



ElectroGnome: Limb-Agnostic Synchronous Gestures via Electric-Field Sensing

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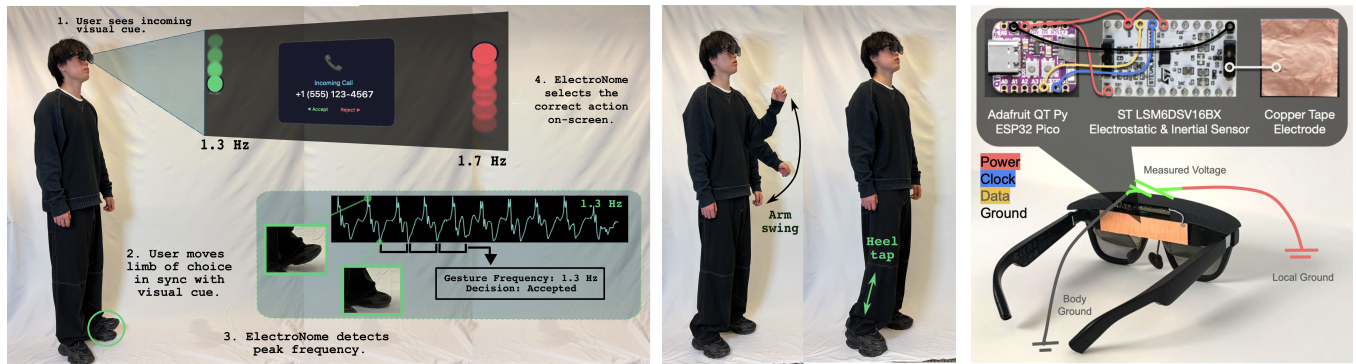


Figure 1: Overview of the *ElectroGnome* system. Left: Visual cues oscillate at different frequencies; users make their selection by gesturing in sync. Here, the user taps their toe at the same frequency as the “accept” option, which the system detects and correspondingly acts on. **Middle:** Any limb movement that distorts the electric field can be used as gestures, including arm swings and heel taps. **Right:** The system interfaces with the body via an electrode on the forehead.

Abstract

To address the need for customizable, adaptive, and efficient interaction methods for smart glasses, we propose *ElectroGnome*, a **limb-agnostic**, low-power, single-site passive electric field sensing approach, combined with intuitive synchronous gestures, where users move to match the frequency a visual cue. Through two studies, we verify that (a) participants can match visual cues, (b) our signal processing methods can accurately determine movement frequency, and (c) participants enjoy using the system relative to

existing interaction techniques, demonstrating *ElectroGnome*’s potential contributions to greater flexibility of smart glasses input.

Keywords

Electric Field Sensing, Sensing, Synchronous Gestures

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1 Introduction and Related Work

Rapid adoption of XR headsets and smart glasses, referred to collectively as “smart glasses”, demonstrates strong user interest. Smart



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glasses provide a ubiquitous platform to bridge the real and digital worlds through applications such as live translation [10] and search [21]. However, interaction modes remain cumbersome, ranging from voice commands to peripheral devices such as wristbands or controllers. Existing approaches come with their own set of limitations, such as failure for users with situational impairments ranging from occupied hands to injury and disability [5, 13, 16].

We fill a critical gap in peripheral-free, privacy-preserving, low-cost interaction with *ElectroGnome*, a novel limb-agnostic interaction modality combining the full-body awareness of electrostatic sensing with the intuitiveness of visual frequency cues. As illustrated in Figure 1, *ElectroGnome* users see visual cues oscillating at different frequencies. The user moves any limb in sync with a chosen cue. A low-power electric field sensor affixed to the glasses detects changes in voltage as the user’s limb moves. Once a frequency is detected, the corresponding option is selected.

To achieve limb-agnostic, peripheral-free interaction, *ElectroGnome* utilizes electric field sensing (EFS). EFS is a low-power technique which measures changes in voltage resulting from disturbances to the electric field around the sensor, in this case from the user’s body movements [8]. Researchers have explored EFS for detection of specific gestures [2–4, 11, 20]. Here, we focus not on a constrained gesture set, but rather, a broad range of movement frequencies—enabled by synchronous gesture interfaces (SGIs).

SGIs are a well-studied set of interaction techniques where a user moves in sync with the *frequency* of a visual or audio cue [14]. Past studies have proposed a variety of motions, from arm-whirling [1, 9, 15] to wrist-tilts [18], moving fingers [12, 19], and eye-tracking [6, 7]. However, many require the user to wear a device on the moving limb. *ElectroGnome* combines SGI with EFS, providing both *gesture*- and *limb-agnostic* interaction without peripherals.

We validate *ElectroGnome*’s novel combination of EFS and SGI through two studies. First, we demonstrate that *ElectroGnome* can determine the frequency of user gestures in real-time across different poses and environments. Then, we conduct a 10-participant user study where we compare *ElectroGnome* to a standard smart glasses voice interface in a notification response task. Taken together, we show that *ElectroGnome* demonstrates potential in providing a flexible, practical interaction technique for smartglasses.

2 *ElectroGnome* System

ElectroGnome comprises a microcontroller, electrostatic charge sensor, and copper tape electrode (Figure 1, right panel). An Adafruit QT Py ESP32 Pico streams sensor signals via WiFi to a smartphone. It also interfaces with an ST LSM6DSV16BX electrostatic charge and inertial sensor over I2C. This sensor measures electrostatic charge variation (“QVar”) and linear acceleration, both of which are sampled at 240 Hz. The microcontroller includes a power management circuit to interface with a 3.7 V battery. To measure the user’s electrostatic charge, we connect a copper tape electrode to the Q1 channel of the sensor. Although the electrode may or may not contact the user’s forehead based on face shape, we empirically found that even air-gapped coupling was sufficient for movement detection. We affix the sensor to a pair of XREAL Air smartglasses, which mirrors the screen of the host smartphone connected via USB-C. In our prototype, the sensor node is electrically isolated from the smartphone and smartglasses subsystem despite being

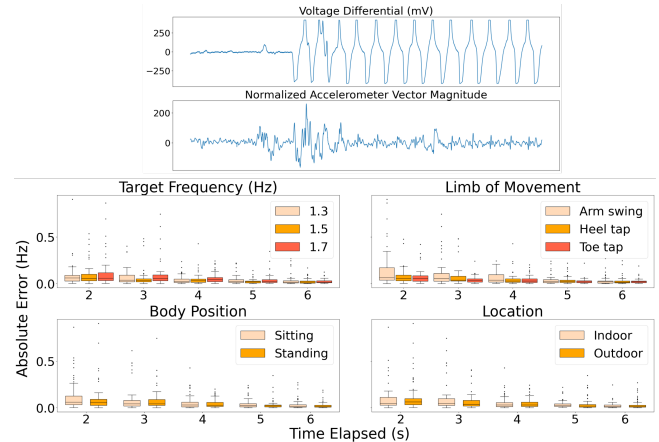


Figure 2: Top: Qualitative comparison of the EFS signal from toe tapping compared to the IMU signal. **Bottom:** Absolute error of a Pearson’s correlation-based method for frequency detection, with an expanding window of signal across experimental variables.

mechanically coupled. Future work includes investigating native integration of the electric field sensor into the smartglasses.

User interface design is critical for effective syncing. We informally evaluated multiple iterations of prototypes with volunteers, including (1) flashing stimuli [12, 18], where volunteers reported that it was hard to anticipate time-to-flash, and (2) circular trajectories [6, 7, 9, 15], which volunteers found poorly-suited for vertical movements. Based on these findings, we adopted a design in which a marker oscillates up and down between clearly indicated endpoints. Our prototype renders the stimuli on the smartphone, which is mirrored in the smartglasses.

Another design consideration is the range of frequencies to present as stimuli. Prior work ranges from 0.5 Hz to 1.25 Hz [12]. We found that faster tempos were easier to sustain, while also inducing a stronger signal via higher limb acceleration. We thus selected 1.3 Hz, 1.5 Hz, and 1.7 Hz as the set of frequencies for evaluation, although in principle more frequencies could be used.

3 Offline Evaluation

To demonstrate that users can match a visual cue at an accuracy robustly detectable by *ElectroGnome*, we recruited 7 volunteers to participate in a study in which they were presented with three frequencies to sync to (1.3 Hz, 1.5 Hz, and 1.7 Hz) in different poses (sitting and standing) and environments (indoors and outdoors).

For each combination of settings, participants were asked to serially synchronize three different limb movements to the stimulus for 30 seconds each: toe-tap, heel-tap, and arm-swing. These movements are remote from the head, where typical sensing would require instrumenting the respective limb, or face occlusions. From visual inspection, the sensor can detect small movements such as a toe tap, where the accelerometer struggles (top panel of Figure 2).

To demonstrate that our system can select the correct frequency across factors, we analyze frequency error over all offline data. To go from raw signal to frequency in Hz, we tested a number

of methods, including autocorrelation, peakfinding, and Pearson's correlation with target-frequency sine waves. We applied these methods over windows from $t = 0$ sec, and extend by 2 sec at each iteration, with a lag of 1 sec. A low-pass filter with a cut-off of 4 Hz was applied per-window. Error was calculated relative to the reference frequency shown to the users (1.3 Hz, 1.5 Hz, or 1.7 Hz).

Pearson's correlation outperforms other methods (Figure 2, bottom). By four windows of data (5 sec), Pearson's reached a stable average error of around 0.036 Hz, or 2.2 beats per minute—well within the 0.2 Hz difference between frequency options, even considering a standard deviation of 0.055 Hz. We select 5 sec as a stabilization point for frequency recognition error based on these results, which align with prior work on frequency-syncing interfaces [18].

4 Online Evaluation

After selecting Pearson's correlation for the analysis pipeline, we invited 10 volunteers to participate in a real-time study comparing *ElectroGnome* to speech recognition, a common input method for smart glasses. Each participant completed four tasks, selected to represent different situational impairments: (1) walking with full hands, (2) standing while packing a bag, (3) walking while talking, and (4) watching a video, seated. During each task, a call notification would appear in the smart glasses display. In the *ElectroGnome* condition, the smart glasses also rendered visual cues, one labeled "Accept" and the other, "Decline" (Figure 1, left panel). In the speech control condition, participants were asked to verbalize "Hey glasses, accept/decline the call." *exactly*. Participants attended to two notifications per condition per task, each task lasting 1.5 minutes.

Users found utility in customizability. Even mid-action, users found the system customizable and adaptive. For example, while walking, P4 tried to tap their foot while walking, found it difficult, and switched to arm swings. P8 and P9 also made similar transitions.

Users preferred *ElectroGnome* in audio-sensitive environments. Users reported that using a voice-based interface competes with other auditory signals; multiple users expressed concern around cutting off a conversation to speak to their smart glasses. Six out of ten participants reported that in public, they would rather use the motion-based system due to societal perceptions.

Users enjoyed the system more over time. Though trials were separate, users said they developed confidence and skill in using the *ElectroGnome* interface over time, even if they struggled at first, suggesting that the system is intuitive to learn to use.

5 Discussion and Conclusion

ElectroGnome introduces a novel limb-agnostic gesture paradigm, which combines the full-body awareness of EFS and the ease of SGIs, allowing users the freedom to adjust interactions based on situational needs without calibration, training, additional instrumentation, or video and audio monitoring. *ElectroGnome* can be easily integrated with existing smart glasses platforms, providing users with seamless, near-infinite options for interactive gestures which do not draw attention to the glasses or distract from the present moment. In contrast to systems that expect users to have certain capacities at all time, such as a free hand or the ability to speak clearly, our system innately provides users with greater flexibility, supporting ability-based designs [5, 17].

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