Human-Computer Input via a Wrist-Based sEMG Wearable

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01 Executive Summary

Surface electromyography (sEMG) technology at the wrist represents the next groundbreaking way for people to control devices throughout their day. This non-invasive wrist device senses and interprets muscle activations which can be used as computer inputs in the form of a human-computer interface (HCI). This will enable people to control their devices "on-the-go" using simple, easy, and expressive input, without needing to shift their attention to a touchscreen or another physical input device. Given the potential of wrist-based sEMG to transform how people interact with computing devices, it is important to understand how the technology works.

This paper provides background on sEMG and its inclusive potential as a new input paradigm for human-computer interactions, and describes four key ways in which sEMG sensing and its device input applications differ from medical technologies and brain-computer interfaces (BCIs), including invasive EMG technologies and implanted devices in the brain:

1. sEMG input technology targets widespread consumer adoption for interaction with computing devices.
2. sEMG at the wrist is a safe and non-invasive technology —it does not require implants or surgery, in contrast to some clinical EMG approaches, as well as implantable BCIs.
3. sEMG operates at the periphery and does not sense neural signals from the brain.
4. sEMG can only sense user outputs using electrical signals from muscle activations—it does not provide information back to the body.

02 Introduction

The development of novel computing devices, such as AI-enabled and augmented reality (AR) glasses, has introduced a new challenge for product designers and consumers alike when it comes to controlling these devices. How can users seamlessly provide inputs when traditional input devices, like a keyboard and mouse or a touchscreen, are not readily available and do not work while "on-the-go"? An sEMG wristband will address this challenge by enabling a person to interact with computing devices using various hand gestures, like swiping their thumb to scroll through songs on a playlist while walking around outside. This is possible since sEMG technology can reliably identify hand gestures based on muscle activity detected from sensors on the surface of the skin near the wrist.[1] This wrist-wearable technology allows people to use computing devices with minimal friction anywhere, because sEMG enables users to provide inputs without manipulating a touchscreen or another physical input device.

When a person flexes their finger, a part of the brain called the motor cortex sends signals to the spinal cord, which in turn sends electrical signals to the muscles through spinal motor neurons. These motor neurons cause muscle fibers to contract and create muscle forces and movements. Sensors placed on the surface of the skin can observe the electrical signals that produce muscle contraction, allowing an sEMG device to detect when a user is controlling the muscles in their arm. This is conceptually similar to detecting a finger movement using a keyboard, but instead relies on sensing the electrical signals generated by the muscle rather than detecting the movement of a key. Muscle signals can be detected even when the movements are subtle or when a surface provides an opposing force that prevents movement. Since movement is not required for sensing, sEMG has great potential as an inclusive technology that works for users with a broad range of physical abilities. A person who is unable to move in a typical way due to injury or a movement disorder could more easily control a device with sEMG than with a traditional controller like a keyboard. Importantly, sEMG can only detect when someone activates their muscles—it is not capable of observing a user's brain activity or reading their "inner thoughts."

(1) CTRL-labs at Reality Labs. "A generic noninvasive neuromotor interface for human-computer interaction." bioRxiv (2024): 2024-02 (link).

03 sEMG as a Broadly Scalable Input Method

Simple and Expressive "Out-of-the-Box" Hand Gestures

Using sEMG at the wrist, people can quickly learn to control devices with familiar and intuitive gestures, such as finger taps, thumb swipes, and wrist rolls. Beyond these simple gestures, this technology also has the potential to detect more complex interactions, like handwriting and typing on a surface.

Notably, sEMG inputs can work out of the box across a diverse range of users. This is possible because the underlying algorithms can be made to generalize to new users if they are trained (using machine learning) on research data collected from a diverse pool of consenting participants in different environments—namely, participants with (i) anatomical differences in skin and wrist structures, (ii) physiological differences in how muscles in the wrist are activated to control hand movements, (iii) diverse demographics (e.g., age, race, ethnicity, gender, etc.), and (iv) variation in how they perform the same gesture.[2] This ability to create generalized (multi-user) algorithms that work right away for new users is part of what makes this technology an exciting breakthrough for seamlessly interacting with new devices.

Detection Across a Range of Physical Movements

Existing consumer HCIs primarily use hardware controllers like a mouse & keyboard or cameras with computer vision (CV) algorithms to track a user's eyes or hands. A wristband with sEMG technology offers several additional capabilities, enabling it to be used on its own or in conjunction with CV and other input modalities. sEMG wristband capabilities include:

- It does not require a user's hands to be in view of a camera sensor. This allows a user to perform gestures in a comfortable range of positions, including reclined postures.
- It can detect subtle gestures with little movement, which may be more ergonomic.
- It can be used to sense different amounts of muscle force, such as the varying pressures applied when squeezing two fingers together, offering an additional dimension of control. This also includes gestures where a user pushes against a surface or their body, which opens up additional interaction opportunities when a user's hands are encumbered (e.g., carrying a bag, a drink, or another object).

(2) CTRL-labs at Reality Labs. "A generic noninvasive neuromotor interface for human-computer interaction." bioRxiv (2024): 2024-02 (link).

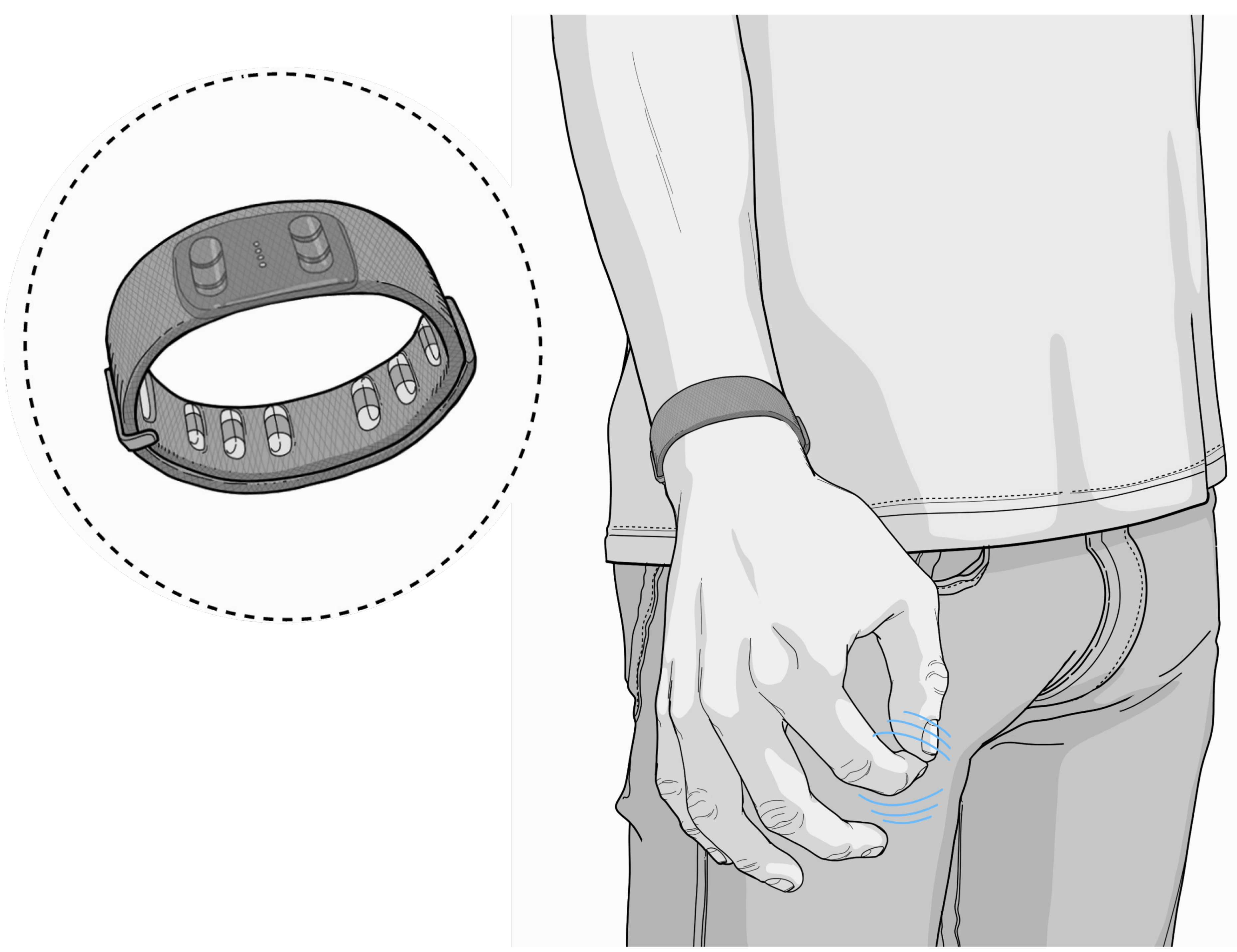
Collectively, these features allow users to perform gestures in a comfortable, natural, and easily accessible way. These inherent properties of sEMG at the wrist can be leveraged to provide immense benefits to people with a wide range of motor capabilities. For example, preliminary research[3] shows that wrist-based sEMG technology can identify intended hand or finger movements in people with spinal cord injuries and hand paralysis. Even though they could not make the hand movements required by traditional input technologies, the research participants were still able to generate a detectable amount of electrical activity at the wrist.

04 Principles of sEMG

Electrical Activity from Muscles Detected at the Skin Surface

The process of creating a movement begins in an area of the brain called the motor cortex, which is responsible for preparing and controlling voluntary movements. Neurons in the motor cortex generate electrical signals (called action potentials) that travel down the spinal cord to activate spinal motor neurons, which in turn send signals to the muscles. When a muscle fiber receives one of these input signals, it causes the fiber to contract and generate force in that muscle.

sEMG technology at the wrist senses muscle activations that mediate the user's physical actions. The detected electrical signals at the wrist surface do not represent an individual's internal thoughts or cognition that might be captured by other technologies which measure neural signals from the brain. sEMG at the wrist is both physically and cognitively non-invasive and a "read-only" technology that cannot write information to the brain.



(3) Carnegie Mellon University, "CMU, Meta Seek To Make Computer-based Tasks Accessible with Wristband Technology," July 9, 2024 (link).

sEMG at the Wrist as a Breakthrough for Consumers

Although sEMG for consumer device control is a recent technological advance, invasive EMG technologies have been used in clinical settings for several decades to monitor or diagnose neuromuscular disorders. sEMG at the wrist is distinct from these clinical EMG systems in two key ways:

- Clinical EMG systems often involve insertion of electrodes into a patient's muscle(s). sEMG at the wrist uses biocompatible sensors in contact with the skin, which is safer and more comfortable for all-day use by consumers.
- Invasive clinical systems are designed for use as part of medical diagnostic procedures, typically involving electrical stimulation and instructions to perform specific muscle contractions. Insertable electrodes allow for isolated recording from a single muscle and can record high-resolution information that is filtered by body tissue before reaching the skin surface. sEMG at the wrist is designed instead to enable inputs for human-computer interactions. These lower-resolution signals, measured at the skin surface, mix information from multiple muscles and are not used in conjunction with electrical stimulation or clinical procedures.

sEMG's Advantages Over Brain-Computer Interfaces

Many BCI companies are developing implantable devices that interface directly with the brain. Unlike sEMG at the wrist, implanted BCIs measure brain activity directly and apply algorithms to interpret these signals (and, for some cases, stimulate activity), in order to control a prosthetic device or provide therapy for neurological disorders (such as epilepsy or Parkinson's disease).

BCIs can be broadly classified by whether they use invasively implanted electrodes or non-invasive methods. Non-invasive BCI approaches like electroencephalography (EEG), magnetoencephalography (MEG), functional magnetic resonance imaging (fMRI), or other modalities sense brain activity through the skull and skin, without using implanted electrodes. These non-invasive BCIs typically feature lower-resolution and noisier signals than implanted devices, but still provide access to brain signals related to a person's internal cognition. Such non-invasive BCIs are common in scientific research and medicine but have not found widespread applications in consumer technology.

Both invasive and non-invasive BCIs face a number of social and ethical considerations, including privacy and data protections, due to their access to the brain and (in some cases) the ability to write information to the brain or modulate its activity. These concerns are mitigated with wrist-based sEMG devices, which operate at the periphery and do not have the same access to the brain. sEMG wristband devices sense only the signals driving the users outward motor behavior, and not the internal cognition from which this behavior arises. Users volitionally control when and how they want to move their arm to engage the device. In addition, a malfunctioning wrist sEMG device cannot directly injure or harm a user, which is not necessarily true for invasive BCI systems or BCIs with the ability to stimulate the brain. Users can turn off or remove a sEMG wristband device whenever they wish.

The combination of safety, comfort, non-invasiveness, and volitional control enabled by sEMG at the wrist make it a promising option for a widely-scalable consumer input device. As such, an HCI based on sEMG is a practical and exciting new paradigm for precisely controlling next-generation computing devices while providing a more privacy-forward approach.

05 Conclusion

sEMG at the wrist holds the potential to revolutionize the way people interface with their devices. Its ability to interpret gestures and subtle muscle forces—whether a user is sitting, standing, or on-the-go—make it broadly applicable for a range of different applications and types of input. In addition, its ability to serve a broad range of people out of the box make it well suited as a universal consumer device. Like the touchscreens, mice, and keyboards that came before, an HCI based on sEMG at the wrist can reshape our interaction with physical and digital systems by offering people a safe, seamless, and user-action focused method to control their digital devices.