Ointment Care Robot for Limited Mobility Users

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I. MOTIVATION

The application of topical ointment may seem like a simple part of one's personal self and wound care routine, but for many individuals with limited upper body mobility (estimated 19 million people in the United States [1]), it can become physically demanding or even impossible. People with limited mobility, recovering from surgery or those living with conditions such as severe arthritis, cerebral palsy, spinal cord injuries may struggle to reach parts of their body where ointments need to be applied [2]. This commonly includes the back, shoulders, or legs. Additionally, regular sunscreen application is crucial for skin cancer prevention [3].

For those without consistent caregiver support, this task becomes not only a matter of physical limitation but also of health and dignity. Failure to apply necessary creams and medications can lead to serious consequences, including untreated wounds, skin infections, and deterioration of chronic conditions like eczema or edema. Additionally, asking others for help with such intimate care can be uncomfortable, making autonomy in this area particularly valuable [4]. The ability to manage ointment application independently would not only alleviate pressure and reduce in-person contact time with caregivers but could also restore a sense of privacy and self-reliance for users.

Although the importance of consistent topical medication for chronic skin conditions, wounds and more is well documented in medical research, and assistive devices for manual application have been explored [5], to our knowledge, fully robotic solutions for more autonomous ointment application remain an underexplored area. Previously, collaborations between the UW and Hello Robot have explored tele-operated ointment and lotion application.

In this project, we developed an assistive robotic system using the Stretch RE2 mobile manipulator to address the challenge of ointment application for users with limited mobility. Our initial system focuses specifically on the leg, a region that is often difficult for individuals to reach independently. We designed a brush applicator that provides an effective and comfortable user experience. The system combines autonomous application with human-in-the-loop interfacing to maintain accuracy, user trust and to ensure safe, adaptive contact with the skin. This project lays the foundation for future work on additional body regions and represents an early step toward empowering individuals with limited mobility to manage more aspects of their personal care independently.

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II. RELATED WORKS

A. Understanding the target user

Wound care is a labor-intensive aspect of healthcare, particularly affecting populations with mobility impairments, chronic illness, or advanced age. A retrospective observational study found that frequent dressing changes are associated with increased nursing workload in intensive care units, compounding care challenges especially for older adults and those with extended hospital stays [6]. In a broader healthcare context, Lindholm and Searle highlight that while dressing materials contribute to cost, it is predominantly the nursing time and hospital infrastructure that drive up expenses [7].

To optimize outcomes and reduce burden, personalized wound care must consider factors like wound type, moisture levels, and patient comorbidities [8]. Additionally, the rising aging population and nursing shortages underscore the need for assistive technologies to support healthcare and caregiving staff [9]. Perspectives from older adults on robotic assistance are nuanced. While many support help with chores, there is hesitancy when it comes to personal care tasks [10], [11]. This indicates a need for human-centered design in assistive technologies, especially in sensitive medical tasks like wound and other forms of personal care.

B. Existing solutions

Several recent studies demonstrate the use of robotics in medical and assistive applications. AutoPeel is the first robotic system designed for safe wound dressing removal [12]. Using physics-based simulation and model predictive control, the system ensures safe interaction with both human and non-human subjects. While this represents progress in robotic wound care, its focus is on dressing removal.

Other work achieves robot-assisted dressing by developing a force-sensing method that allows robots to estimate what a person physically feels during garment manipulation [13]. This highlights the importance of force perception when interacting directly with humans, a concern that also applies to wound application context. Lastly, note that many systems fail to adequately address user autonomy preferences or involve actual target users in testing—gaps our project aims to avoid [14].

On the interface side, findings have emphasized the tradeoffs between user autonomy and system control, suggesting a need for flexible autonomy levels depending on task complexity and user comfort [15]. This is especially relevant for our project, which explores ointment application robots that must offer both safety and user-centered interaction models.

Our work builds on these insights by focusing on a robot that not only aids in wound care, ointment application and general personal care but does so with a balance of autonomy and human-in-the-loop work, a focus on reducing nursing workload, improving patient safety, and respecting user preferences.

III. System

A. Design

Our design decisions were grounded in insights from interviews with individuals with eczema, professional caregivers, and an occupational therapist from Hello Robot. These conversations revealed not only physical constraints in ointment application, but also emotional, logistical, and environmental factors that shaped every aspect of our system.

Early in the process, we explored applying ointment to the back or spine, but interviews quickly revealed this would require assistance from a second person due to the need for consistent positioning, garment removal, and difficult reach angles. In contrast, users described the legs as one of the hardest areas to reach on their own, yet still accessible enough to support independent care with the right assistive tool. This helped us scope the robot toward the leg region, striking a balance between ease of access and meaningful impact.

The decision to use a brush-based application method stemmed from user comments about how applying ointment to dry, cracked skin could be painful. A brush offered a way to spread ointment gently and evenly without requiring the user to rub it in with force. During testing, one user described the brush as feeling "gentle and deliberate". The user also emphasized that they often delay treatment when they're tired or alone, especially before bed. This shaped our emphasis on a system that could be used while seated, with minimal prep.

Interviews also highlighted the emotional toll of relying on others for skincare. One user described this as "vulnerable" and said asking for help, particularly for intimate or repetitive tasks, undermined their sense of autonomy. As a result, we prioritized user agency throughout the design. Rather than fully automating the process, we designed a system that users can manually calibrate and control using a simple, easy-to-understand GUI. Through the interface, users can micro-adjust the robot's position and define the area to apply ointment. To ensure user understanding of Stretch, our GUI provided a popup of a labeled Stretch diagram highlighting the parts that are involved in the ointment application task (see Figure 1).

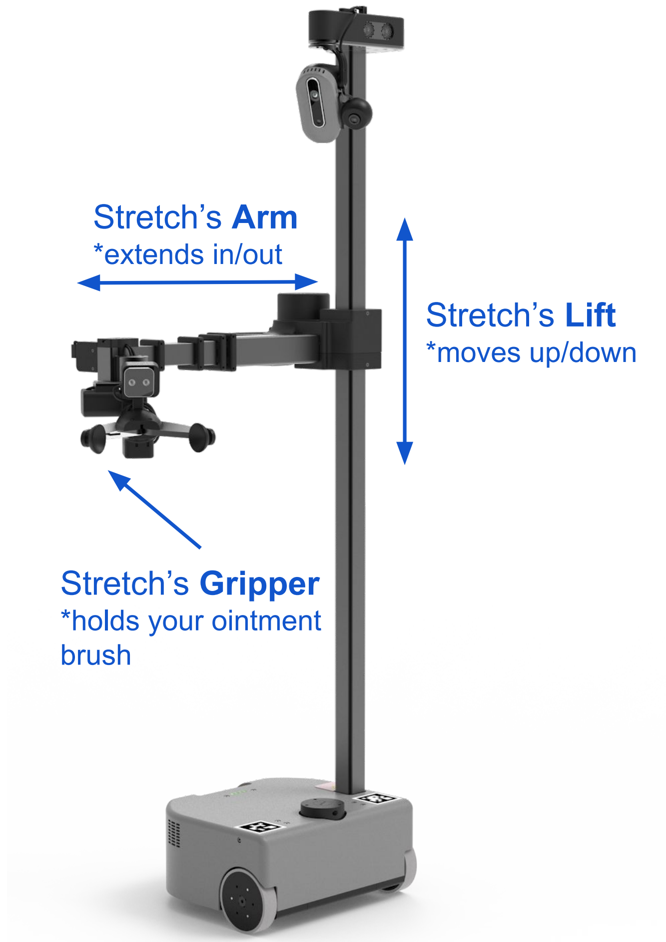


Fig. 1. The provided labeled Stretch diagram in GUI.

The stop button was another crucial addition driven by user concern about safety. One participant specifically noted they felt most secure when they could halt the process at any time. We made this a central part of the interface, allowing for immediate shutdown in case of discomfort or error. From a design standpoint, this also aligned with caregiver input, who recommended additional fail-safes such as speech-based control for patients with more severe mobility limitations.

Each of these choices was shaped not by assumptions, but by lived experiences shared in our interviews. By grounding our design in these real-world constraints and values, we aimed to create a system that empowers users.

Our interview questions related to designs are listed below.

Caregiver / Occupational Therapist Questions

- How often are you responsible for applying ointment to patients or residents?
- How many times a day are you required to do so? What happens if you aren't able to apply ointment consistently?

- What types of patients require the most assistance with ointment application?
- What areas of the body do patients struggle with applying ointment to?
- What are some of the challenges you face while helping with wound care or topical treatment?
- On average, how much time does this task take per patient (including navigation, prep, and more)?
- Do you feel this task takes time away from other aspects of care?
- How physically demanding or repetitive is ointment application in your daily workflow?
- How comfortable do patients typically feel asking for help with this?
- After seeing the robot demonstration, how do you think it could fit into a real care environment?
- Would a tool like this help you reduce workload or free up time for other caregiving tasks?

User Questions

- Can you describe your daily routine when it comes to applying ointment or lotion?
- Are there specific areas of your body that are especially hard for you to reach?
- What happens if you aren't able to apply ointment consistently?
- How often do you rely on someone else to help you with this task?
- Without applying ointment, how much does eczema interfere with your daily life?
- When you are regularly applying ointment as prescribed, how much does eczema still interfere with your daily life?
- What specific aspects of your life improve the most when you apply ointment consistently?
- What ointments do you use if you're comfortable sharing? How thick are they?
- Would it feel uncomfortable to rely on someone else for something as personal as wound / skin care?
- Have you ever delayed or avoided treatment because it was too hard to apply?
- When you skip or delay treatment, how much worse do your symptoms get?
- Do you feel your eczema would improve if you could apply ointment more consistently?
- Does relying on others for ointment application affect your sense of independence?

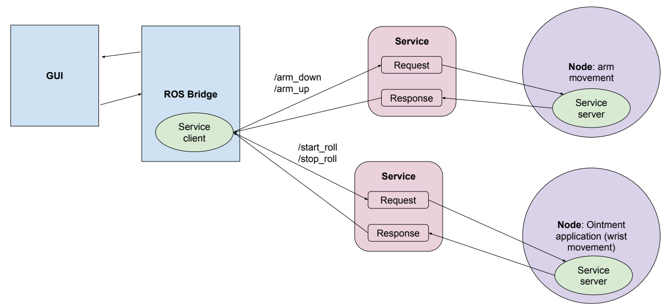
B. Robot Platform

We use the Stretch RE2 mobile manipulator, developed by Hello Robot. Stretch has a differential drive base and a 3 degree-of-freedom manipulator. The manipulator consists of a telescoping arm that extends 50cm horizontally and a prismatic lift that reaches 110cm vertically. The arm has a 1 degree of freedom gripper attached to a rotational joint. For sensing, Stretch has a Lidar sensor attached to its base, a Realsense camera attached to a pan-tilt head, and two fixed fish-eye cameras: one with an overhead view of the base and arm and the other with a view of the gripper.

C. Custom hardware

We designed a custom, detachable, and soft brush attachment that we can secure to the robot's gripper. Rather than using tape, which poses reliability and hygiene concerns, we used a foam mounting bracket that locks into the gripper using its force-closing mechanism and integrated notches.

D. Software



Our system utilizes a variety of tools and packages to enable smooth interactions between Stretch, the GUI, and the user, including ROS 2, Python, JavaScript (roslibjs), and RViz. These components work together to coordinate robot motion, user feedback, and safe physical interaction.

To enable safe and effective ointment application, the robot uses programming by demonstration. A custom script records a demonstrated motion sequence, which the robot can then repeat. We allow the user to halt motion if excessive force is detected, maintaining user comfort.

A web-based GUI built with rosbridge server and roslibjs ties the system together. It lets users calibrate the application area, start or stop the motion, and monitor the robot's behavior. By centralizing control and feedback, the GUI ensures an intuitive and reliable user experience.

IV. Evaluation

Our evaluation involves systematic testing of the robot across different configurations and a user study.

As a comparative evaluation, we compared our robot-based solution with an application brush vs a human caregiver performing the ointment treatment task.

A. System Evaluation

1) Tasks: Our main evaluation task was focused on the robot applying medical ointment using our brush attachment. Our sub-tasks involved the following:

- **Ointment application to brush:** The robot positioning the brush in an easy-to-access spot for the user to apply the ointment to the brush.
- **Application area identification** The robot must correctly identify the area to apply ointment per the user's input via the GUI.
- **Ointment Rubbing:** The robot must smoothly apply the ointment into the user's leg skin using the brush

attachment. Pressure needs to be "just right" – not too powerful and not too light.

2) Metrics: **Accuracy/success**: We recorded the percentage of times the robot is able to successfully complete each sub-task. We also record failed attempts where the robot needs >1 attempts at a particular sub-task. For the ointment rubbing task, we assessed how many times at least 90% of the treatment area is cared for with the ointment and if most of the ointment is spread and rubbed into the skin.

Efficiency: We recorded total task completion duration. We aimed for the entire task to not take more than five minutes, with the ointment application and application area identification taking no more than 1-2 minutes. The application area identification sub-task also tested the usability of the GUI, as it featured teleoperation for the user to identify the area they desire treatment on.

Trials: We ran the entire task 5 times each for application on the knee and application on the shin.

Comparison Hypothesis: We hypothesized that the robot will be slower than a human applicator, as it is better to be slower and gentle, rather than faster but harsh on the user. On this note, we may explore opportunities for user input through our GUI in the future – allowing for the user to adjust pressure level through easy-to-understand buttons.

Qualitative Data: We recorded the different ways in which the robot fails to complete a certain sub-task (e.g. application error). From this we make suggestions for for more diverse user positions to support robot performance as well as user comfort in future work.

3) Procedure: A trial starts when the user initiates the start of our project through the GUI. A trial ends when the robot stops the ointment rubbing (or fails at a midway operation during a sub-task or user decides to use the hard stop button.)

Experimenter A set up the robot to be near and facing Experimenter B with the brush applicator grasped by Stretch's gripper. Experimenter B acted as the user being cared for and sat in the same chair position for all trials (and adjusted for knee vs skin leg positions as described above). Each trial followed the execution steps that in order of our sub-tasks. Experimenter C recorded accuracy and efficiency metrics for each of the 5 trials under the various configurations we mentioned in "Trials".

B. User Evaluation

We conducted a user evaluation to ensure our assistive ointment application system is usable, safe, and aligned with the needs of individuals with limited mobility. Given the intimate and personal nature of ointment application, it was critical that the system was not only functional but also trusted and accepted by potential users. We evaluated our system with users who have lived experience with eczema and a certified nursing assistant who could integrate this into their workflow. Our goals were to (1) verify that users could effectively operate the robot with minimal assistance, (2) evaluate whether the robot applied ointment accurately and comfortably, and (3) gather feedback to improve the system's usability, comfort, and autonomy.

1) Tasks & Materials: We conducted both in person and video demonstrations of our robot.

Our **in-person evaluation** consisted of a guided interaction with the robot in a controlled environment. The system was configured by the user through the GUI to apply ointment to the their lower leg. The tasks were broken down into the following steps:

1) The user was introduced to the system, shown a short demonstration of the robot in action on a mannequin, and trained on how to initiate and interact with the robot.
2) The user sat comfortable seated position, where they could easily see the robot and what it was doing. Through the camera on the GUI, they also saw the part of their leg the ointment was applied to.
3) The user selected their application region and instructed the robot to begin application through the GUI.
4) We performed variations on the site of application. In particular, we tested easy to apply areas such as the shin, and harder, more precise areas such as the knee.
5) The user completed a feedback interview with us.

The **remote interview** showcased a video demonstration which included a narrated walkthrough of the system applying ointment to a mannequin. The video showed:

- The full setup including GUI and robotic arm
- Selection of the application region through the interface
- Ointment application to a specific body part
- Use of safety features like the emergency stop

After watching the video, remote participants completed a follow-up interview to discuss their impressions and suggestions.

2) Metrics: **Objective metrics**:

- Success rate: Whether the ointment was applied to the correct region without assistance.
- Application accuracy: Degree of alignment between the user-specified target region and the actual ointment path (measured via video and post-hoc inspection).
- Time to complete: Time from initiation to task completion.
- Number of user prompts/errors: Count of times the user needed to reissue a command or the robot failed to perform as intended.

Subjective metrics: We used a custom questionnaire informed by the System Usability Scale (SUS) and NASA TLX to capture user experience, including:

Participants rated agreement on a 5-point Likert scale with the following statements:

1) It was easy to learn to operate the robot.
2) I felt safe during the ointment application.
3) The robot applied the ointment in the right place.
4) The pressure of the applicator felt comfortable.
5) I felt in control of the robot throughout the process.
6) I would be willing to use this robot regularly for self-care.

7) The robot helped me feel more independent.
8) The system reduced the need to ask for assistance.
9) The system worked efficiently without unnecessary delays.
10) The interface was intuitive to use.

Open ended questions:

1) How did you feel about our project's ability to apply ointment?
2) Did you feel safe during the robot's operation?
3) How comfortable was the pressure and speed of application?
4) Did the ointment reach the area you expected it to?
5) How did you feel about the length of time for application?
6) Was the interface easy for you to use? What was confusing, if anything?
7) Was there anything frustrating about this process?
8) Did using the robot help you feel more independent?
9) Would you feel comfortable using this robot daily or weekly?
10) Would you prefer more or less automation in future versions?
11) What features would make this robot more useful or trustworthy for you?
12) Are there specific times of day or situations where this tool would be especially helpful?
13) What improvements would make you want to use this system long-term?
14) What types of robot errors would be unacceptable to you? Do you feel this system has the chance to make any of those?

Certain questions, listed below, were caregiver specific.

1) Do you think patients would feel comfortable being treated by a robot like this?
2) Are there any patient types or scenarios where this wouldn't be a good fit?
3) What risks or concerns would you want addressed before using this in the field?
4) Would you prefer more or less automation in future versions?
5) Would you trust this robot to apply ointment in your absence? Why or why not?
6) What are some must-have features or changes to make this system more usable in healthcare? If this tool worked well, what other tasks would you want to see automated in your workflow?

Additionally, we had a series of open-ended questions asked to caregivers and users for design purposes, as listed in the prior design section.

3) Procedure:

1) Consent & Introduction: The participant is given an overview of the study and signs a consent form.
2) Training: They are trained on using the interface and shown a short demo of the robot.
3) Task Execution: The robot performs two ointment application tasks as described above.
4) Monitoring & Safety: A researcher remains present to monitor safety and intervene if needed.
5) Feedback Collection: After completing the tasks, the participant fills out a questionnaire and participates in a semi-structured interview.
6) Debriefing: We explain the study goals and answer any remaining questions.

4) Participant(s): We conducted our user evaluation with multiple users.

- **Participant 1** is an adult with lived experience managing chronic eczema. They apply ointment multiple times a day, often needing assistance to reach areas like their back or legs. They described experiencing flare-ups, sleep disruption, and emotional discomfort when unable to apply ointment consistently. This participant values independence in self-care and was particularly motivated by the potential for a tool that reduces the need to rely on others.
- **Participant 2** is an adult with lived experience managing mild to moderate eczema. While their symptoms are less severe than Participant 1's, they still experience discomfort when skipping applications, especially during dry weather or periods of stress. They also reported difficulty reaching certain areas of their body and occasionally needing help. This participant emphasized the value of convenience and consistency in treatment, and viewed the robot as a helpful tool for maintaining a routine with minimal disruption.
- **Participant 3** is a certified nursing assistant (CNA) with professional experience in caring for individuals with limited mobility, including those who require routine skin or wound care. They provided insight into how such a system could be integrated into clinical or home care settings, and evaluated the system from both a usability and care workflow standpoint.

We also worked with an occupational therapist from Hello Robot for initial project ideation.

These perspectives of lived experience, clinical and caregiver experience allowed us to assess both personal usability and broader applicability of our system in support and healthcare contexts.

V. Findings

A. System Evaluation

Our results are summarized in Table I. Overall, the robot demonstrated more consistent and accurate performance in the shin trials compared to the knee trials, validating our hypothesis that flat or uniform body surfaces would be better suited for robotic application.

For the shin trials, the robot achieved a perfect 100% success rate in both the application area identification and ointment dispensing sub-tasks. The rubbing sub-task also showed high performance, achieving a success rate of 80%, with one minor failure attributed to unexpected user movement in response to excessive pressure. The flat surface of the shin clearly allowed for more reliable positioning and more uniform pressure application, resulting in smoother motion, better ointment coverage, and an overall task duration well within the 5-minute target window. These results suggest that the shin is a highly suitable site for robotic assistance and that the system is already performing near deployment-quality levels in this context.

In contrast, the knee trials highlighted challenges arising from the curved and less predictable geometry of the joint. Application area identification on the knee achieved only a 60% success rate, often due to difficulties in precisely aligning the robot on an uneven surface. Rubbing coverage also dropped significantly (40%), with uneven pressure and poor contact consistency being primary issues. Despite these challenges, the total task time for the knee still stayed within the 5-minute goal, indicating that efficiency was maintained even when effectiveness varied.

These findings underscore the importance of surface geometry in robotic assistance tasks and highlight the shin as an ideal early-use case for robotic skincare or rehabilitation support. Future iterations of the system could incorporate real-time feedback or pressure adjustments to adapt better to irregular surfaces like joints, improving robustness and expanding the usability to a wider range of body areas.

Our human comparison hypothesis was correct. The robot ointment application cycle was slower than a human, but felt safe and comfortable to not only our own experimenters but also to Participant 2 who mentioned " It was gentle, deliberate. Maybe it was a little slow, but it was accurate". Additionally, P2 stated "It definitely took longer than when I would do it for myself but if I don't need to ask someone else, it was perfectly fine", highlighting the empowerment users felt from this design. More participant feedback is discussed in subsection V-B.

B. User Evaluation

1) Quantitative Results: We asked users to evaluate the system across 10 criteria using a 1–5 Likert scale (see Table II).

2) Objective Metrics: See Table III for results on our identified objective metrics when testing with P2.

3) Qualitative Insights: Participant feedback revealed a deep emotional and logistical context around eczema care that shaped their perception of the robot.

Participant 2 shared:

> "It was gentle, deliberate, and maybe slightly slow, but it was accurate—so I didn't mind it. Yeah, it was definitely longer than when I do it for myself, but if I don't need to ask someone else, that's worth it."

Participant 1 emphasized the social and emotional toll of eczema and dependence on others:

> "Your skin is what people see... and as much as we want to say 'I don't care what people think,' we're all human. Having to ask someone to put ointment on your back means you have to be shirtless in front of them—it's not easy."

Participant 2, who was able to test our system in person, also described how the robot improved their autonomy:

> "Absolutely. That's one of the biggest benefits for me. Using the robot helped me feel more independent, like I could take care of myself without needing to ask for help."

Participant 3, a certified nursing assistant also commented on the robot's potential in caregiving contexts:

> "Being able to have this robot apply ointment gives them a sense of dignity [...] that they did something on their own without needing our help."

4) Discussion and Improvements: Users responded positively to the system's ease of use, safety, and autonomy-enabling features. The interface was described as intuitive, though "a bit wordy," and some users mentioned the application process involved "a lot of clicking around." Despite minor slowness, the deliberate pace was appreciated for its accuracy.

Negative feedback primarily centered on:

- **Accuracy:** Some users reported that the applicator felt slightly imprecise, with one spot being missed.
- **Speed and efficiency:** The application process was slower than manual methods, though perhaps not in a caregiving context.
- **Cleaning and maintenance:** Participants raised concerns about post-use cleanup and hygiene, especially in a clinical context.

To address these concerns, future versions should consider:

- Adding pressure adjustment settings for sensitive skin.
- Allowing saved application presets for faster setup and reapplication.
- Incorporating voice commands or a speech-based stop function.
- Building in a self-cleaning or disposable brush system for hygiene.

Overall, users valued the robot's ability to reduce dependency, increase consistency in care, and provide emotional relief tied to greater independence.

VI. Lessons learned

Throughout this quarter, we learned important lessons about user studies, mechanical design, and system design.

As we enter an AI-dominated world, it can be easy to lose sight of what makes an effective product. While autonomous systems are commonly implemented these days, HRI practices have shown that the level of autonomy users prefer with robots is context dependent. From our conversations with participants, we realized that physically assistive robots, especially for healthcare settings, need to allow user control. Our solution combined self-selection of application areas, emergency stop buttons, and automated brush strokes. As such, it enabled user agency without adding burden of robot operation. Lastly, we resonated with the notion of "design is never done". Every

Sub-task	Location	Success Rate (%)	Avg. Duration (s)	Failure Modes / Notes
Knee Trials				
Application Area Identification	Knee	60	45	Hard to precisely position robot as movements weren't precise
Ointment Application	Knee	100	30	No issues - robot moved to top and ointment could be applied
Ointment Rubbing ($\geq$ 90% coverage)	Knee	40	105	Uneven pressure due to knee being an uneven surface
Total Task (All Sub-tasks)	Knee	—	180	Within 5-minute goal
Shin Trials				
Application Area Identification	Shin	100	60	Robot accurately positioned to a large area of application
Ointment Application	Shin	100	30	No issues - robot moved to top and ointment could be applied
Ointment Rubbing ($\geq$ 90% coverage)	Shin	80	150	Experimenter moved leg slightly away due to too much pressure
Total Task (All Sub-tasks)	Shin	—	240	Within 5-Minute goal

TABLE I
ROBOT PERFORMANCE RESULTS ACROSS TRIALS FOR KNEE AND SHIN APPLICATIONS

Evaluation Question	Average Rating
It was easy to learn to operate the robot.	5.0
I felt safe during the ointment application.	4.0
The robot applied the ointment in the right place.	4.5
The pressure of the applicator felt comfortable.	4.0
I felt in control of the robot throughout the process.	5.0
I would be willing to use this robot regularly for self-care.	4.0
The robot helped me feel more independent.	5.0
The system reduced the need to ask for assistance.	5.0
The system worked efficiently without unnecessary delays.	3.0
The interface was intuitive to use.	5.0

TABLE II
AVERAGE USER RATINGS FOR LIKERT SCALE QUESTIONS

participant interview taught us something new to consider, some of which we addressed and some of which are our future work.

With trial-and-error, the mechanical design of the ointment applicator adapted throughout the quarter. At first, we were very confident that existing ointment application rollers would be successful. When we tested it on ourselves, we realized that the application was very patchy and noncomprehensive. Additionally, it was not successful with applying ointment to different curvatures because the roller simply could not make contact with such areas. From there, we quickly adapted to a brush application. For that, we tested earlier and realized that we needed to apply additional foam to the brush so that the Stretch gripper could securely grasp onto the brush and prevent it from falling off. Overall, an iterative design process taught us about the importance of developing early prototypes to surface usability issues. With the goal of safe, comfortable ointment application, we built our MVP solution into the full system.

Finally, this course taught us about modular system design. Separating the functionality of our solution into nodes that grouped similar/repetitive functionality allowed for easier programming workflows. Tackling debugging tasks meant that we could quickly identify the error location. Similarly, our GUI was developed through pages dedicated to single functionality, after we realized that a single page would bring complex, interleaved code, and not to mention an overwhelming amount of information to the user at once. This ensured that our backend ROS bridge connection was developed, tested, and debugged efficiently. Continuing these system design practices will allow us to implement maintainable programming practices in future systems we design/scaling of this project.

VII. FUTURE WORK

A high-yielding area for improvement is the ointment applicator itself. Since this is the main point of contact with the user, more development is needed to fine-tune the brush for sensitive areas such as behind the knees, inner elbows, or around the neck. The brush should also be able to handle more viscous ointments like Triamcinolone, which may require stronger motors or different materials.

Another direction worth exploring is improving the actual brush stroke. Adding new motions like small, constant pitch shifts or subtle wrist rolls may lead to a smoother, more even application and a more comfortable experience for the user.

Integrating pressure sensors or depth sensors near the wrist could help keep the robot within a safe operating range, preventing excessive force and reducing the need for manual calibration. This would also allow for more autonomous and consistent applications.

On the UI side, the web interface could be improved, particularly the button controls used to position the robot. Adjusting the sensitivity of movement per button click would help ensure the robot responds predictably and minimizes user discomfort.

Early conversations with our CNA participant informed us of robot cleaning and brush sanitation logistics that would need to be addressed in the future.

From a workflow perspective, the robot should eventually support saving custom user profiles and application areas so users do not have to redefine the top and bottom boundaries every time. This would significantly streamline repeated use. Also, support for adjustment of how many brush strokes are used for application can help users adjust for different ointment consistencies and application area sizes.

Lastly, for the robot to function in a personal or clinical setting, environment navigation and obstacle detection would need to be implemented. Ideally, the robot should be able to locate and navigate to the user autonomously rather than requiring the user to position themselves in front of it.

Sub-task	Location	Success Rate (%)	Duration (s)	Failure Modes / Notes
Knee Trials				
Application Area Identification	Knee	100	85	Took time finalize an area up to standards
Ointment Application	Knee	100	10	No issues, felt intuitive
Ointment Rubbing ($\geq$ 90% coverage)	Knee	0	95	Did not cover everything that was needed
Total Task (All Sub-tasks)	Knee	—	190	Within 5-minute goal
Shin Trials				
Application Area Identification	Shin	100	60	Easier to set area for shin
Ointment Application	Shin	100	10	No issues
Ointment Rubbing ($\geq$ 90% coverage)	Shin	100	150	Felt comfortable
Total Task (All Sub-tasks)	Shin	—	220	Within 5-Minute goal

TABLE III
ROBOT PERFORMANCE RESULTS FOR PARTICIPANT 2

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