing of the lower garment stretching unit.

Phase 7: The user removes the lower garments from the hooks of the lower garment stretching units.

By operating switches, the developed system stretches, undresses, and dresses in lower garments. The user judges the end of each phase and operates the switches to perform the required actions in each phase.

The lower garment stretching and lower garment up-and-down units were designed to be mounted within the space formed by the width, depth, and height of the frame of the walker used as the weight support unit. This allowed the

system to be portable in toilets without affecting the operability of the walker.

III. EXPERIMENTS

We conducted a lower garment dressing and undressing experiment to confirm the basic performance of the developed system in assisting with the dressing and undressing of lower garments in toilets. The participant in the experiment was one of the authors of this study, an able-bodied person (23 years old, 162 cm, 60 kg) with no difficulty in performing daily living activities. Fig. 7 shows the experimental environment. The experiment was conducted in a multifunctional toilet with a structure similar to that in an actual nursing home. Prior to the experiment, the system was placed in front of a toilet bowl. The participants wore a nursing-care trouser (Care Fashion Co., Ltd., Japan) and boxer briefs (UNIQLO Co., Ltd., Japan), which are used in nursing-care facilities, to simulate an actual nursing-care situation. In addition, to ensure the privacy of the participants, the innerwear was briefly worn under a boxer brief. In the experiment, the hooks of the lower garment stretching unit were placed in a brief, and both the trousers and briefs were undressed and dressed simultaneously. The series of actions mentioned in the system integration section was performed 10 times, and the success rate was evaluated to simulate toilet activities. However, in Phase 4, only standing and sitting on the toilet seat were performed. When both of the following criteria determined from the anatomical positions were fulfilled in the series of actions, the session was judged successful.

1. In Phase 3, the waist opening of the lower garments descends to a height below the popliteal fossa (Fig. 4).
2. In Phase 5, the waist opening of the lower garments raises to a height above the iliac crest (Fig. 4).

The positions of the popliteal fossa and the iliac crest were confirmed by touch. At the end of Phases 3 and 5 of the experiment, the success or failure of dressing and undressing was determined by checking the lower garment waist opening and designated positions visually and from the video recorded during the experiment, respectively. After 10 sessions, the success rate was calculated.

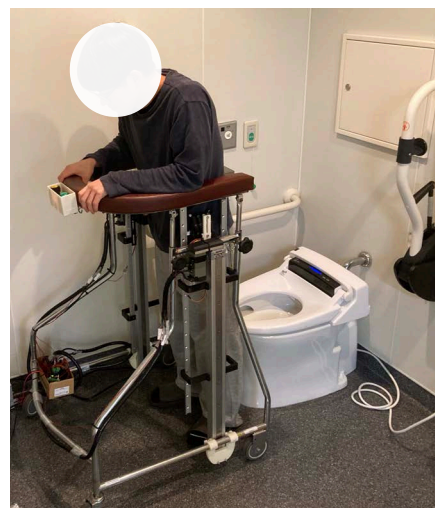


Figure 7. Experimental environment

TABLE I. RESULT OF BASIC EXPERIMENT

	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Session 7	Session 8	Session 9	Session 10
Success or Failure	○	○	○	○	○	○	○	○	○	○
Time required [s]	85	85	77	85	78	89	75	86	74	83

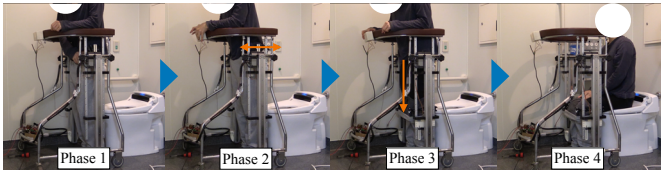


Figure 8. One of the representative results of lower garments undressing

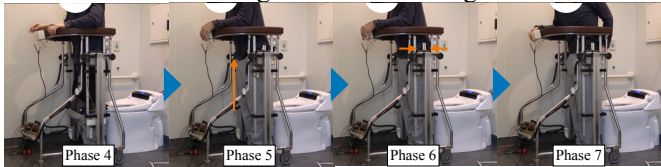


Figure 9. One of the representative results of lower garments dressing

Furthermore, to confirm that the proposed system could assist in dressing and undressing within an acceptable time for use in an actual toilet, we measured the time taken from the start of Phase 1 to the end of Phase 5 of each session. The acceptable time was set at 231 s, which is the minimum toilet assistance time, excluding defecation time, calculated for actual elderly care facilities [14].

IV. RESULTS

Table 1 lists the success or failure and the time required from the start of Phase 1 to the end of Phase 5 of each session. Figs. 8 and 9 show one of the representative results of undressing and dressing. Figs. 10 and 11 show the front view of the dressing and undressing in another session in Phases 3 and 5. The criteria for lowering and raising the lower garments at all of the sessions were fulfilled, resulting in a success rate of 100%. The time required was confirmed to be less than the acceptable time for all sessions.

V. DISCUSSION

In Phases 2 to 7 of the experiment, the lower garment stretching unit maintained the grasping of the lower garments. This suggests that the lower garment stretching unit was capable of sufficiently extending the elastic waist of the lower garment and grasping it using tension for dressing and undressing. The success rate indicates that the developed system can provide stable dressing and undressing support.



Figure 10. Front view of undressing in Phase 3

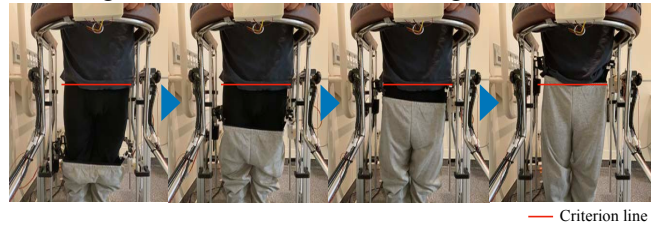


Figure 11. Front view of dressing in Phase 5.

The time required for each session was within the acceptable range for all the sessions, suggesting that the proposed system can provide assistance in dressing and undressing within the acceptable range for use in an actual toilet. We confirmed that the system had the basic performance of dressing and undressing support with grasping and up-and-down of the lower garments, which was necessary before and after excretion. The system is expected to not only reduce the physical and mental burden on caregivers and care receivers but also safely increase opportunities for independent walking to prevent disuse.

In the future, we plan to develop a method to automatically insert the hooks of a lower garment stretching unit to enable care receivers with various conditions, such as decreased finger dexterity, to use the toilet independently. Moreover, we will conduct experiments to verify the safety and feasibility of the system using care receivers with various body shapes and mobility abilities.

VI. CONCLUSION

In this study, we developed a lower garment dressing and undressing portable support system attached to a walker for a care receiver with an independent gait function to support daily toilet activities with dignity. Through a basic experiment with one of the authors of this study, the system could move lower garments for each target height of dressing and undressing without the lower garments coming off during the

process. Furthermore, the system could assist in dressing and undressing within an acceptable time. We confirmed the basic performance of the system in supporting the dressing and undressing of lower garments in the toilet. This system is expected to reduce physical and mental burdens on caregivers and care receivers.

REFERENCES

- [1] United Nations ,“World Social Report 2023”,
<https://www.un.org/development/desa/pd/content/launch-world-social-report-2023> (2024/4/29)
- [2] H. Hazel. “The nurse’s role in helping older people to use the toilet” Nursing standard (Royal College of Nursing (Great Britain) : 1987) vol. 24.2, pp.43-47, 2009.
- [3] Y. Enomoto, et al., "Acute Hospital Nurses’ Recognition of and Approaches to Functional Recovery/Independent Excretion Care for Elderly Patients with Pneumonia" *Asian Journal of Human Services* 14, pp.24-37, 2018.
- [4] E. C. King, et al., "Assisting frail seniors with toileting in a home bathroom: approaches used by home care providers" *Journal of applied gerontology* 38.5, pp.717-749, 2019.
- [5] E. C. King, P. J. Holliday, and G. J. Andrews, "Care challenges in the bathroom: The views of professional care providers working in clients’ homes" *Journal of Applied Gerontology* 37.4, pp.493-515, 2018.
- [6] R. Sumiyoshi, et al., “Toire nai dousa jiritu no tameni hitsuyou na kashi kinryoku oyobi baransu nouryoku no bunseki (Analysis of lower limb muscle strength and balance required for independence in toileting)” , *Physical Therapy Japan Supplement* 2013, pp.0632, 2014 (in Japanese).
- [7] Ministry of Health, Labor, and Welfare, ” Report on the needs and seeds coordination council for nursing care robots nationwide installation and operation ”, <https://www.mhlw.go.jp/content/12300000/000501347.pdf> (2024/4/29)
- [8] K. Yamazaki, et al., "Bottom dressing by a dual-arm robot using a clothing state estimation based on dynamic shape changes" *International Journal of Advanced Robotic Systems* 13.1, pp. 5, 2016.
- [9] Y. Hagihara, Y. Hagihara, “Toire ni okeru ihuku dattiyaku shien system kaihatsu no kokoromi(An Attempt to Develop a Clothes Removing and Dressing Assistance System for Restrooms)” , *Journal of the Society of Biomechanisms* 32.4, pp. 215-220, 2008 (in Japanese).
- [10] H. Kameyama, ”Toire ni okeru ihuku dattiyaku shien system no kaihatsu ni kansuru kenkyu (Research on the development of a support system for dressing and undressing in toilets)” , *The Society of Life Support Engineering* 15.2, pp.72-73, 2003 (in Japanese).
- [11] C. Pettersson, et al., “The impact of the physical environment for caregiving in ordinary housing: Experiences of staff in home- and health-care services”, *Applied Ergonomics* vol. 92, 103352, 2021.
- [12] G. Kathryn et al., “Absorbent products for incontinence: 'treatment effects' and impact on quality of life” *Journal of clinical nursing* 16.10, pp.1936-45, 2007.
- [13] M. Kouchi, et al., “Anthropometric database for Japanese Population1997-98”, Japanese Industrial Standards Center (AIST, MITI), 2000.
- [14] T. Y. Yoto, et al., “Survey of elderly care facilities for the development of toilet assistance devices” *Japan Human Factors and Ergonomics Society* 59.Supplement (2023): P1E5-26.