Proceedings of the 2025 SICE Festival with Annual Conference
September 9-12, 2025, Chiang Mai, Thailand

Compliant Gripper Design Concept for Safe Manipulation of Human-Worn Clothing

Jayant Unde, Jacinto Colan and Yasuhisa Hasegawa

***Abstract*— Safely manipulating human-worn clothing is a key challenge in robotic dressing assistance for aging populations. This paper presents a novel compliant gripper concept specifically for trousers, targeting key issues in physical human-robot interaction (pHRI) safety, adaptability to varied fabrics and body shapes, and reliable operation in confined spaces. Our proposed hybrid gripper integrates a roller gripper module, with a compliant anthropomorphic linkage finger. This synergistic design ensures secure trouser grasping while finger mechanical compliance and a roller module suspension system provide inherent safety. A 3D-printed prototype was produced to validate the concept using bio-compatible materials. Overall, the proposed gripper contributes to bridging critical gaps in assistive dressing technology, paving the way for safer and more effective robotic dressing support.**

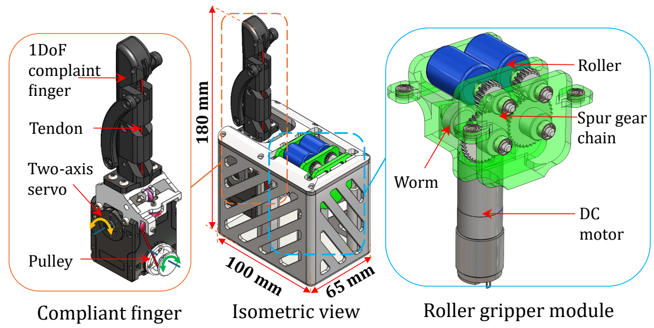

Fig. 1. Proposed compliant gripper design

I. Introduction

Aging global populations, particularly in developed nations like Japan where over 29% are aged 65+, increase the demand for assistive technologies for Activities of Daily Living (ADLs) [1]. Robotic assistance for dressing, especially manipulating trousers, presents significant challenges due to the need for safety in physical human-robot interaction (pHRI), adaptability to diverse body shapes and clothing materials, and reliable handling of non-linear textiles in constrained spaces [2]. Current robotic grippers often struggle to meet these specific demands, particularly for clothing already worn by a person. A key bottleneck is gripper design, needing to balance gentle, secure grasping with the dynamic nature of clothing manipulation during tasks like trouser dressing/undressing. This paper introduces a novel hybrid gripper concept designed specifically to address these challenges, integrating adaptive grasping with inherent compliance for safe and effective human-worn trouser manipulation.

II. Related Work

Manipulating fabrics robotically has seen significant progress, yet handling human-worn clothing, particularly for dressing assistance, remains a challenge. Rigid grippers, typically two-finger parallel-jaw designs, offer precision for tasks like folding fabrics flat but lack the adaptability and inherent safety required for compliant textiles on a human body [3]. Soft grippers, utilizing compliant materials such as pneumatic or tendon-driven designs, provide better safety and adaptability by conforming to surfaces [4]. However, they lack the precision and robust pinch force necessary for specific actions like securely gripping trouser edges. Hybrid grippers attempt to combine rigid and soft elements, with examples including grippers using magnets for precision on specially prepared garments (Mag-Gripper) [5] or those combining compliance with magnetic actuation for dressing (DressGripper) [6]. While promising, existing hybrid designs are not fully optimized for the specific demands of manipulating worn trousers, which require robust edge grasping, slip prevention, and high safety.

Manipulating clothing worn by humans necessitates enhanced safety to prevent injury during close interaction, adaptability to varied body shapes and clothing thicknesses, and functionality within confined spaces such as bathrooms. Existing solutions often lack validation in these real-world scenarios. Our proposed design specifically targets these gaps.

III. Proposed Compliant Gripper Design

Effective manipulation of trousers during dressing and undressing requires a gripper that can securely grasp fabric while ensuring user safety. Building on insights from prior work, we propose a hybrid gripper design that combines a roller module [7] and a compliant linkage finger [8]. This configuration enables safe, firm, and adaptive grasping of garments worn by a human subject.

The roller module is specifically designed to engage a single layer of fabric while avoiding contact with the underlying skin. It achieves this by applying controlled normal and tangential forces, which help separate fabric layers and form a crease. Once the roller securely holds the fabric, an opening is created between the waistband of the trousers and human skin. This opening provides a safe and accessible space for the compliant finger to be inserted. The finger then

This work was supported by JST [Moonshot R&D] [Grant Number JPMJMS2034].

All authors are with the Intelligent Robotics and Biomechatronics Laboratory, Dept. of Micro-Nano Mechanical Science and Engineering, Nagoya University, Nagoya, Japan. unde@robo.mein.nagoya-u.ac.jp

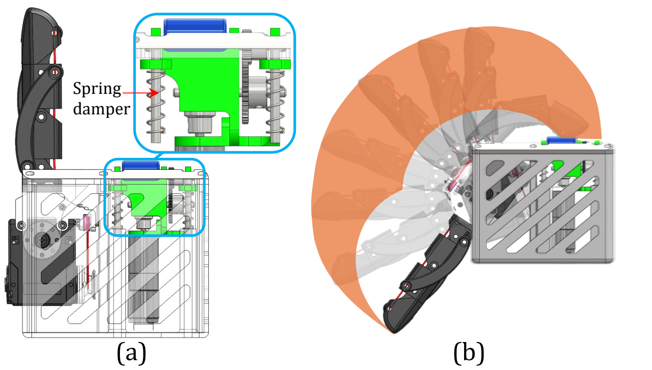

Fig. 2. (a) Spring damper system for roller module (b) Workspace of proposed gripper

Fig. 3. Prototype of proposed compliant gripper

establishes a firm grasp on the fabric. This sequential process ensures both safe interaction with the user and reliable handling of the garment.

A. Roller Gripper Module

This component uses two parallel rollers (Fig. 1), driven by a single DC motor (Faulhaber, 1717T006SR). The rollers rotate inwards (counterclockwise on the right, clockwise on the left) to pull fabric between them, forming a crease. The rollers stop once the crease reaches a set point, securing the fabric. Release involves reversing rotation.

B. Compliant Linkage Finger

This anthropomorphic finger uses two series-connected four-bar linkage mechanisms, mimicking human finger motion but limiting movement past horizontal. It is actuated by a single two axis servo (Dyanmixel, 2XL430-W250) [9] controlling tendon-driven coiling (flexion) and finger orientation (rotation). This extra rotational degree of freedom enhances workspace and opening width (Fig. 2 (b)). The linkage design provides controlled, compliant motion.

C. Integration

The roller gripper module and linkage finger are integrated into one unit as shown in Fig. 1. The roller module is mounted on a suspension system, adding another layer of safety by absorbing external forces during pHRI (Fig. 2 (a)). The combined system provides sufficient grasping force for secure trouser handling while remaining compact for use in confined spaces. This hybrid approach leverages the roller's adaptability and the finger's precision and compliance.

IV. Prototype

As shown in Fig. 3, a prototype was fabricated using 3D printing. The support structure uses PLA-CF (Polylactic Acid - Carbon Fiber) for strength and toughness. The tendon-driven finger uses Formlabs BioMed Black Resin, chosen for its bio-compatibility and rigidity. Roller components are made from PLA, with Gecko Grip pad [10] material selected for the roller surface due to its high friction and non-damaging grip on various fabrics, inspired by gecko adhesion. The prototype weighs approximately 350 grams including the actuator. It is designed to provide adequate grasping force for trouser manipulation tasks.

V. Experimental Evaluation

To quantitatively assess the performance of the proposed gripper, we conducted a series of experiments measuring the peak holding force in the shear direction across three fabric types: Cotton (0.3 mm thickness), Polyester (0.1 mm), and Fleece (0.7 mm). The evaluation focused on three gripper configurations: Finger only, Roller only, and Finger + Roller.

A. Experimental Setup

The experiments were performed using an IMADA force measurement system with a 50N load cell. The gripper was mounted on a test stand, as illustrated in Fig. 4 (a), and actuated via a control system shown in Fig. 4 (c). The control system comprises a Maxon DC motor, EPOS4 motor driver, Raspberry Pi, U2D2 power hub, and a 2-axis Dynamixel servo. Each fabric type depicted in Fig. 4 (b) was tested five times per configuration to ensure statistical reliability.

B. Results

The results, summarized in Fig. 5, show the average peak holding force with standard deviation error bars for each configuration and fabric type.

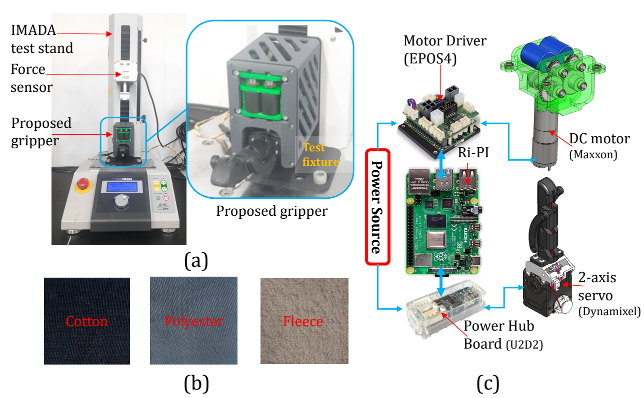

Fig. 4. (a) Experimental setup (b) Test specimens (c) Control system

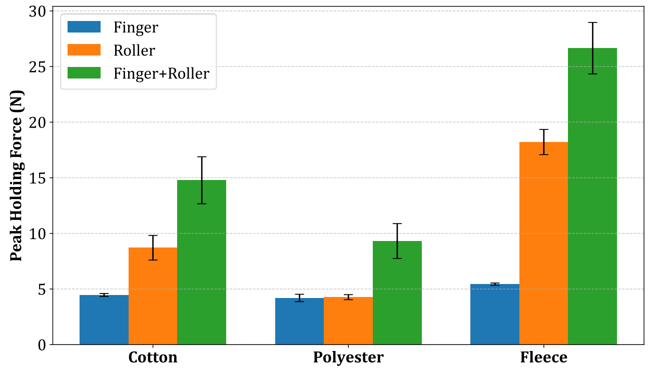

Fig. 5. Experimental results

- Roller module showed moderate performance, outperforming the Finger configuration in all cases, especially on fleece.
- Compliant finger exhibited the lower holding force, with relatively consistent but lower values across all fabrics.
- Finger + Roller consistently achieved the highest holding force across all fabrics, with particularly strong performance on fleece.

These findings confirm that the combination of the roller mechanism with compliant fingers significantly enhances grip strength, particularly for thicker or more textured fabrics like fleece. The roller mechanism alone also contributes substantially to grip performance, while the compliant fingers provide limited holding force when used in isolation.

The experimental results validate the effectiveness of the proposed hybrid gripper design. The synergy between the roller and compliant finger mechanisms enables robust and adaptable gripping across a range of textile materials. This capability is critical for applications in robotic garment handling, where material variability and safe pHRI present significant challenges.

VI. Conclusion

This article presented a novel hybrid gripper concept specifically designed for the safe and effective manipulation of human-worn trousers in assistive dressing scenarios. By combining an adaptable roller mechanism with a compliant linkage finger and incorporating safety features like passive adaptability and a suspension system, the design addresses key challenges in pHRI, material variability, and operational constraints. The prototype demonstrates the feasibility of this approach using suitable materials and fabrication techniques. Experimental evaluations demonstrated the gripper's ability to generate sufficient holding force across various fabric types, with the hybrid configuration outperforming individual components. Future work will focus on experimental validation of the gripper's performance in realistic dressing and undressing tasks (Fig. 6).

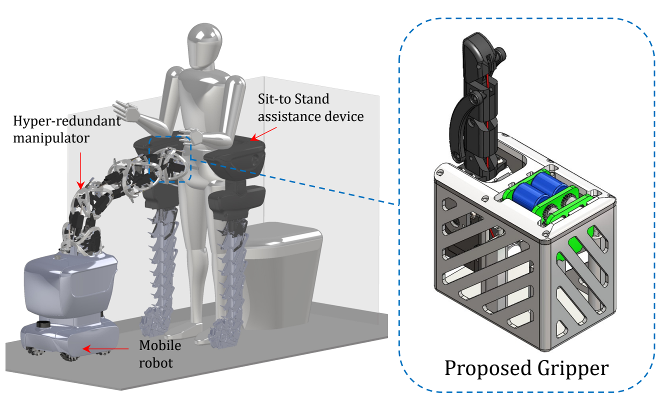

Fig. 6. Prospective application of proposed gripper

References

[1] A. Reuter, T. Bärnighausen, and S. Kohler, "Global ageing and health," in The Routledge Handbook of the Economics of Ageing, Taylor & Francis, 2024.

[2] J. Unde, T. Inden, Y. Wakayama, J. Colan, Y. Zhu, T. Aoyama, and Y. Hasegawa, "Development of a compliant gripper for safe robot-assisted trouser dressing-undressing," Advanced Robotics, vol. 38, no. 19-20, pp. 1424-1440, 2024.

[3] Birglen, L., Schlicht, T., 2018. A statistical review of industrial robotic grippers. Robotics and Computer Integrated Manufacturing 49, 88–97.

[4] J. Shintake, V. Cacucciolo, D. Floreano, and H. Shea, "Soft Robotic Grippers," Advanced Materials, vol. 30, 2018.

[5] S. Marullo, S. Bartoccini, G. Salvietti, M. Z. Iqbal and D. Prattichizzo, "The Mag-Gripper: A Soft-Rigid Gripper Augmented With an Electromagnet to Precisely Handle Clothes," in IEEE Robotics and Automation Letters, vol. 5, no. 4, pp. 6591-6598, 2020.

[6] M. Dragusanu et al., "The DressGripper: A Collaborative Gripper With Electromagnetic Fingertips for Dressing Assistance," in IEEE Robotics and Automation Letters, vol. 7, no. 3, pp. 7479-7486, 2022.

[7] J. Unde, J. Colan and Y. Hasegawa, "Design, Modeling, and Experimental Verification of Passively Adaptable Roller Gripper for Separating Stacked Fabric," in IEEE Robotics and Automation Letters, vol. 9, no. 11, pp. 9335-9342, 2024.

[8] J. Unde, J. Colan, Y. Zhu, T. Aoyama and Y. Hasegawa, "Single Actuator Tendon Driven Two Finger Linkage Gripper with Strong Pinch and Adaptable Cylindrical Grasp," 2023 32nd IEEE International Conference on Robot and Human Interactive Communication (RO-MAN), Busan, Korea, Republic of, 2023, pp. 119-125.

[9] ROBOTIS, "2XL430-W250," e-Manual, 2023. [Online]. Available: `https://emanual.robotis.com/docs/en/dxl/x/2xl430-w250/`. [Accessed: March 6, 2025].

[10] Setex Technologies, "Game Changing Gripping Material," [Online]. Available: `https://www.setextechnologies.com/grips/`. [Accessed: March 6, 2025].