“It Worked on a Mannequin, But Not on a Human”: Lessons from Human Discomfort in Robotic Repositioning

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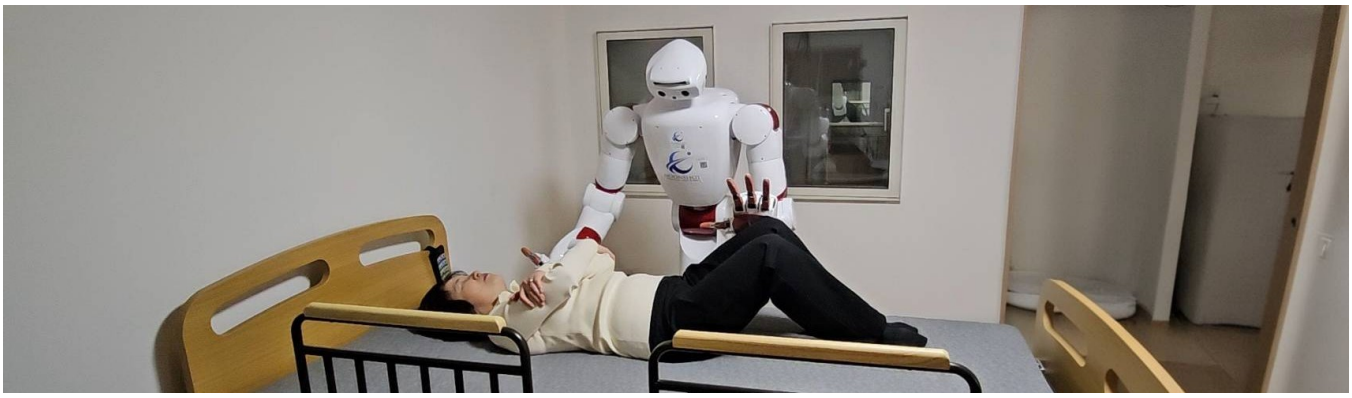

Figure 1: Posture change performed by a robot

Abstract

Physical caregiving tasks such as patient repositioning require close human–robot interaction and impose significant physical burdens on caregivers. In particular, repositioning from a supine to a lateral position involves direct body contact, demanding high levels of safety, adaptability, and comfort. This study proposes an autonomous repositioning method using a humanoid robot that integrates near-range three-dimensional posture recognition, individualized motion trajectory generation, and coordinated dual-arm control. A Mediapipe-based skeletal estimation framework combined with RGB-D sensing enables close-range posture recognition, while patient-specific trajectories are generated based on the initial body configuration. Furthermore, a biomechanical model is introduced to estimate optimal pushing timing, reducing the force required during shoulder manipulation. Experiments conducted with mannequins of varying body sizes demonstrate the feasibility of the proposed approach. However, experiments with human subjects revealed that even when performing identical motions, participants experienced discomfort depending on factors such as hand insertion direction and surface friction. These findings highlight a misalignment between mechanically feasible motions validated on mannequins and the lived bodily experiences of human subjects. We argue that designing robotic caregiving motions requires not only feasibility-driven validation but also experience-centered evaluation and iterative redesign grounded in human feedback.

1 Introduction

In healthcare, rehabilitation, and daily living support, robots are increasingly required to engage in direct physical interaction with humans [8]. In these settings, touch is not merely a means of task execution but a critical element that shapes how robotic assistance is experienced, particularly in terms of comfort, safety, and trust [2]. Despite this, robot-initiated touch is still commonly designed and evaluated primarily based on kinematic feasibility or task success, while the human felt experience is often treated as subjective, implicit, and difficult to formalize within motion design frameworks [3, 7]. This has led to a persistent gap between qualitative human feedback and the concrete behaviors of caregiving robots deployed in close physical contact.

This study focuses on automated repositioning from a supine to a lateral position using a humanoid robot, a caregiving task that requires sustained bodily contact and close coordination between human and robot. To autonomously perform this task in real-world bedside environments, high-precision posture recognition and motion planning that adapt to individual physical characteristics are essential, particularly under near-range and spatially constrained

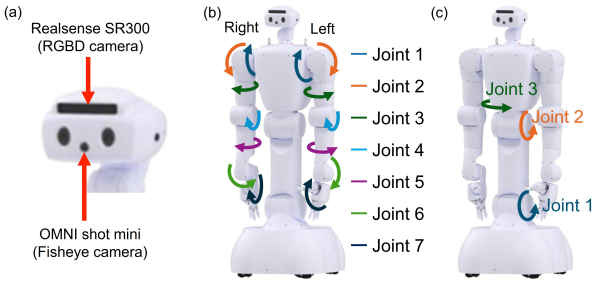

Figure 2: (a)Cameras (b) Arm Joints (c) Torso Joints

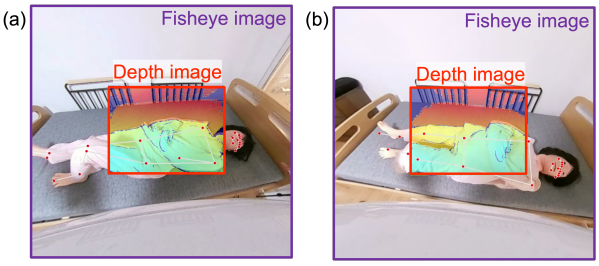

Figure 3: Camera View

conditions [5, 6]. In this approach, we first validate the effectiveness of the proposed patient-specific repositioning motions using mannequins. We then conduct experiments with human participants to investigate which design factors are critical when robots physically contact humans. Through experiments with mannequins and human participants, we reveal a misalignment between mechanically feasible motions and human bodily experience, and discuss the implications of this gap for the design of acceptable and comfortable physical human–robot interaction in caregiving contexts.

2 Proposed Method

2.1 Robot Platform and Sensing Setup

Experiments were conducted using the humanoid robot Dry-AIREC (Tokyo Robotics Inc., Tokyo, Japan). A wide-angle fisheye camera and an RGB-D camera are mounted on the robot head to capture visual and depth information (Fig. 2(a)). Dry-AIREC is equipped with 7-DOF arms and a 3-DOF torso and supports impedance control, enabling compliant physical interaction with humans (Fig. 2(b)(c)).

2.2 Near-Range 3D Posture Recognition

For posture recognition, a Mediapipe-based skeletal estimation model was applied to fisheye camera images to detect 33 body joints [1]. After distortion correction, the fisheye images were aligned with the RGB-D depth images to estimate three-dimensional joint positions (Fig. 3). To reduce frame-to-frame noise, joint coordinates were averaged over 5 consecutive frames.

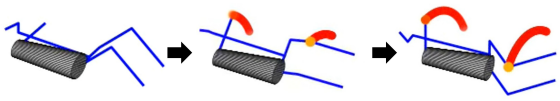

Figure 4: Patient Model for Trajectory Calculation

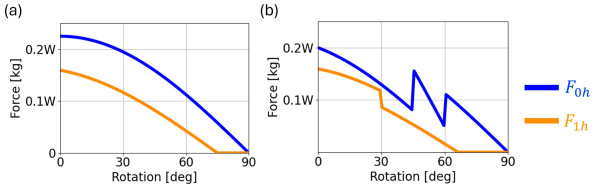

Figure 5: Required force (a) When pushing shoulders and knees simultaneously (b) When pushing knees 30 degrees ahead

2.3 Individualized Motion Trajectory Generation

To adapt robot motion to individual body shapes, patient motion trajectories were predicted based on initial joint positions. The body–bed contact surface was modeled as a truncated cone, and joint trajectories were predicted by rotating the model from 0 to 90 degrees (Fig. 4).

2.4 Biomechanical Model and Estimation of Pushing Timing

To reduce the force required for repositioning, the human body was divided into upper and lower segments, and moment equilibrium equations were derived [9]. Optimal timing for initiating pushing forces was calculated as a function of rotation angle [10]. Simulation results showed that initiating knee rotation prior to shoulder pushing can theoretically reduce the required shoulder force.

3 System Validation with a Mannequin

3.1 Experiment

Position change experiments were conducted using six mannequins of varying sizes and weights. Trajectories generated using the proposed close-range posture recognition and trajectory prediction from the initial posture were implemented on the robot. After rotating the left knee 30 degrees, the left shoulder was sequentially lifted.

3.2 Results and Discussion

For all mannequins, the robot successfully achieved positional changes from the supine position to the lateral recumbent position. Figure 6 shows an example of the robot performing a positional change on a mannequin. These results indicate that the proposed reaching and rotation strategy is mechanically feasible across a range of body dimensions, serving as a baseline for subsequent human experiments.

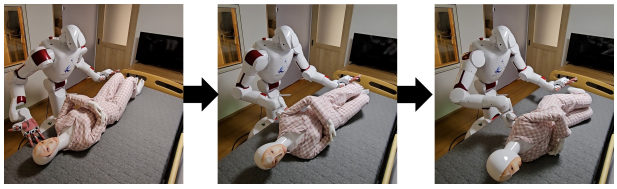

Figure 6: Rotation of a Mannequin

4 Human Experiment

4.1 Experiment

The same position-changing experiment performed on mannequins was conducted on 7 human participants ranging in age from their 20s to 60s. To examine the influence of motion sequencing, the initial rotation angle of the left knee was varied across three conditions: 0, 15, and 30 degrees.

Following the procedure, patients completed a questionnaire assessing their comfort during the procedure, using a 7-point Likert scale for evaluation[4].

All human experiments were conducted with informed consent from the participants, and the experimental protocol was approved by the Waseda University Research Ethics Committee (Approval No. 2025-291).

5 Results and Discussion

The subjective evaluation results from the questionnaire are shown in Figure 7. However, the experiment was discontinued for the action of simultaneously pushing the shoulder and knee because some subjects reported pain. Therefore, the figure shows only the results when the knee was rotated first, either 15 degrees or 30 degrees ahead.

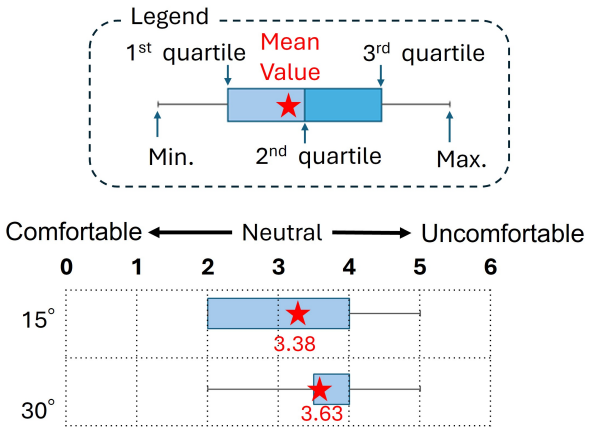

Figure 7: Results of human experiments

The results of the open-ended questionnaire administered after completing the position change are shown below.

- When inserting the robotic hand, the fingers get stuck on the shoulder and pain occured (Fig. 9(a))

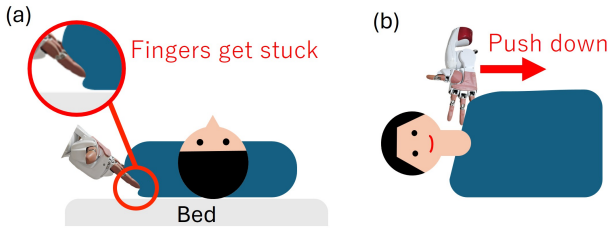

Figure 8: Cause of discomfort

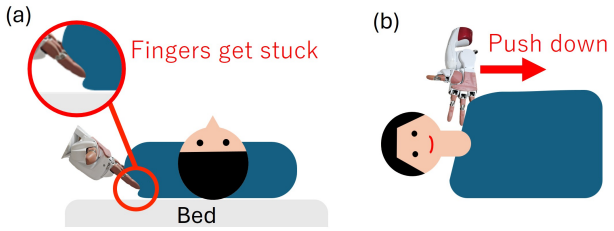

Figure 9: Cause of discomfort

- It feels uncomfortable because the shoulder is rotated while being pushed down (Fig. 9(b))
- Please push the knees further inward to make it easier to lift the shoulder

These qualitative responses reveal that discomfort was not caused by task failure, but rather by how physical contact was initiated and sustained. Specifically, the insertion direction of the robotic hand, surface friction of the hand, and the angle at which the knee was pushed forward played a critical role in shaping participants' comfort.

These findings indicate that mechanically feasible motions validated on mannequins may still lead to discomfort in human interaction, underscoring the importance of incorporating human experience and qualitative feedback into the design of physical human–robot interaction.

In addition, feedback from participating healthcare professionals emphasized that patients who require frequent repositioning often have joint contractures or fragile skin. This underscores the need for robotic repositioning motions to prioritize safety and gentleness, particularly for populations who are most vulnerable to physical contact.

Future improvement proposals include considering the use of low-friction materials for the robot hand and changing the hand insertion direction from above the shoulder to from the side (Fig..

6 Conclusion

This study presented an autonomous repositioning method for transitioning a person from a supine to a lateral position using

a humanoid robot, focusing on safe and comfortable physical human–robot interaction. By integrating near-range posture recognition, individualized motion trajectory prediction, and biomechanically informed pushing timing, the proposed system enables adaptive assistance tailored to the patient's initial posture.

Experiments using mannequins confirmed the mechanical feasibility of this method across various body types. However, experiments with human subjects revealed that even when performing identical motions, discomfort could arise due to factors such as the insertion direction of the robotic hand and the friction level of the hand. This suggests that when designing robotic movements, it is necessary to base the design not only on the feasibility of the action but also on the subject's experience. These findings indicate a misalignment between mechanically feasible motions and the lived bodily experiences of human subjects. They suggest that designing robotic caregiving motions requires not only feasibility-driven validation but also experience-centered evaluation that accounts for subjective comfort and perception during physical human–robot interaction.

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