EMS-Based Simulation of Touch Sensations in Wearables

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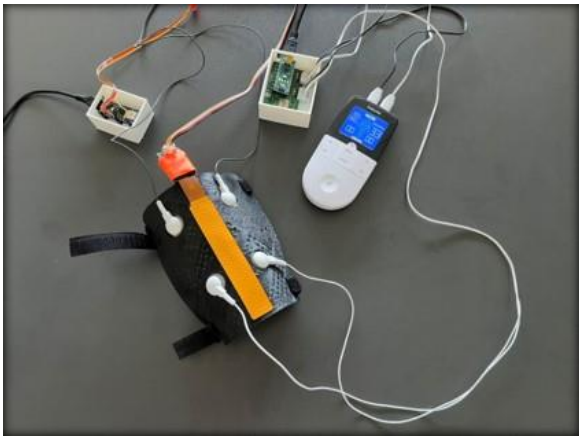

Fig. 1. Prototype of the EMS-based wearable system, consisting of a 3D-printed arm sleeve, EMS electrodes, a Trill touch sensor, and the *Let Your Body Move* toolkit.

Long-distance relationships often lack the subtle physical cues that foster emotional closeness, such as touch. As a step toward reintroducing touch into remote interaction, we present a wearable prototype that uses Electrical Muscle Stimulation (EMS) to generate gentle tactile sensations. Our system translates simple touch gestures into EMS stimulation aimed at recreating the feeling of being touched in a natural and comfortable way. The prototype consists of a 3D-printed arm sleeve, the *Let Your Body Move* toolkit, and a Trill Flex sensor. The result is a functional proof of concept demonstrating technical feasibility and a design focused on comfort and usability. A small exploratory study evaluated recognition performance as well as perceived comfort and naturalness. Future work will explore the potential of such sensations to support emotional connection and non-verbal communication in long-distance contexts.

CCS Concepts: • **Human-centered computing → Haptic devices**.

Additional Key Words and Phrases: Electrotactile Feedback, Remote Communication, Prototype

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1 Introduction

Being physically close to family or friends is a fundamentally different experience than connecting over long distances through digital solutions such as video calls, messaging apps, or online games. Through the physical proximity, passive aspects, such as footsteps, create a sense of presence and deepen the sense of togetherness. These cues are often lost in remote communication, reducing the depth of emotional connection, especially in relationships separated by distance, such as between partners, children and parents, or family members temporarily apart [12].

In order to combat the issue of missing passive aspects of social life, peripheral technologies can be used as a tool to re-create certain aspects of passive presence. Among the many channels of non-verbal communication, touch is the primary channel for conveying intimacy and emotion [13].

This paper explores how Electrical Muscle Stimulation (EMS) can be used to generate touch sensations that feel subtle, natural, and comfortable. EMS enables tactile feedback directly on the body, ranging from gentle sensations to noticeable muscle contractions [5]. Inspired by Seetohul et al.'s ShoulderTapper [10], we investigate the design of EMS-based touch sensations in a wearable form factor.

While the long-term goal is to understand how such sensations might be integrated into non-verbal communication, the focus of this work lies on the design of a wearable prototype and the evaluation of EMS-based touch sensations. This first step provides a foundation for future research on the role of EMS in social contexts.

2 Related Work

Electrical muscle stimulation has gained attention in human-computer interaction as a means of providing haptic feedback and creating embodied experiences. Prior work has explored EMS across various domains, including feedback in wearable devices, remote communication, creation of sensations, and user acceptance. Our research builds upon these foundations, with a focus on designing subtle and natural touch sensations in a wearable format.

EMS is widely used to deliver tactile feedback, often through muscle activation or perceptual sensations. Pfeiffer and Rohs [8] demonstrate its potential in wearable textiles, highlighting key factors like electrode placement, parameter tuning, and individual differences in sensation. Their open source *Let Your Body Move* toolkit enables experimentation with EMS in wearable contexts. Similarly, Knibbe et al. [6] investigate wearables with built-in electrodes and emphasize comfort, aesthetics, and adaptability through stretchable fabrics. These works show that EMS can be effectively embedded in clothing and tuned to provide perceptible feedback. While they offer insights into the design and integration of EMS into wearables, their focus lies primarily on functionality and comfort in textile design rather than on the quality of tactile sensations themselves.

Beyond haptic feedback, EMS has also been studied for conveying information and emotions. Schneegass and Rzayev [9] use EMS to deliver subtle, implicit notifications directly on the body, reducing the need for users to visually check devices. Haritaipan et al. [2] explore massage inspired feedback through vibration, emphasizing the emotional impact of remote haptic stimulation. Their work shows that haptic feedback can enhance physical and emotional connection. Hassib et al. [3] explore remote communication of emotions by triggering gestures using EMS based on detected emotional states. Their work shows that EMS can intensify shared emotions, but it also raises acceptance and safety concerns when physical movements are externally controlled. This suggests that users may prefer sharing sensations rather than being forced into movements. Other approaches to social presence focus on various mediums for connecting distant people, often through non-tactile means. For example, PalPalette [4] uses ambient lighting to create a continuous sense of presence between long-distance friends, showing how subtle cues can strengthen emotional connection without direct interaction. Such works highlight the potential of subtle cues for maintaining presence, but they do not explore the usage of EMS in that context.

To mimic touch using EMS, it is important to understand how EMS is perceived. Knibbe et al. [5] systematically studied how users perceive different EMS parameter settings, finding strong individual differences in comfort and sensation thresholds. Their findings reinforce the importance of calibration, especially for applications beyond forced motion. They also provide a mapping of frequencies and pulse widths to perceived sensations. At a broader level, Faltaous et al. [1] reviewed over 150 EMS-related publications, proposing a taxonomy that categorizes EMS systems by whether they aim to move the body (action) or alter perception. Most existing work falls into the "perception augmentation" category, where EMS enhances an existing experience. Far fewer studies explore "perception induction", where EMS introduces a completely new sensation. Our work fits into this less explored space by investigating how EMS can induce new touch sensations that are perceived as subtle, natural, and comfortable, rather than relying on muscle actuation or augmenting an existing interaction.

The acceptance of EMS-based systems is also relevant. Shahu et al. [11] show that users are more open to EMS in non-critical, playful scenarios and prefer to stay in control of when stimulation occurs. This supports the use of EMS for non-intrusive applications, especially for usage limited to perceptual stimulation rather than muscle actuation.

Taken together, these works demonstrate that EMS is a flexible technology for haptic feedback and has potential in emotional and communicative contexts. They also show that EMS can work well in wearables. However, existing research has largely focused on functional tasks, notifications, or emotion-driven movement. Far less attention has been given to how EMS stimulation can be used to simulate subtle, natural, and comfortable touch sensations. Addressing this gap, we propose the following research question:

RQ: How can an Electrical Muscle Stimulation based wearable be designed to simulate touch sensations that feel subtle, natural, and comfortable to the user?

To support the design process and exploration of the research question, we further propose the following sub-questions:

- **SQ1:** Which EMS parameter settings (e.g., frequency, pulse width) are perceived as subtle and comfortable?
- **SQ2:** To what extent are these EMS settings perceived as natural?
- **SQ3:** How can a wearable device be designed and implemented to deliver EMS-based touch sensations in practice?

3 Research Methodology

This project follows an iterative design and prototyping process, supported by literature analysis and technical experimentation, to explore how EMS-based wearables can simulate natural and comfortable touch sensations. The project is grounded in prior research on EMS feedback and wearable interaction, particularly the work of Pfeiffer et al. [7] and Knibbe et al. [5, 6]. Our approach includes a literature analysis, technical experimentation, and design iteration.

We explored EMS signal characteristics, form factor usability, and remote interaction methods through hands-on prototyping with flexible hardware, textiles, and 3D-printed components. Our prototyping process was guided by iterative evaluation, allowing us to adapt the design in response to observed usability and hardware challenges.

To assess the perceived comfort, naturalness, and subtlety of the stimulation, we plan to conduct a small-scale user study with a handful of participants interacting with the final prototype. Future work will extend this evaluation to explore the emotional and social dimensions of EMS-based touch sensations.

4 Prototyping

4.1 Hardware

The hardware implementation is based primarily on the *Let Your Body Move* toolkit [7], which serves as the EMS controller by translating digital commands into electrical stimulation. Touch input is captured with a Trill Flex sensor[1], which provides positional data of the user's arm. This input is processed by an Arduino microcontroller[2], which sends commands to the toolkit. The toolkit controls a commercial EMS generator, the Beurer EM49[3], which produces the stimulation delivered through adhesive electrodes placed on the arm.

The complete prototype setup, including the 3D-printed EMS arm sleeve, EMS electrodes, the Trill Flex sensor, and the *Let Your Body Move* toolkit, is shown in Figure 1.

4.2 Prototype Development

The prototype was developed in an iterative, four-phase process, combining hardware design, EMS parameter testing, and the integration of input methods. Electrical Muscle Stimulation was chosen because it allows controlled modulation of muscle and skin responses, offering the potential to approximate tactile sensations more closely than conventional haptic approaches. The system is composed of three main components: the Let Your Body Move EMS toolkit as controller, an EMS generator for delivering stimulation, and a Trill Flex sensor for capturing touch input. Throughout development, we iterated on electrode placement, sleeve design, and stimulation patterns to improve reliability, stability, and usability. Each phase contributed to refining both the hardware and interaction design toward a functional wearable prototype.

4.2.1 Phase 1. The first phase focused on finding of suitable frequency and pulse width settings of the EMS Generator. As defined by our research question, the stimulation is intended to feel subtle and comfortable, while resembling natural touch as closely as possible. To achieve this, we tested several parameter combinations, based on the mapping created by Knibbe et al. [5]. Based on these tests, we selected the five most promising combinations for further evaluation. The top five results can be found in table 1. Table 1 lists the selected frequency and pulse width combinations, along with the perceived sensations as reported by members of our team. The entries are ordered by how closely they resembled natural touch, from most to least similar.

Frequency (Hz)	Pulse Width (µs)	Sensation
120	250	Tingling or vibration on the surface of the skin
40	150	Pressure or tingling, but very slight and comfortable
120	100	Slight pulling, but gentle
40	100	Tingling, localized and comfortable
10	100	Tapping

Table 1. Top five results from EMS testing, including frequencies, pulse widths, and perceived sensations.

[1]https://learn.bela.io/using-trill/working-with-trill-flex/
[2]https://store.arduino.cc/products/arduino-nano-33-ble
[3]https://www.beurer.com/de/p/66205/

4.2.2 Phase 2. Following the initial parameter testing, we aimed to address the challenge of keeping the electrodes in place during use. Over time, standard adhesive electrodes tend to lose contact with the skin. To mitigate this, we developed an arm sleeve that holds the electrodes securely against the forearm.

In our first approach, we used a commercially available, stretchable textile arm sleeve. This allowed the prototype to accommodate different arm sizes while maintaining enough pressure on the electrodes. However, in order to attach the electrodes into the fabric, we needed to 3D print mounts for the electrodes, so that they are not torn apart when stretching it. The 3D printed mounts were printed using flexible filament and were strong enough to stop the electrodes from tearing, but still allowed them to move with the stretchable fabric around the arm. These mounts were glued to the inside of the fabric, as seen in Figure 2.

(a) Electrode mounts

(b) Printed electrode mounts inside the arm sleeve

Fig. 2. 3D print model of the electrode mounts and their placement in the textile arm sleeve

Although this first version proved to be functional, the materials presented multiple problems. The fabric moved a lot, even when tightly wrapped around the arm, the fabric crumpled, and the seams and glue detached from the repeated stretching.

To resolve these issues, we developed a second version of the arm sleeve, that was fully 3D printed using the same flexible filament. This version used Velcro straps for adjustable closure for different arm sizes. A 3D print for this idea can be seen in Figure 3. The new sleeve provided a more stable structure while remaining flexible enough to comfortably wrap around the arm. Electrodes could be glued directly onto the sleeve surface without requiring an additional mounting layer. This approach significantly improved mechanical stability and maintained reliable skin contact during use.

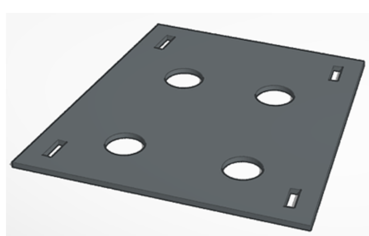


Fig. 3. 3D print model of the arm sleeve

4.2.3 Phase 3. After designing a suitable arm sleeve, the next step was to create a corresponding input and output method.

Our first approach to the input method was a custom Python application, designed to simulate a person creating a touch input and sending it to their friend's arm sleeve, where it is recreated using EMS stimulation. The interface of this application can be seen in Figure 4.

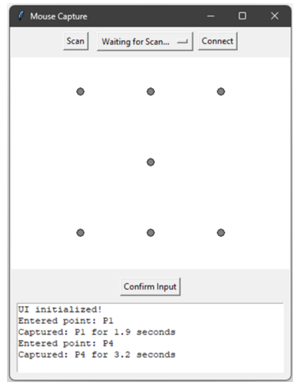
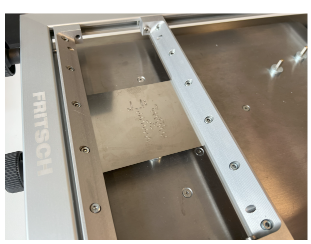


Fig. 4. Python application for creating a touch input

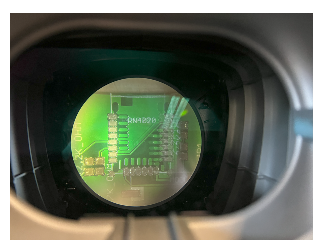
The application connects to a Bluetooth Low Energy (BLE) device and send commands to it. These commands are generated based on mouse interactions within the central area of the interface. Each point in this area corresponds to one of the four electrodes, the midpoint between two electrodes on the same channel, or the center between both channels. The application measures how long the user hovers over each point and converts that information into a stimulation command that activates the appropriate electrode channels.

To create an EMS output using this command, we used the *Let Your Body Move* toolkit, developed by Pfeiffer et al. [7], which enabled programmatic control of the EMS channels. We replicated the toolkit following the documentation on its wiki [4]. Parts of building process are shown in Figures 5 and 6.

Figure 5a shows the stencil for one side of the PCB, with the board fitted beneath it. This allows solder paste to be applied easily and accurately to the designated areas. A close-up view of the PCB under a microscope after solder paste application is shown in Figure 5b.



(a) PCB with its stencil above it



(b) PCB under a microscope after applying solder paste

Fig. 5. Application of solder paste to one side of the PCB using a stencil

[4]https://bitbucket.org/MaxPfeiffer/letyourbodymove/wiki/Home

After applying the solder paste, the components were placed on the PCB. Due to their small size, we used a machine that allowed us to accurately position the parts with a small needle, which held the parts using a vacuum. This process is shown in Figure 6. Subsequently, the PCB was placed in a reflow oven to solder the components onto the board. The same procedure was then repeated for the other side of the PCB.

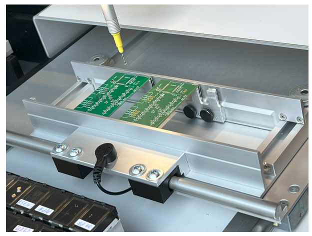
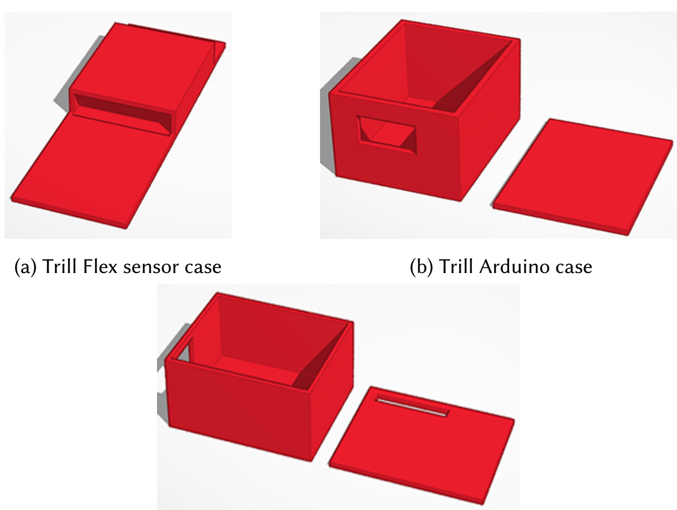


Fig. 6. Placing parts on the prepared PCB

To demonstrate the functionality and autonomy of the complete prototype, we also developed a second input method that operates directly on the device itself. By integrating a Trill Flex sensor on the top of the sleeve, users could generate touch input without relying on an external application. This allowed the prototype to function as a standalone system, capable of sensing and responding to touch through EMS stimulation entirely on its own. Further details on the system architecture can be found in Section 4.3.

4.2.4 Phase 4. The final phase of prototyping focused on designing custom 3D cases for the remaining hardware components and integrating all elements into a unified system. Specifically, 3D models were created for the Trill Flex sensor, the Arduino of the Trill Flex sensor, and the *Let Your Body Move* toolkit.



(a) Trill Flex sensor case

(b) Trill Arduino case

(c) *Let Your Body Move* toolkit case

Fig. 7. 3D print models of the Trill Flex sensor, Trill Arduino and *Let Your Body Move* toolkit cases

In the final version of the prototype, the Trill Flex sensor and its case were glued directly onto the arm sleeve to ensure stable contact during interaction. The remaining components, including the Trill Flex sensor's Arduino and the *Let Your Body Move* toolkit, were placed inside a small pouch attached to the arm, with their 3D printed cases providing protection from external factors.

4.3 System Architecture

The system follows a pipeline of touch input, signal processing, EMS control, and stimulation output. A user interacts with the Trill Flex sensor by touching the arm sleeve, and this interaction is translated into electrical muscle stimulation on the same or a remote user's arm. The overall architecture is shown in Figure 8.

The system follows a pipeline of touch input, signal processing, EMS control, and stimulation output. A user interacts with the Trill Flex sensor by touching the arm sleeve, which produces a positional value that is processed by the Arduino. This input is then translated into a stimulation command and sent wirelessly to the *Let Your Body Move* toolkit (EMS control). The overall architecture is shown in Figure 8.

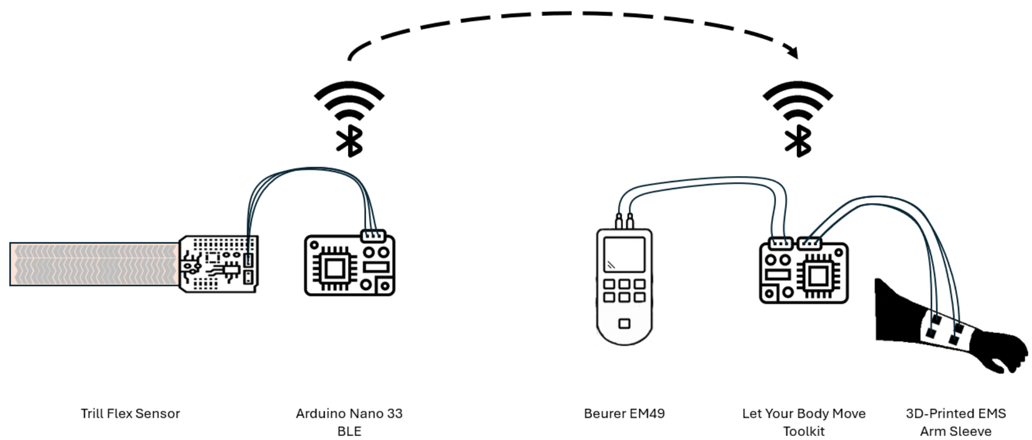


Fig. 8. System architecture of the prototype, from touch input (Trill Flex sensor) through processing (Arduino Nano 33 BLE and *Let Your Body Move* toolkit) to EMS output (3D-printed arm sleeve).

In more detail, the Trill Flex sensor provides a positional value between 0 and 3127, representing the touch location along its surface. This value is read by the Arduino Nano 33 BLE, which maps the position to one of three stimulation zones: Channel 1, Channel 2, or the middle area between them. Based on this mapping, the Arduino constructs a command string for the *Let Your Body Move* toolkit. The command format follows the specification described in the toolkit documentation[5], for example "`C0I100T500G`". Here, "C" denotes the channel (0 or 1), "I" the stimulation intensity (0-100%, based on individual calibration), "T" the stimulation duration in milliseconds, and "G" a confirmation flag to execute the command.

The command is transmitted via BLE to the toolkit, which deciphers the instruction and activates the corresponding EMS channel. A built-in safety mechanism ensures that stimulation time is limited by the software to avoid excessive activation. The EMS generator (Beurer EM49) is kept constantly on, with base parameters such as frequency, pulse width, and a general intensity level defined beforehand (based on calibration). Fine-grained adjustments are then handled by

[5]https://bitbucket.org/MaxPfeiffer/letyourbodymove/wiki/Home/ToolKitAndroidApps

the toolkit, which modulates the percentage intensity per channel. When a channel is triggered, the toolkit activates the corresponding channel, allowing the predefined EMS signal to be delivered through the electrodes embedded in the 3D-printed arm sleeve.

The complete source code for all hardware components and their communication, and all 3D models are available in a GitHub repository[6].

5 Study

5.1 Study Design

To evaluate the system's ability to generate subtle, natural, and comfortable touch sensations through EMS, we conducted a small-scale study. Participants first completed a safety check and contraindication questionnaire before putting on the prototype EMS sleeve. Stimulation intensity was calibrated to each participant's perception threshold. The study consisted of two recognition tasks and a following questionnaire. In the zone recognition task, participants received stimulation in one of the three forearm zones in a randomized order (two trials per zone) and were asked to identify the stimulated zone. In the flow recognition task, participants experienced sequences of stimulation across zones (1⟶3, 3⟶1), again randomized and repeated twice. Recognition accuracy was recorded for each condition. Following the tests, participants completed the Comfort Rating Scale (CRS) and the EMS-CORE questionnaire, which assessed naturalness, subtlety, detectability, and wearability. Open comments and preference rankings were also collected.

5.2 Study Results

Five participants (ages 21–59, 3 female, 2 male) took part in the exploratory study. Each completed the recognition tasks, the Comfort Rating Scale, and the EMS-CORE questionnaire.

5.2.1 Recognition Performance. Overall, participants were able to distinguish stimulation zones and flows with reasonable accuracy. Flows (1⟶3 and 3⟶1) were recognized reliably, with most participants identifying them correctly in both trials. Zone recognition was somewhat less consistent: while upper and lower zones were usually identified correctly, the middle zone was often confused with the upper zone. This shows that EMS can effectively signal different areas on the arm, but since the middle zone was harder to distinguish, future versions may require more precise electrode placement and finer tuning of stimulation intensity.

5.2.2 Comfort and Wearability. CRS ratings indicated that the sleeve was generally comfortable to wear. Participants reported no pain, irritation, or movement restriction, and attachment was often rated highly, suggesting that the 3D-printed sleeve provided a stable fit. A few participants noted mild nervousness while wearing the device, but overall anxiety ratings remained low. This anxiety may partly reflect the participants' unfamiliarity with EMS rather than discomfort with the device itself. Additionally, one participant explicitly commented that the prototype "should be smaller", highlighting size and bulk as a potential limitation.

5.2.3 Perceived Quality of Stimulation. EMS-CORE results revealed a consistent pattern. Participants rated the signals as highly detectable and subtle, but low in naturalness. In other words, users could reliably perceive and interpret the stimulation without finding it intrusive, but the sensation did not convincingly resemble real touch. This aligns with internal prototyping observations and highlights naturalness as an open design challenge for EMS-based touch feedback.

[6]https://github.com/cruv3/EMS-Based-Simulation

5.2.4 Additional Impressions. Open comments reflected both potential and skepticism. Multiple participants emphasized that the sensations were “not like a real human”, underlining the challenge of naturalness. At the same time, others saw promise for social contexts, describing the prototype as a “vibe for relationships” or imagining its use in long-distance situations to say things like “Hi, I’m here!” or “I’m thinking about you”. Another participant suggested that the prototype “should be smaller”, emphasizing the need for a more compact form factor. One participant noted simply that they “do not like wearables anyway”, suggesting that acceptance may vary depending on individual attitudes.

6 Discussion

6.1 Implications

The study results, combined with the prototyping and internal testing phases, reveal several key implications for the design of EMS-based wearables for generating subtle and natural touch sensations.

First, the project demonstrates a functional proof of concept for translating simple touch gestures into EMS-based tactile feedback. Participants were generally able to distinguish stimulation zones and reliably recognize flows, although the middle zone was often confused with the upper zone. This indicates that EMS can effectively communicate spatial differences, but electrode placement and finer intensity tuning remain important design considerations. These findings reflect observations by Knibbe et al. [6], who noted that achieving finer spatial resolution with EMS likely requires an increased number or smaller electrodes. The technical feasibility of sensing a gesture on one side and recreating a stimulation on the other was validated through a working prototype in combination with an external Python application, which mimicked the counterpart of our sleeve.

Second, the custom 3D-printed arm sleeve proved effective at holding electrodes in place with consistent pressure, which is crucial for reliable EMS stimulation. CRS ratings confirmed that participants experienced little to no pain, irritation, or movement restriction, and attachment was rated highly. This suggests that the sleeve design successfully addressed common problems with adhesive electrodes, such as detachment or inconsistent contact, and offers a replicable solution for similar wearable systems.

Third, the use of a Trill Flex sensor as a touch input method showed promising potential for intuitive interaction. By embedding the sensor on the same arm that receives stimulation, users could simulate the act of touching someone else’s arm simply by touching their own. Open comments highlighted both the promise of this design (e.g., imagining its use for long-distance communication to say things like “Hi, I’m here!”) and its limitations (e.g., the device “should be smaller”). The comments on the usage in long-distance communication echo the value of subtle peripheral cues shown in work on passive co-presence [12], where they were found to support togetherness in remote settings. This mix of feedback points to both the feasibility and the need for refinement in future versions.

Together, these findings lay a technical and conceptual foundation for future systems aiming to simulate natural touch sensations through EMS.

6.2 Reflection on Research Question

Our central research question was:

- **RQ:** How can an Electrical Muscle Stimulation based wearable be designed to simulate touch sensations that feel subtle, natural, and comfortable to the user?

The exploratory study allows us to address this question and its sub-questions.

Our work demonstrates that it is technically feasible to build an EMS-based wearable capable of generating tactile sensations that are subtle and comfortable. Through iterative prototyping and user testing, we identified a functional combination of hardware, EMS parameters, and a wearable form factor that enables reliable tactile feedback. However, while the system was found to be comfortable and easy to detect, the sensations did not convincingly replicate natural touch.

In the following, we reflect on each sub-question individually:

- **SQ1:** Which EMS parameter settings (e.g., frequency, pulse width) are perceived as subtle and comfortable?

Internal testing, calibration and user ratings suggest that a setting of 120 Hz and 250 μs pulse width was perceived as the most comfortable among the tested configurations. However, none of the tested signals convincingly resembled natural touch, highlighting the limitations of EMS in reproducing natural tactile sensations.

- **SQ2:** To what extent are these EMS settings perceived as natural by users?

The selected configuration was found to be non-irritating and suitable for repeated use, suggesting a degree of comfort. Nevertheless, participants consistently emphasized that the sensations were "not like a real human", indicating that naturalness remains an open design challenge. This matches the observations of Knibbe et al. [5], who reported that participants often described a variety of EMS sensations, but none as resembling natural human touch.

- **SQ3:** How can a wearable device be designed and implemented to consistently deliver EMS-based touch sensations in practice?

The prototype presented in this project serves as a working example of such a device. It integrates sensing (Trill), wireless communication (BLE), and a form-fitting 3D-printed sleeve to ensure consistent EMS delivery. Recognition performance suggests that the device can reliably convey flows and most zones, but also highlights the need for clearer separation between neighboring electrodes or finer calibration.

6.3 Validity and Limitations

Since this work follows an exploratory, iterative design and prototyping approach with a small scale study (five participants), the validity of the findings is currently limited. The presented system reliably delivered EMS signals in response to touch input and maintained stable contact through a custom wearable sleeve, demonstrating technical feasibility. Additionally, the overall interaction concept of mapping touch gestures to stimulation was found to be implementable with low-latency BLE communication and off-the-shelf components.

However, the validity of perceived naturalness and long-term comfort has not yet been assessed beyond this small sample. Anxiety ratings may have been influenced by participants' unfamiliarity with EMS rather than by the device itself. Moreover, the second wearable prototype was replaced with a Python application in this study, limiting the evaluation of remote interaction. As such, claims about the social effectiveness of the system remain speculative. However, our focus on subtle perceptual feedback rather than movement control is consistent with acceptance findings by Shahu et al. [11], who showed users are more open to EMS in non-critical, playful contexts when they remain in control.

Future studies are required to evaluate the system in realistic long-distance contexts, with integrated hardware and communication protocols such as MQTT, to validate its ability to support non-verbal communication in a natural and meaningful way.

7 Future Work

Several directions remain for future development and evaluation of the system. While the current prototype demonstrates technical feasibility, it is not yet optimized for everyday use. The EMS generator is relatively bulky, which limits portability. Future versions should focus on miniaturizing the hardware, including embedding the microcontrollers, battery, and cables directly into the arm sleeve to create a more seamless and wearable form factor.

To increase the realism and precision of the touch sensation, future iterations could incorporate smaller and more numerous electrodes, allowing for finer stimulation. Another potential could be the use of embedded conductive materials directly within a textile arm sleeve, similar to the "Skill-Sleeves" proposed by Knibbe et al. [6], which may enhance both comfort and stimulation control without relying on adhesive pads.

In this project, the originally planned second wearable prototype for remote interaction was replaced with a Python application to facilitate the study. Future work should extend this setup into a fully integrated dual-prototype system, enabling evaluation of remote interaction in practice. Moreover, while Bluetooth Low Energy provided sufficient performance for our lab-based prototype, long-distance communication would require alternative protocols such as MQTT to ensure reliable connectivity.

The exploratory study also revealed several important design directions. While participants reliably recognized flows, the middle stimulation zone was often confused with the upper one. Future iterations should therefore explore more precise electrode placement and finer intensity tuning to improve spatial differentiation. Participants consistently rated the signals as subtle and easily detectable, but noted that they did not feel like natural human touch. Addressing this gap remains an open design challenge, possibly through new signal patterns or by including more and smaller electrodes. Finally, while some participants highlighted the potential of EMS for long-distance communication (e.g., sending cues such as "Hi, I'm here!"), others expressed skepticism toward wearables in general. This suggests that future studies should include larger and more diverse participant groups to explore acceptance in different contexts and to better understand for whom EMS-based wearables can become meaningful.

A key next step is the implementation of a long-term user study to evaluate how the system is perceived in realistic scenarios. Such a study should assess not only technical usability and comfort, but also the naturalness and subtlety of EMS-based touch sensations over extended use. Beyond technical aspects, future research should investigate how such sensations might support social presence, emotional connection, and non-verbal communication in long-distance contexts. This would provide insights into how EMS-based touch feedback can be made socially meaningful.

8 Conclusion

This project explored how Electrical Muscle Stimulation can be used to generate subtle and comfortable touch sensations in a wearable form factor. Through an iterative design and prototyping process, we developed and evaluated a functional prototype consisting of a 3D-printed arm sleeve, the *Let Your Body Move* toolkit, a Trill Flex sensor, and EMS feedback triggered wirelessly. While the system successfully translates touch gestures into remote tactile stimulation, early testing showed that while the sensations were comfortable, they did not convincingly resemble natural human touch.

Our findings highlight both the technical feasibility and the current limitations of EMS for simulating natural touch sensations. Future work should focus on increasing the realism of the stimulation, embedding hardware more seamlessly into the wearable, and conducting long-term user studies to evaluate comfort, naturalness, and potential applications in social communication.

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