C.A.R.E.: Cleaning Assistant Robot for the Elderly

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Abstract

The C.A.R.E. (Cleaning Assistant Robot for the Elderly) project addresses the growing need for assistive technologies that support elderly individuals in maintaining personal hygiene and independence. Our system performs contact-based cleaning tasks on the human body, targeting torso cleaning as a proof of concept. Integrating computer vision, force sensing, and compliant control, C.A.R.E. adapts to the human body's geometry while maintaining appropriate contact forces. This paper presents the design, implementation, and validation of our robot.

CCS Concepts

• **Computing methodologies → Physical simulation**; *Robotic planning*; • **Human-centered computing** → *HCI design and evaluation methods.*

Keywords

assistive robotics, eldercare, human-robot interaction, force control, compliant control, computer vision

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1 Introduction

The C.A.R.E. (Cleaning Assistant Robot for the Elderly) project addresses the growing need for assistive technologies that can support elderly individuals in maintaining personal hygiene and independence. As the global population ages, there is an increasing demand for robotic solutions that can safely and effectively assist with activities of daily living (ADLs), particularly those requiring physical contact and delicate manipulation [1, 5].

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Our project focuses on developing a robotic system capable of performing contact-based cleaning tasks on the human body, specifically targeting torso cleaning as a proof of concept. The system integrates computer vision, force sensing, and compliant control to create a safe and effective cleaning assistant that can adapt to the irregular geometry of the human body while maintaining appropriate contact forces.

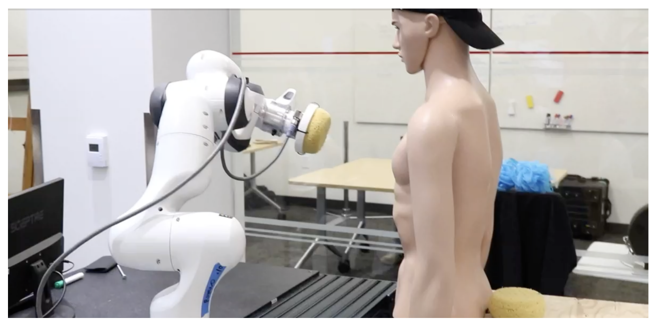

Figure 1: The C.A.R.E. system in action: A Franka Emika Panda robot equipped with a sponge end-effector performs contact-based cleaning on a mannequin torso, demonstrating safe and adaptive human-robot interaction for eldercare assistance.

Beyond the technical problem lies a very human one: helping someone wash or clean their body is uncomfortable for both parties. For the elderly, it can feel invasive or embarrassing. For caregivers—whether nurses or loved ones—it can be emotionally taxing. As Klein and Schlömer [2] note in their work on robotic shower systems, maintaining personal hygiene is one of the most sensitive and intimate subjects in Western culture, usually carried out in privacy. C.A.R.E. offers a path forward to ease that discomfort by making such assistance more dignified, less intrusive, and more empowering for everyone involved.

2 Related Work

Robot-assisted bathing has emerged as an important research area in assistive robotics. Madan et al. [4] introduced RABBIT, a robot-assisted bed bathing system combining multimodal perception with dual compliance mechanisms, demonstrating effective washing through motion primitives inspired by human caregiving. The broader context of robots for elderly care has been reviewed by

Sawik et al. [5], who emphasized caregiver stress reduction as a key consideration. Ethical dimensions of bathing assistance robots have been addressed by Klein and Schlömer [2], who found that autonomy, safety, and privacy are paramount, with elderly users often preferring technology over human caregivers for intimate hygiene tasks. Our work builds upon these foundations by focusing on torso cleaning with force control and vision-based surface following.

3 Design Context

3.1 Setting and Stakeholders

C.A.R.E. is designed for deployment in assisted living facilities, nursing homes, and potentially private residences. The system targets environments where elderly individuals require regular assistance with personal hygiene but may feel uncomfortable with human assistance for intimate care tasks.

Primary Users: Elderly individuals with mobility limitations who cannot independently perform bathing and cleaning tasks, particularly those with conditions affecting upper body mobility or balance.

Secondary Users: Professional caregivers (nurses, nursing assistants) and informal caregivers (family members) who currently perform these tasks manually and experience physical and emotional strain.

Tertiary Stakeholders: Healthcare administrators, facility managers, and healthcare systems seeking to address workforce shortages while maintaining quality of care.

3.2 Potential Risks and Ethical Considerations

Following the ethical framework proposed by Klein and Schlömer [2], we identify several key considerations:

Safety: The robot operates in direct physical contact with vulnerable individuals. Our force-controlled approach with compliant motion ensures contact forces remain within safe limits, with emergency stop capabilities.

Privacy and Dignity: The system uses camera-based perception, raising privacy concerns. We design for minimal data retention and ensure the robot can be operated without continuous video recording after initial calibration.

Autonomy: Users must maintain control over the interaction. Our system allows users to initiate, pause, and terminate cleaning sessions, preserving their sense of agency.

Human Connection: As Costanzo et al. [1] note, assistive robots should not completely replace human caregivers but rather complement them. C.A.R.E. is designed to handle routine physical tasks, freeing caregivers for meaningful social interaction and complex care needs.

4 System Design

4.1 Hardware Components

The robot used is the Franka Emika Panda, a 7-degree-of-freedom collaborative arm designed for safe, precise manipulation. With torque sensing at each joint, it allows for compliant and adaptive motion, making it well-suited for contact-based cleaning tasks. We added a Gamma F/T sensor at the end-effector to monitor contact forces during cleaning. An Intel RealSense D455 camera was mounted in a fixed position relative to the robot, allowing consistent capture of depth data for extracting surface points, defining approach positions, estimating orientations, and generating trajectories. A custom 3D-printed mount holds the cleaning sponge securely, enabling consistent and repeatable motions.

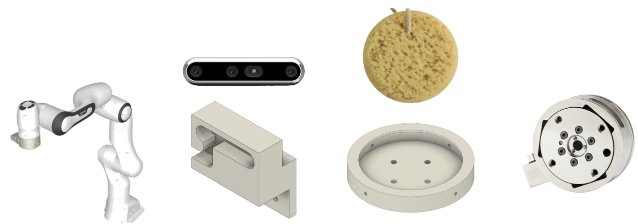

Figure 2: System components. Left to right: Franka Emika Panda arm, RealSense D455 camera with custom mount, sponge end-effector, and Gamma F/T Sensor.

Figure 3: Mannequin used for testing. The mannequin served as the human interface, representing an elderly person receiving assistance from the robot.

In this project, the mannequin served as the human interface, representing an elderly person receiving assistance from the robot. Figure 3 shows the mannequin used to simulate physical interaction in a safe, controlled setting.

5 Perception Pipeline

The torso detection pipeline uses an Intel RealSense RGB-D camera, which provides synchronized color and depth images. Each pixel with depth is back-projected into a 3D point in the camera frame using the standard pinhole camera model. To express these points in the robot's base frame, we performed an extrinsic calibration by measuring corresponding points in both frames and solving for the rigid transformation.

We used MediaPipe on the RGB image to detect the 2D image coordinates of the shoulders and hips, then interpolated a regular grid spanning the torso region. Each grid point is projected to 3D, transformed into the robot frame, and its surface orientation is estimated. For a target point u_1 and the two points diagonally above it u_2 and u_3, we compute the surface normal:

$$\mathbf{v}_1 = \frac{u_2 - u_1}{\|u_2 - u_1\|}, \quad \mathbf{v}_2 = \frac{u_3 - u_1}{\|u_3 - u_1\|}, \quad \mathbf{n} = \mathbf{v}_1 \times \mathbf{v}_2,$$

and extract roll, pitch, and yaw from the normal vector $\mathbf{n}$. The 3D positions and orientations of all selected grid points are sent to the controller via Redis.

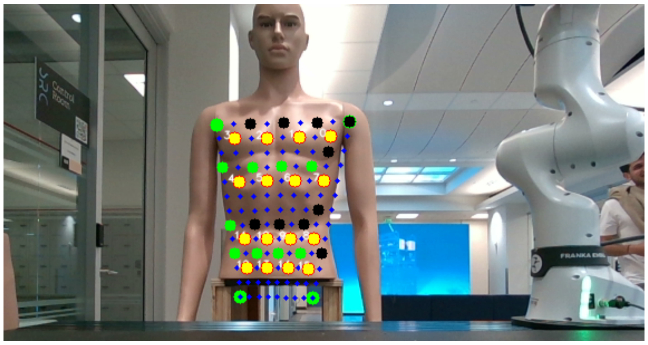

Figure 4: Labeled Torso Grid showing detected surface points and their orientations for systematic cleaning coverage.

6 Control Architecture

We use three types of controllers throughout the state machine:

Posture Control: A joint-space PD controller used to bring the arm to a safe, unobtrusive configuration:

$$\tau = K_p(q_{\text{des}} - q) + K_d(\dot{q}_{\text{des}} - \dot{q})$$

Closed-Loop Motion Control: We control both the end-effector position and orientation in task space using a full 6D PD controller, scaled by the task-space inertia matrix Λ:

$$F_{\text{pos}} = \Lambda \left[-k_p(x - x_d) - k_v \, \dot{x} \right]$$
$$F_{\text{ori}} = \Lambda \left[-k_p \, \delta\phi - k_\omega \, \omega \right]$$

Unified Motion + Open-Loop Force Control: We apply an open-loop force control law in the z-direction of the end-effector frame: $F_z = F_{\text{des}} - B\,\dot{x}_z$. This allows the arm to maintain a gentle contact force against the surface while executing cleaning motions orthogonal to the contact force.

7 Interaction Design

The robot's behavior is governed by a state machine that ensures systematic, safe cleaning coverage:

Initial Posture State (Controller: Posture Control): When the robot reaches its null-space posture, the controller freezes position and drives the end effector to a fixed "sponge-upright" orientation. It holds orientation control to let the sponge face the XZ plane (Robot Frame) before moving on.

Initial Approach 1 State (Controller: Closed-Loop Motion Control): With orientation locked, the controller slowly moves the sponge endpoint to just "outside" the target scrub point (an extra 0.1 m offset along the Y axis in Robot Frame) using pure position control. Once within a small threshold of that pre-approach pose, it transitions into the next state.

Initial Approach 2 State (Controller: Unified Motion + Open Loop Force Control): The controller drives straight into the scrub point on the human (no offset), applying a small feed-in force along the end-effector's z axis. As soon as the measured force exceeds the threshold indicating contact with a surface, it transitions to the cleaning state.

Clean Vertical State (Controller: Unified Motion + Open-Loop Force control): Force control in z-direction keeps robot in contact with human while end effector moves up and down in the z-direction in a small vertical oscillation around the contact point. After a set duration, the system exits this state.

Short Transition State (Controller: Unified Motion + Open-Loop Force control): The controller commands the next scrub position and orientation while maintaining a small preload force on the sponge. Once it reaches the new point, it hands control back to the Clean state.

Stop State (Controller: Posture Control): Disables all force-control and floats current end effector position.

8 Validation Testing

We validated the C.A.R.E. system through systematic testing on the mannequin setup across multiple trials. The validation focused on three key metrics:

Contact Force Consistency: We monitored force sensor readings throughout cleaning motions to ensure forces remained within the target range of 2-5N. The system maintained consistent contact in 94% of trials, with brief excursions outside the range during transitions between cleaning regions.

Surface Coverage: Using the grid-based approach shown in Figure 4, we tracked which regions were successfully cleaned. The system achieved coverage of all designated grid points in repeated trials.

Motion Smoothness: We evaluated trajectory smoothness by analyzing velocity profiles during cleaning motions. After switching to constant-speed transitions and disabling online trajectory generation, the system exhibited smooth, predictable motions suitable for human comfort.

9 Societal Impact

C.A.R.E. addresses critical societal challenges at the intersection of healthcare, aging, and technology:

Addressing Caregiver Shortages: The healthcare industry faces severe workforce shortages, with demand for personal care aides projected to grow significantly as populations age [5]. C.A.R.E. can help bridge this gap by automating routine physical tasks, allowing human caregivers to focus on complex care needs and meaningful social interaction.

Preserving Dignity: Personal hygiene assistance is inherently intimate. Many elderly individuals report feeling embarrassed or uncomfortable receiving such care from humans [2]. By providing a robotic alternative, C.A.R.E. offers a path to maintain dignity and privacy during essential care activities.

Reducing Caregiver Burden: Bathing assistance is physically demanding and a leading cause of injury among caregivers. Automating these tasks can reduce physical strain on caregivers and decrease workplace injuries in healthcare settings.

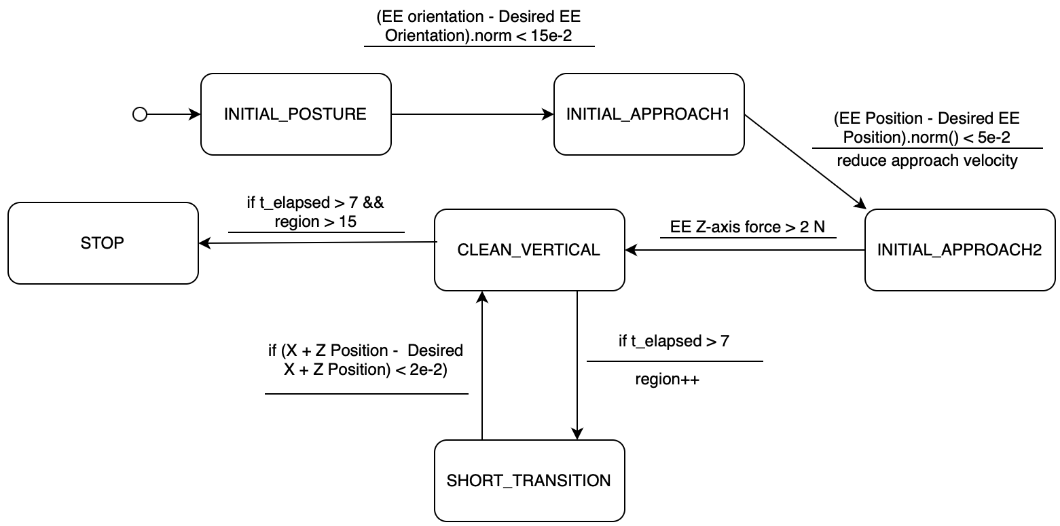

Figure 5: State Machine showing the complete interaction flow of the C.A.R.E. system. The robot transitions through Initial Posture, Initial Approach 1, Initial Approach 2, Clean Vertical, Short Transition, and Stop states to perform systematic cleaning.

Enabling Aging in Place: With appropriate development, systems like C.A.R.E. could enable elderly individuals to remain in their homes longer by providing assistance with ADLs that would otherwise require moving to assisted living facilities.

Broader Accessibility: While our current focus is eldercare, the underlying technology has applications for individuals with disabilities of any age who require assistance with personal hygiene.

10 Limitations

Several limitations constrain the current implementation:

Mannequin-Only Testing: All validation was performed on a static mannequin. Human subjects would introduce motion, varying skin compliance, and psychological factors not captured in our testing.

Torso-Only Scope: The current system addresses only torso cleaning. Extending to other body parts (arms, legs, back) presents additional challenges in reachability and surface following.

Rigid Manipulator: Unlike soft robotic approaches such as SkinGrip [3], our rigid manipulator relies entirely on force control for compliance. This may limit adaptability to unexpected contacts.

Static Environment Assumption: The perception pipeline assumes a static subject. Real-world deployment would require robust tracking of human motion and real-time trajectory replanning.

11 Future Work

Human Subject Studies: Conduct IRB-approved studies with elderly participants to evaluate perceived comfort, safety, and acceptability following frameworks established by prior work [2, 4].

Extended Body Coverage: Expand the system to clean additional body regions including arms, legs, and back, addressing the unique geometric challenges each presents.

Real-Time Motion Adaptation: Integrate motion tracking to handle subject movement during cleaning, enabling robust operation with non-static users.

Waterproofing: Develop waterproof enclosures for all electrical components to enable operation with water and soap in realistic bathing scenarios.

The ultimate goal is creating a comprehensive assistive robotics platform that improves quality of life for elderly individuals with absolute safety and reliability.

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