Wearable Glove Cursor Controller

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Introduction

Problem

For digital artists and everyday computer users, traditional input devices such as mousepads and trackpads impose significant limitations. These devices constrain the natural range of motion of the hand, making tasks like free-form drawing, sketching, or handwriting on a laptop cumbersome and unintuitive. While styluses and pen tablets exist, they can be costly and are often restricted to specific surfaces. Similarly, gesture-based input devices currently available in the market tend to rely on external cameras or sensors, which not only increase the price but also require substantial desk space and controlled environments for reliable performance. Such constraints limit accessibility and discourage more natural, fluid interaction with digital systems. A wearable device that eliminates reliance on external cameras or bulky setups would address these gaps and provide users with an input method that feels as natural as moving their own hand.

Solution

We propose a wearable glove system that enables users to control a computer cursor with natural hand movements and perform mouse actions through simple finger pinches. Unlike camera-based systems, the glove is fully self-contained, embedding motion sensors directly into the fabric for portable, low-cost operation without external hardware. To achieve this, the glove integrates motion sensors that capture hand orientation and translate it into cursor movement, while pinch detection provides reliable left and right click actions. Wireless communication streams this data to a computer in real time, ensuring low-latency interaction. Haptic feedback is incorporated so users receive immediate confirmation of their inputs without needing to look at the screen. This design balances cost, portability, and usability, making it a practical alternative to traditional input devices for digital artists and everyday users alike. The glove is designed to be lightweight and non-restrictive for extended wear, while its sensing and communication architecture ensures smooth interaction that feels as close as possible to using a traditional mouse, but with the added benefit of free-form, intuitive control.

Visual Aid

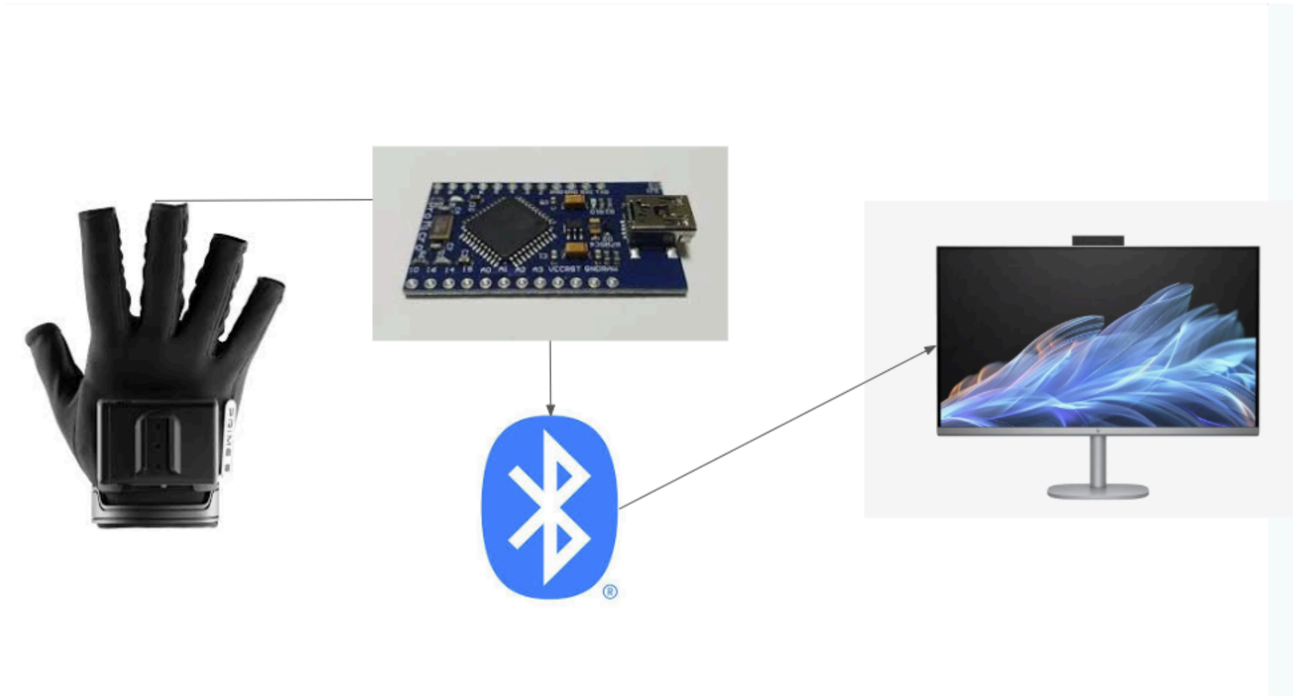

Figure 1

The glove has touch sensors and haptic feedback motors embedded in it

High-level requirements

1) The glove must achieve an end-to-end latency under 100 milliseconds between motion or gesture input and corresponding cursor or haptic output.

2) The motion tracking subsystem must provide orientation updates at a minimum rate of 100 Hz.

3) The gesture detection subsystem must recognize intentional touch activations with at least 97% accuracy while maintaining a false-positive rate below 2%.

Design

Block diagram

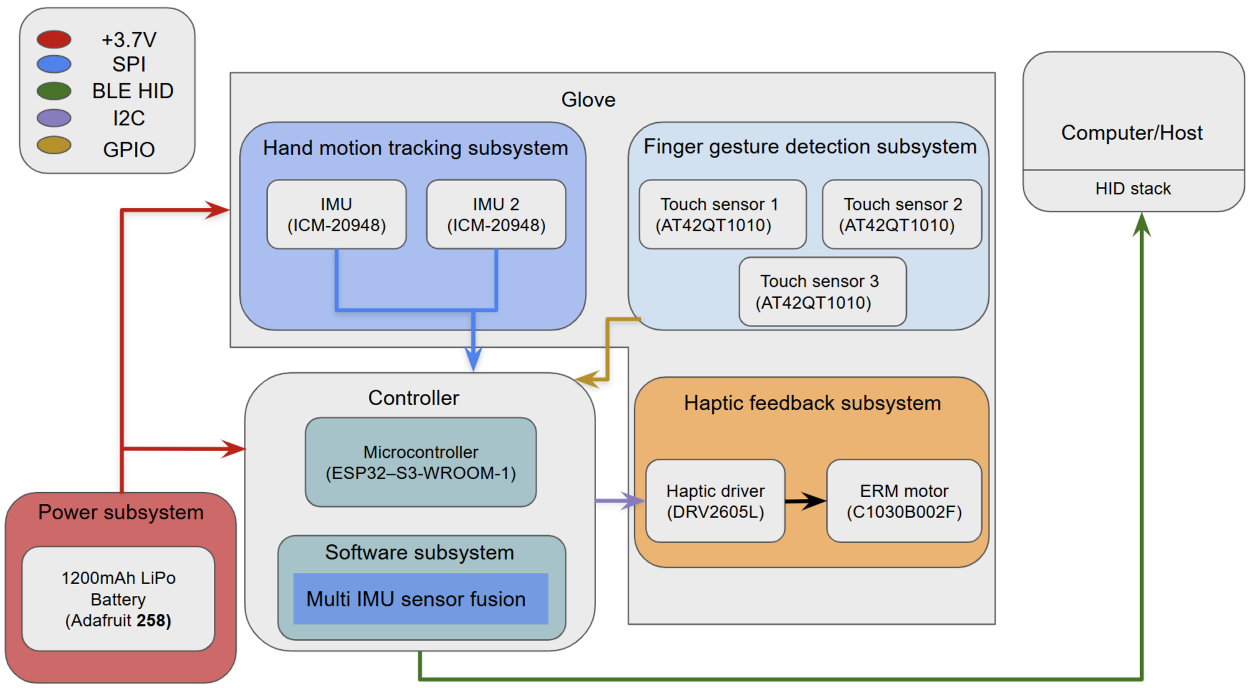

Figure 2

Subsystem Overview

Hand Motion Tracking Subsystem

This part of the glove is what makes the cursor move naturally. It uses embedded motion sensors to measure angular rotation and acceleration, which are processed to produce relative cursor movements. That information is then processed by the software, which translates it into smooth cursor movement on the screen. It connects closely with the gesture sensors, since the cursor should only move when the user intends it to, like during a pinch. Without it, the glove would not be able to sense how the hand is moving, and the cursor would be stuck.

Finger Gesture Detection Subsystem

The Finger Gesture Detection Subsystem enables the glove to recognize intuitive pinch gestures, such as thumb to ring and thumb to middle finger contact, corresponding to left and right mouse clicks, with the index to thumb being for actual mouse movement. The signals from these sensors go straight to the software, where they're turned into actual click events. They also work in step with the motion tracking so that clicks and movements happen together in a natural way. This is what makes the glove feel like a real mouse rather than just a motion tracker.

Haptic Feedback Subsystem
This is the part of the glove that "talks back" to the user. When a pinch is recognized as a click, a small vibration motor buzzes just enough to let the user know the input went through. That vibration is triggered by the software and powered by the same battery as everything else. It's a small detail, but it makes the glove much more intuitive to use—you don't have to look at the screen to confirm that your pinch was detected.

Software Subsystem
The software is the brain, tying everything together. It gathers the constant stream of motion data, listens for pinch signals, and decides how to turn all of that into cursor movements and mouse clicks. At the same time, it sends signals back out to trigger the haptic feedback so the user knows when an action is registered. Finally, it communicates wirelessly with the computer, making the glove feel like a standard input device. Without this coordination, the other subsystems would just be working in isolation.

Power Subsystem
The Power Subsystem provides regulated energy to all other subsystems. It consists of a rechargeable battery, a charging circuit, and voltage regulation, ensuring that stable 3.7 V supply rails are available for sensors, microcontroller, and haptic components. Without it, none of the glove's subsystems would function. It is the foundation of the entire design, enabling continuous and reliable operation during extended use.

Subsystem Requirements

<u>Power Subsystem</u>

Block Description:
The Power Subsystem provides electrical power for the glove. It consists of a 1200 mAh 3.7 V Li-Po battery. There will be a rail powering the IMUs, gesture sensors, controller, and haptic driver. Because the glove must operate continuously during extended use, this subsystem ensures sufficient energy storage and stable voltage regulation even under transient current draws.

Contribution to High-Level Requirements:
This subsystem enables the glove to remain wearable and user-friendly by supporting long operation times and avoiding unexpected resets or reduced responsiveness. A stable supply of power is critical for the IMUs and microcontroller to maintain natural cursor control without jitter, and for the haptic driver to provide consistent feedback during gestures.

Interfaces:

- Battery input: 3.7 V nominal
- Output rail: Regulated 3.7 V ± 0.1 V, continuous load ≥300 mA, transient peaks ≥500 mA connected to all devices to provide power
- Grounding: Common system ground with star-ground routing to isolate haptic current return.

Requirements:

- Must supply 3.7 V ± 0.1 V continuously because without it, the ESP32 will brown out and lose power
- Must tolerate 100–150 mA transients; otherwise, the haptic feedback will not function properly, hampering user feedback
- Must provide battery protection otherwise, cell damage or unsafe operation can occur which is not safe for usage

<u>Software subsystem</u>

Block Description:
The software subsystem acts as the brain of the glove, built around the ESP32-S3-WROOM-1 module. It processes raw sensor data, executes gesture detection logic, drives haptic feedback commands, and communicates wirelessly with the host computer over bluetooth. It runs a ~100 Hz task loop that fuses IMU inputs, applies filtering and deadband logic, and generates mouse reports with minimal latency. It also manages all the SPI and I2C protocol handling to communicate with the different parts of the glove

Contribution to High-Level Requirements:
This subsystem is essential for natural cursor control, as it translates hand orientation into smooth, low-latency cursor motion. It also ensures gesture-based input, interpreting touch signals as mouse clicks and synchronizing tactile feedback. Finally, it supports wearability by integrating wireless bluetooth connectivity into a compact, lightweight module.

Interfaces:

- Two independent chip-select lines to IMUs which are used to manage the hand movement with inputs from the sensors to control and translate the hand movements into actual mouse movements which will be done by the microcontroller
- Three digital inputs for touch sensors to detect when user taps and convert that to mouse movement and feedback to the screen
- I2C communication to the haptic feedback sensor to provide a realistic feedback to the user and timing it correctly to correspond to user mouse interactions
- ~80Hz “mouse” reports connection to the computer device via Bluetooth
- +3.7 V ±0.1 V current drawn from the power system to ensure steady function

Requirements:

- Must process IMU data at ≥100 Hz otherwise cursor lags or stutters and it would not be a smooth interaction and inputs might be missed
- Must transmit bluetooth reports with less latency otherwise real-time interaction is not met and mouse will feel laggy
- Must handle at least 3 touch inputs for ring, middle and index fingers otherwise gestures cannot be recognized and user movements will not be processed well

Hand Motion Tracking subsystem

Block Description:
The Hand Motion Tracking Module contains two ICM-20948 9-axis IMUs, mounted at strategic points on the glove to capture angular rate and acceleration. Each sensor is configured with gyroscope full-scale ±1000 dps and accelerometer full-scale ±4 g, operating at ≥400 Hz. The IMUs provide the raw data needed to compute smooth cursor deltas during a pinch gesture. Data is transmitted to the controller subsystem via SPI for low-latency performance. Will use sensor fusion and (ideally) Karman filters to do this and will avoid drift caused by IMUs to be fixed

Contribution to High-Level Requirements:
Accurate motion sensing is a very high priority for natural cursor control, as the IMUs directly capture the user's hand orientation and dynamics. Without precise and stable motion data, cursor movement would be jittery and laggy undermining the system's real-time usability.

Interfaces:

- Two independent chip-select lines to IMUs which are used to manage the hand movement with inputs from the sensors to control and translate the hand movements into actual mouse movements. The hand tracking module will record the sensor data and send it to the microcontroller for processing via SPI.
- Power: 3.7 V ±0.1 V will be drawn from the battery and power subsystem and will be used to.

Requirements:

- The subsystem must provide fused orientation updates at a minimum rate of 100 Hz with a processing latency of less than 10 ms.
- The effective velocity-to-cursor mapping must remain stable such that cumulative drift does not exceed the equivalent of 1 cm of unintended displacement per 30 seconds of stationary use

Finger Gesture Detection Subsystem

Block Description:
This module implements gesture recognition via three AT42QT1010 capacitive touch ICs, each configured as a binary detector for thumb-to-finger pinches. Electrodes are sized 8–12 mm in diameter and shielded to prevent environmental noise or sweat interference. Each sensor outputs a digital logic signal directly to the ESP32 GPIOs.

Contribution to High-Level Requirements:
Enables reliable gesture-based input by allowing intuitive finger pinches to trigger left/right click events. Without this subsystem, users would not be able to perform mouse clicks naturally, severely limiting the glove's functionality.

Interfaces:

- Digital outputs: 3× active-low signals to ESP32
- Power: 3.7 V ±0.1 V

Requirements:

- Must detect pinch gestures within ≤30 ms; otherwise system responsiveness drops.
- Must maintain a false-positive rate ≤2%; otherwise input becomes unreliable.
- Must provide clear logic levels; otherwise ESP32 cannot interpret clicks.

Haptic Feedback subsystem

Block Description:
The Haptic Feedback Module provides tactile confirmation of user gestures through an ERM coin vibration motor (e.g., Jinlong C1030B002F) driven by a DRV2605L haptic driver IC. The DRV2605L communicates with the ESP32 via I2C, allowing the controller to trigger preloaded vibration effects or direct PWM-like drive waveforms. The driver's integrated closed-loop control ensures consistent vibration strength across battery voltage variations, while the ERM motor delivers short bursts of feedback (<50 ms) to signal clicks or special actions.

Contribution to High-Level Requirements:
Tactile feedback is essential for reinforcing the "mouse click" illusion without requiring visual confirmation, enabling eyes-free operation and improving user confidence in gesture recognition. Without reliable haptics, users may be unsure whether their pinch was registered, reducing usability and overall intuitiveness.

Interfaces:

- I2C control bus from ESP32 (SDA/SCL, 400 kHz).
- Interrupt pin (optional) for playback completion status.
- Driver outputs (OUT+ / OUT–) directly wired to ERM motor terminals.

Power:
Supplied by regulated +3.7 V rail.

Tolerance Analysis

A major risk in this design is IMU noise and the drift that results when acceleration is integrated to estimate motion. Mathematically, if we take a typical accelerometer noise of about 0.02 m/s^2 and sample at 100 Hz, then after 10 s the velocity error grows only modestly, on the order of $\sigma_v \approx \sigma_a(\text{sqrt}(N)\Delta t) \approx 0.006$ m/s. However, double integrating this same noise into position compounds the error quadratically with time, leading to $\sigma_x \approx 0.5\sigma_a t^2 \approx 1$ m drift over 10 s which is large enough that the cursor would quickly become unusable. Our approach avoids this by integrating only once and mapping velocity changes directly to HID cursor deltas, analogous to how a standard optical mouse reports relative movement rather than absolute position. In this single-integration scheme, bias grows much more slowly, and the effective displacement error remains bounded to the centimeter-equivalent scale over several seconds, rather than exploding to meters. Further stability can be enforced through orientation fusion with Kalman filters or Madgwick filters and periodic zero-velocity updates when the glove is stationary, ensuring that drift is corrected before it accumulates. This makes the velocity-based mapping approach mathematically feasible for smooth, low-drift cursor control in practice.

Ethics and Safety

1. Electrical and Battery Safety
    a. The glove will be powered by a 3.7 V Li-Po cell and to mitigate the risk of overheat, overcharging or puncture we intend on having a design that includes overcharge, over-discharge and short-circuit protection circuitry.
    b. All testing will use protective casings and charging modules compliant with standard safety guidelines
    c. Wires and PCBs will be insulated to prevent short circuits or exposed conductors from contacting the user’s skin
2. Wearability and Ergonomics
    a. The glove must remain lightweight and breathable to avoid strain or discomfort
    b. Sensor and battery placement will be designed to minimize obstruction to natural hand movements and prevent circulation restriction.
3. Data Privacy and Security
    a. The system transmits only gesture and motion data via Bluetooth HID. No personal or identifying information is collected, stored, or transmitted.
4. Environmental and Sustainability Considerations
    a. Whenever possible, we will use readily available, RoHS-compliant components.
    b. Rechargeable batteries are used to reduce electronic waste. Disposal guidelines for Li-Po cells will be followed and communicated to users.