EMG-Driven Stiffness-Modulating Palpation for Telerehabilitation

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I. Introduction

Telerehabilitation, the remote delivery of therapy using telecommunication technologies, has seen rapid growth, especially after the COVID-19 pandemic. It enables access to care for patients who are quarantined, immobile, or living far from clinical facilities [10, 9, 1].

Although many robotic systems support remote rehabilitation [8, 2], a major limitation is the lack of digital palpation. This hands-on method is essential for physiotherapists to assess muscle activation and stiffness [3]. Without it, therapists may find it difficult to evaluate muscle engagement remotely, and deliver a meaningful assistance for patients.

Kinesthetic feedback is essential for replicating palpation. Unlike cutaneous feedback, such as vibration or electrical stimulation, which provides indirect cues [12], kinesthetic devices can simulate realistic touch by applying direct force to the finger [13]. In telerehabilitation, these devices can render palpation by using force measurements when the remote robot presses on the patient's muscle. However, latency in teleoperation causes desynchronization between motion commands and force feedback [4], resulting in distorted and unreliable haptic sensations. Moreover, accurately assessing small or deep muscles is challenging when using a relatively large robot finger, further limiting the effectiveness of this approach.

Electromyography (EMG) sensors offer a promising alternative by measuring muscle engagement and activation, which reflects muscle stiffness and abnormal synergies [14]. EMG is particularly useful for assessing small or deep muscles. However, the signal is typically displayed visually on a computer screen, which lacks tactile realism and may divide the therapist's attention during assessment.

In previous work [7], we developed a lightweight, wearable haptic device that uses a honeycomb jamming mechanism for stiffness rendering in teleoperated object-grasping tasks. In this abstract, we explore adapting this device into a palpation tool (HJ-Pal) for telerehabilitation. HJ-Pal modulates its stiffness to provide kinesthetic feedback based on EMG signals, allowing therapists to perceive muscle engagement remotely. Given the inherent noise in EMG signals, directly mapping these signals to device stiffness poses a challenge. As an initial step, we evaluate HJ-Pal's capability to track EMG signals from small muscles, demonstrating its potential for remote muscle assessment. In future work, we plan to investigate the correlation between EMG activity and the device's rendered stiffness, validating its effectiveness for digital palpation in remote rehabilitation contexts.

II. Relevance to HRCM

This work contributes to the goals of the Workshop on Human-Robot Contact and Manipulation (HRCM 2025) by presenting a novel application of wearable haptics for physical human-robot interaction (pHRI) in remote healthcare. HJ-Pal offers a new approach to remote palpation during telerehabilitation by using a honeycomb-jamming mechanism to modulate stiffness in response to EMG signals. This allows therapists to physically perceive muscle engagement, even in small or deep muscles, bridging the gap between traditional hands-on assessment and remote therapy. Unlike conventional visual EMG displays, HJ-Pal reintroduces tactile perception into the therapist's workflow, enhancing clinical intuition and reducing cognitive load. By introducing HJ-Pal, we aim to open new directions in remote patient monitoring by using haptics that go beyond surgical applications.

To advance this research, we aim to investigate how kinesthetic feedback influences therapist decision-making, user trust, and perceived effectiveness in real-world clinical environments. This work serves as both a contribution and a starting point for discussions within the workshop on how pHRI frameworks can be extended to address the evolving demands of remote and home-based healthcare.

III. HJ-Pal for Remote Palpation

HJ-Pal is a lightweight, thumb-wearable haptic device that leverages a honeycomb jamming mechanism to deliver kinesthetic feedback for remote muscle assessment in telerehabilitation. It builds upon our previous work on stiffness-modulating haptics [7]. By adjusting vacuum pressure, the honeycomb structure modulates its stiffness in real time. For detailed mechanical design and characterization, refer to [7].

Unlike traditional haptic systems that rely on delayed force feedback from remote robots, HJ-Pal modulates stiffness lo-

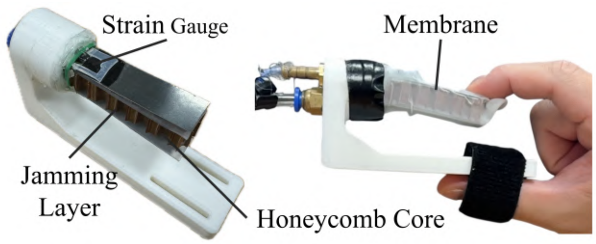

Fig. 1. The prototype of honeycomb-jamming palpation device (HJ-Pal).

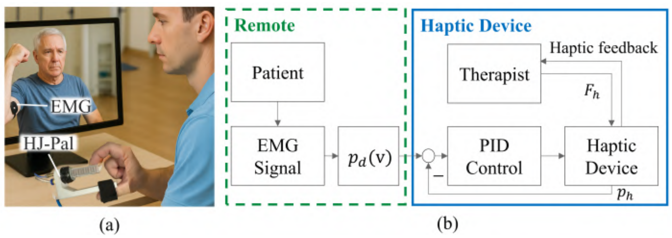

Fig. 2. (a) Conceptual illustration of a telerehabilitation scenario using HJ-Pal, generated with Sora by OpenAI [11]. (b) The proposed remote palpation framework for HJ-Pal. Here, p_d denotes the desired pressure, p_h is the measured feedback pressure, and F_h represents the fingertip force applied by the therapist.

cally based on EMG signals, enabling therapists to perceive muscle activation through direct touch.

As shown in Fig.1, the device incorporates a honeycomb core, membrane and jamming layers, enabling stiffness modulation up to 0.85N/mm under vacuum pressure. A strain gauge captures finger indentation, while a PID-controlled vacuum pump adjusts internal pressure and stiffness of honeycomb-jamming mechanism based on EMG signals. The overall remote palpation framework is illustrated in Fig.2. When therapists press on the device, they experience kinesthetic haptic feedback that reflects the patient's muscle activation. When released, HJ-Pal automatically returns to its original, flexible state.

As shown in Fig. 2, we use EMG sensors (Delsys Trigno) to measure muscle activation and map the processed signal to the desired pressure (p_d) within HJ-Pal's available stiffness range. The raw EMG data are filtered using a 4th-order Butterworth bandpass filter (10–500Hz), then detrended, rectified, and smoothed with a moving mean filter. The resulting signal is normalized to the participant's Maximum Voluntary Contraction (MVC).

This is the novel application of EMG-driven jamming in a digital palpation framework. It can potentially integrate with upper limb exoskeleton [5, 6]. In this case, HJ-Pal enables therapists to sense patient muscle engagement and adjust robotic assistance, offering a interactive physical human-robot interaction for telerehabilitation.

A. Results & Discussion

As an initial step toward developing HJ-Pal as a palpation tool for remote muscle assessment, we conducted a preliminary experiment to evaluate its ability to render EMG-driven stiffness modulation via pressure tracking. Given the difficulty in assessing small muscles through traditional palpation, we selected the pronator and supinator muscles as targets.

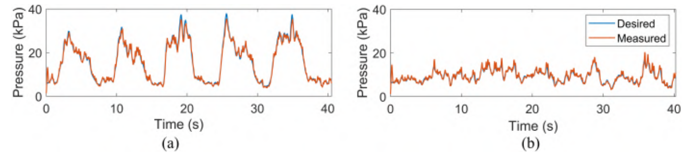

Fig. 3. Vacuum pressure tracking of EMG-derived commands during forearm supination: (a) supinator and (b) pronator muscle activation.

Two EMG sensors (placed according to SENIAM guidelines) recorded muscle activation from a single participant. During the experiment, the participant rested his forearms on a table in a neutral position and performed five cycles of slow forearm supination (rotating palms upward), briefly holding the position before returning to neutral and relaxing.

The processed EMG signals were mapped to desired pressure values (p_d), which were tracked by the PID-controlled vacuum system of HJ-Pal. As shown in Fig. 3, the measured internal pressure closely followed the EMG-derived pressure commands. The system achieved low root-mean-square error (RMSE) values of 1.0060.031kPa in supinator and 0.9040.056kPa in pronator. Furthermore, the measured pressure correlated strongly with the EMG-derived commands (Pearson's correlation with $r = 0.9940.0004$ in supinator; $r = 0.9660.010$ in pronator, all $p < 0.0001$), confirming that the HJ-Pal is capable of responding to the high-frequency, noisy nature of EMG input.

These results suggest that HJ-Pal can deliver reliable kinesthetic feedback based on muscle activity. Such fidelity is essential for enabling therapists to perceive subtle variations in muscle engagement—especially in small or deep muscles—through haptic feedback. This functionality positions HJ-Pal as a promising tool for remote muscle assessment in telerehabilitation settings, where traditional force feedback mechanisms may be delayed, distorted, or infeasible.

Future work will explore the correlation between EMG activity and HJ-Pal's perceived stiffness, further validating HJ-Pal's application for digital palpation. We also plan to conduct user studies to assess the usability of HJ-Pal in realistic telerehabilitation scenarios. In particular, we aim to compare EMG-based haptic feedback with traditional approaches such as visualizing real-time EMG signals on a computer screen and employing force-based haptic feedback. Comparative metrics will include diagnostic accuracy in identifying muscle activation levels and the user's cognitive load.

IV. Conclusion

This work presents HJ-Pal, a lightweight, thumb-wearable haptic device that uses honeycomb jamming to render kinesthetic feedback based on EMG signals. Preliminary results show reliable pressure tracking and strong correlation with muscle activity, demonstrating HJ-Pal's potential for remote palpation and assessment of small muscles in telerehabilitation.

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