VIRTUAL SCROLL WHEEL INPUT DEVICE WITH ADAPTIVE TOUCH SENSING AND MODULAR HAPTIC FEEDBACK

ABSTRACT

A virtual scroll wheel replaces physical rollers in laptops/mice using a curved touch strip (arc of a disk segment) with smartwatch-derived haptic feedback. Key innovations include tilt-to-horizontal scroll (MEMS accelerometer), pressure-sensitive zoom (capacitive force sensing), and adaptive sensitivity modes. The modular design enables sub-10mm thickness for ultraportable laptops while providing tactile detents and inertial scrolling via optimized PWM haptic profiles. Since there are no moving parts the virtual scroll wheel lasts longer and requires less maintenance than a physical scroll wheel. It can also be customized to enhance a user's productivity, without the need to carry around a separate mouse and find a flat surface to work on.

TECHNICAL FIELD

This invention relates to computer input devices with curved touch surfaces implementing scroll wheel functionality through improved capacitance sensing and smartwatch-derived haptic systems, particularly suitable for thin-profile laptops and peripheral devices, allowing scrolling an image in multiple directions relative to a display screen.

BACKGROUND OF THE INVENTION

The typical arrow keys on a laptop keyboard provide an unsatisfactory experience when navigating content on the computer screen. For example, in Word documents the up and down arrow keys cause movement from line to line and jerky movements between pages. Wired and wireless mice have been in common use with both desktop computers and laptops. Many of these mice also contain an endlessly rotating scroll wheel. The scroll wheel is very convenient for moving the image on the computer screen up or down. It is particularly convenient for infinite scrolling which is common on social media platforms, news feeds, and e-commerce sites. The user does not need to position the cursor on the up or down arrows on the scroll bar and click repeatedly to move the screen up or down. The user also does not need to click on and drag the thumb on the scroll bar up or down. All these actions require a lot of focus and effort on the part of the user. With respect to laptop computers, to use a wired or wireless mouse, it is assumed the user is sitting at a desk or table. When a laptop user is sitting on a sofa, they cannot use a mouse let alone a scroll wheel that it may have. Most laptops contain a built-in touchpad to position the cursor on the screen, which obviates the need for a mouse. In the prior art it has been proposed to integrate scroll wheel(s) into the laptop keyboard to move the screen up and down or side to side. Though this looks good on paper, in reality there are no laptops on the market with built in scroll wheel(s). The reason is that laptop computers are continuing to get thinner and thinner every year. Though mice manufacturers don’t disclose the size of their scroll wheels, rough measurements of existing models indicate they range roughly anywhere from 15-22 mm in diameter. Even a scroll wheel with a 15 mm diameter is too large for most laptops. The problem is that if the diameter is decreased even further the scroll wheel is too impractical to use. Moreover, the optical encoder and other parts of the scroll wheel need to be completely redesigned and miniaturized to fit in a laptop. To avoid all these problems, some manufacturers include scroll line(s) or scroll strip(s) on the touchpad to allow virtual scrolling. However, these features are difficult to use because they are so sensitive. The experience is more akin to clicking and dragging the thumb on the scroll bar(s). This is adequate for scrolling large distances. However, when the user wants to switch to fine scrolling, they need to use the up and down arrows on the scroll bar. Quickly switching back and forth between coarse and fine scrolling is even more problematic. Many people have also experienced difficulties getting scroll line(s) and scroll strip(s) to work after software updates due to numerous driver issues. It is better to keep the scroll strip separate from the touchpad to minimize driver conflicts. Scroll line(s) and scroll strip(s) also take up space on the touchpad, reducing its useable area and requiring the user to be vigilant in avoiding these areas to prevent inadvertent scrolling while simply trying to reposition the cursor. In the prior art it has also been proposed to include a small scroll strip in place of the scroll wheel on computer mice. However, these suffer the same problems as the scroll line(s) and scroll strip(s) on touchpads. Moreover, their use is not as easy or intuitive as a scroll wheel. Using the index finger to rapidly switch between coarse and fine scrolling on a scroll wheel to zero in on the exact area of interest is very easy.

Note that many mice have an optical-mechanical roller with a ratchet mechanism. This provides tactile feedback via the gentle clicks felt when the user moves the roller on the mouse. Some Logitech mice also allow users to switch between click scroll and free scroll, which is like swiping hard and letting the momentum move the page. Some touch strips proposed on mice in the prior art provide haptic feedback. However, haptic feedback on a flat strip is not intuitive and only provides basic vibration.

Some mice have a scroll wheel which can be tilted left or right to scroll horizontally. However, these involve large, complicated assemblies that won’t fit within a thin laptop. An improved tilt-to-horizontal scroll mechanism is provided, which is useful for horizontal scrolling of large distances on spreadsheets and graphics files.

BRIEF SUMMARY OF THE INVENTION

In this invention a virtual scroll wheel is used to provide scroll wheel functionality in laptops within the size constraints of even the thinnest laptops, while providing the feel and haptic feedback of a scroll wheel vs a flat touch strip.

Using an implied diameter of 22 mm the maximum height of the virtual scroll wheel is 11mm (i.e. the radius). Even this is excessive. In practice the chord length can be 17 mm while the height of the disk segment would be 4.02 mm. This is approximately the same size as the exposed part of physical scroll wheels on most mice. Note that the RX electrodes would be evenly spaced along the arc of the disk segment. It is well known in the prior art how to create touch sensitive surfaces on curved screens using various technologies, particularly for smartphones. One of these technologies can be used to create a touch sensitive surface along the arc of the disk segment. Note that since the electrodes are evenly spaced and the touch sensitive surface is not bendable, its manufacture should be easier than in other applications.

The disk segment is bonded to a haptic motor along part of its chord. Note that the haptic motor, contains a linear resonant actuator (LRA) such as the one found in Apple Watches that is the perfect size for this purpose. The height of the assembly stack for a virtual scroll wheel is calculated as follows: with a height of 4 mm for the disk segment, plus 3 mm in thickness for the LRA, plus a vibration damping silicone isolator layer of 1mm which is bonded to the printed circuit board (PCB). For most consumer electronics, including laptops, and input devices like the virtual scroll wheel, PCB thickness between 0.6 mm and 1.6 mm is typical and provides sufficient rigidity for reliable operation. The thickness of the walls of a laptop body (the outer casing or chassis) typically ranges from 0.5 mm to 2 mm, depending on the material (aluminum, magnesium alloy, or plastic) and the specific design requirements for strength, rigidity, and weight. The PCB is usually placed 0.5 mm to 1 mm away from the laptop body walls to ensure reliable assembly and operation.

Note that the 0.55 mm thick MEMS accelerometer is soldered directly onto the Printed Circuit Board (PCB) at least several mm away from the LRA, at the same level as the silicone layer. A rigid metal post with a silicone sleeve transfers force directly from the touch arc to the PCB. When the PCB flexes slightly it is detected by the MEMS accelerometer nearby.

If the disk segment protrudes from the keyboard 2 mm (i.e. about flush with the keys of the laptop), this assembly stack for the virtual scroll wheel would be within the constraints of a 10 mm thick keyboard of a thin laptop.

The feel and functionality of a virtual scroll wheel would be determined entirely through software. The sensitivity of the scrolling as well as the degree of haptic feedback for a given swipe or movement of the finger along the touch sensitive surface can be adjusted in the software. If desired the user can even enable free scrolling.

The precision touch sensing system utilizes a mutual capacitance array, edge-tracking algorithm, and adaptive sensitivity modes. Haptic feedback is improved using an LRA and haptic profiles matching common UI interactions. Other useful features include tilt-to-horizontal scroll and pressure-sensitive zoom.

Industrial applications include Medical Imaging: Pressure-sensitive zoom for CT scan navigation. Gaming Controllers: Haptic recoil feedback synchronized with in-game events. Accessibility Devices: Tilt-based scrolling for motor-impaired users

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows the order of components in the stack from top to bottom

Fig. 2 is a side view of a virtual scroll wheel according to the present invention.

Fig. 3 is a side view of a virtual scroll wheel showing dimensions of components (in mm)

Fig. 4 is a top view of a virtual scroll wheel in a laptop body showing recesses on the ends

Fig. 5 is a top view of the touch arc showing the TX and RX electrodes

Fig. 6 is a perspective view of a laptop with a virtual scroll wheel located near the upper right corner of the touchpad.

Fig. 7 is a perspective view of a laptop with a virtual scroll wheel located near the lower right corner of the keyboard.

Fig. 8 is a side view of a computer mouse with a virtual scroll wheel mounted according to the slope of the mouse giving the same outward look and feel as a physical scroll wheel.

Fig. 9 is a prior art differentiation table

Fig. 10 is a conflict mitigation table for zoom that uses capacitive force sensing

Fig. 11 Exploded LRA mounting assembly

Fig. 12 System block diagram with DSP pipeline

Fig. 13 Touch pattern recognition flowchart

DETAILED DESCRIPTION OF THE FIGURES

Fig. 1 shows the virtual scroll wheel stack order from top to bottom

Fig. 2 illustrates side view of virtual scroll wheel with a touch strip 1 mounted over a disk segment 2. Part of the chord of the disk segment is bonded to a haptic motor containing an LRA 3 which is bonded to vibration damping material 4 which is bonded to the PCB 5. The rigid metal post 6 with a silicone sleeve transmits force from the touch arc to the PCB. The MEMS accelerometer 7 is soldered to the PCB and is located 2 or more mm from the attachment point of the rigid post on the PCB, the MEMS accelerometer senses flexing of the PCB. The outer casing 8 of the laptop is less than 1 mm away from the PCB. The upper surface of the laptop housing 9 has recessed areas 10 and 11.

Note that the LRA's dimensions are Length 12 mm, Width 5 mm, and Thickness of 3 mm. While large for a watch, these dimensions are insignificant for a laptop computer and perfect for virtual scroll wheels.

Fig. 3 is a side view of a virtual scroll wheel showing dimensions of components (in mm)

Fig. 4 is a top view of disk segment 2 protruding from the laptop housing with recessed areas 10 and 11 in the laptop housing at the two ends of the virtual scroll wheel, rendering more of the arc accessible to the index finger

Fig. 5 is a top view of the touch arc showing the TX electrode 12 and RX electrodes 13

Fig. 6 is a perspective view of a laptop 14 showing one embodiment with a virtual scroll wheel 15 located near the upper right corner of the touchpad 16. Every laptop has its own size, shape, and location for its touchpad. The figures showing the location(s) of the virtual scroll wheels on the laptop are only illustrative and will vary in practice.

Fig. 7 is a perspective view of a laptop 14 showing one embodiment with a virtual scroll wheel 15 in an alternative location next to the lower right corner of the keys on keyboard 17. Note that whether the virtual scroll wheel is placed near the touchpad 16 or the lower right corner of the keyboard 17, the virtual scroll wheel would not be prone to accidental touches even with both hands in the typing position.

Fig. 8 is a side view of a mouse 18 with a virtual scroll wheel assembly 19 mounted on a sloped internal surface 20 of PCB in accordance with the external slope of the mouse. Note that virtual scroll wheels, though optimal for laptops, can also be used in computer mice since they have no moving parts, are more precise, and will last longer with less maintenance.

Fig. 9 is a prior art differentiation table

Fig. 10 is a conflict mitigation table for zoom that uses capacitive force sensing

Fig. 11 Exploded LRA mounting assembly

Fig. 12 is a block diagram for the virtual scroll wheel's Digital Signal Processing (DSP) pipeline, based on mutual capacitance touch sensing and haptic feedback control. The DSP Pipeline utilizes filtering (rejects common-mode interference)

Fig. 13 is a touch pattern recognition flowchart specific to the virtual scroll wheel's leading-edge detection system.

DETAILED DESCRIPTION OF THE INVENTION

Enable multi-axis control by implementing tilt-to-horizontal-scroll using integrated MEMS accelerometer (±2g range). Force Transmission Mechanism: User applies force to touch arc → Rigid post transfers force directly to PCB → PCB flexes slightly → MEMS accelerometer detects flexure as tilt/pressure. The haptic motor's vibrations are absorbed by the silicone layer, preventing interference with force measurements.

For consumer devices like the virtual scroll wheel, the Bosch BMA580 MEMS accelerometer's noise and offset performance are more than sufficient for detecting tilt, pressure, or gesture inputs, especially when combined with good mechanical isolation and signal processing. The BMA580's 6.4 kHz sampling and programmable low-pass filters provide robust anti-aliasing and noise reduction, making it suitable for the virtual scroll wheel's demanding haptic and gesture-sensing requirements. Other suggestions to improve performance of the MEMS accelerometer include implementing SBG-style FIR filters in the DSP pipeline to reject haptic-induced noise. The Bosch BMA580 detects subtle movements (e.g., tilt, pressure-induced PCB flexure) with minimal noise, critical for precise scrolling and zoom detection. It also supports adaptive sensitivity algorithms (e.g., precision mode after 500ms contact) and has an ultra-compact size of 1.2 mm x 0.8 mm x 0.55 mm which is perfect for virtual scroll wheels. Moreover, it is used in premium consumer devices (such as the Apple Watch), ensuring reliability and compatibility with haptic feedback systems.

Note that vibrations from the haptic motor *could* transmit through the rigid post to the PCB and interfere with the MEMS accelerometer's measurements, but this risk can be mitigated with careful design. Here's how: anchor the post to the touch arc *away from the haptic motor's mounting point* (e.g., near the arc's edge along the chord). Ensure the silicone has a high damping coefficient (e.g., 50–70 Shore A hardness) to absorb haptic motor oscillations. Mount the MEMS accelerometer ≥2mm away from the post's PCB anchor point to reduce vibration coupling.

With proper isolation of the rigid post and optimized damping, the MEMS accelerometer will primarily detect intentional tilt/pressure inputs (via PCB flexure) while rejecting haptic feedback vibrations. This aligns with the goal of replicating mechanical scroll wheel functionality without compromising measurement accuracy.

A haptic motor driver is the electronic interface between the device's controller and the haptic motor, precisely controlling the vibration patterns that provide tactile feedback to the user. It is essential for creating realistic, responsive, and customizable haptic effects in modern input devices.

In a virtual scroll wheel the haptic motor driver is mounted on the PCB and receives commands from the controller chip. When the user interacts with the touch arc, the controller signals the haptic driver to activate the LRA motor, producing vibrations that simulate the tactile feel of a mechanical scroll wheel.

The controller and the MEMS accelerometer are placed side by side on the same surface of the PCB**.** This allows efficient routing from the controller to the touch electrodes, haptic motor driver, and MEMS accelerometer.

The modular mounting system of virtual scroll wheels is compatible with: Laptop keyboards (4.02mm protrusion), Mouse enclosures, and External numpads (USB-C powered configuration).

Improved Touch Sensing Mechanism uses mutual capacitance sensing with 16+ RX electrodes for 0.5mm resolution. Optional detection logic for edge-based scrolling tracks the leading edge of the touch area instead of the centroid for more responsive and intuitive scrolling. Implement inertial scrolling algorithms mimicking physical wheel momentum.

Improved haptic feedback system by integrating linear resonant actuators (LRA) from smartwatches (12x5x3mm dimensions) with variable resistance simulation using: 0.1N·m torque for click detents and 0.05N·m for free-spin modes. Adding vibration damping layer (1mm silicone isolator) below the LRA isolates haptics from the MEMS accelerometer and laptop body.

Optimized Pulse Width Modulation (PWM) haptic control parameters for the virtual scroll wheel's Linear Resonant Actuator (LRA) include: Base Frequency Range of 100–200 Hz (matches LRA resonant frequencies for tactile clarity). Duty Cycle Modulation for Detent Clicks: 50% duty cycle (sharp 1–2ms pulses), Free-Scroll Vibration: 10–30% duty cycle (continuous sine modulation), Pressure-Sensitive Feedback: 5–80% (proportional to finger force). Waveform Types include: Square Wave: Crisp detents (e.g., 175Hz, 50% duty), Sine Wave: Smooth inertial scrolling (frequency sweep 100→200Hz), and Burst Mode: 3–5 cycles at 175Hz for "page turn" feedback. Closed-Loop Control includes: Back-EMF Sensing: Adjusts PWM in real-time using LRA's voltage feedback, Auto-Resonance Tracking: Maintains peak efficiency across temperature/aging.

Pressure Detection Mechanism uses Capacitive Force Sensing: the mutual capacitance touch strip (1 TX + 16+ RX electrodes) detects not only finger position but also changes in contact area caused by pressure. Harder presses flatten the finger, increasing the capacitive coupling between electrodes. With Threshold Activation a force threshold of >10g triggers zoom mode. This avoids accidental activation during normal scrolling. Force-to-Zoom Curve: linear mapping of capacitive force (10–50g) to zoom granularity (e.g., 10g = 1x, 50g = 5x).

Haptic Feedback Integration uses Variable Haptic Pulses: Light pressure: Subtle 0.05N·m vibrations for fine adjustments. Heavy pressure: Strong 0.1N·m detents for coarse zooming. The pressure data is processed by the Controller on the PCB, which also manages the LRA haptic motor and the MEMS accelerometer (for tilt-based horizontal scrolling).

Key Advantages vs prior art for pressure sensing: No separate sensor: Uses existing mutual capacitance electrodes for pressure detection, avoiding added hardware. Context-Aware: Automatically disables pressure zoom during horizontal scrolling (via MEMS tilt data). User Customization: Sensitivity and haptic strength adjustable in software

Though there are several ways to enable zoom in versus zoom out, in practice the most intuitive and widely adopted method is to combine finger movement direction with pressure. The scroll wheel detects both the direction of the user's finger movement, and the pressure applied.

Scrolling up (forward) with pressure**:** Zooms in (increased pressure = more zoom in). Scrolling down (backward) with pressure**:** Zooms out (increased pressure = more zoom out).

This mimics the behavior of many professional applications (e.g., Photoshop, video editors) where the scroll direction determines zoom in/out, and pressure can control the speed or granularity. This approach could be implemented in the virtual scroll wheel software for a seamless user experience.

Touch Detection: Edge-tracking algorithm (leading-edge detection) and Multi-touch rejection logic: rejecting unintended touches by tracking contact area changes and ignoring secondary touches during active scrolling.

Gesture Recognition: Scroll velocity calculation and Tilt-to-horizontal conversion (using accelerometer data)

Adaptive Sensitivity: Precision mode activation after 500ms continuous contact and Dynamic haptic strength adjustment

Centroid calculation is a weighted average method to find the "center" of a touch on a sensor array, widely used in touch panels and sliders for precise position detection.

Centroid calculation enables smooth, high-resolution touch tracking, allowing for precise gesture and position detection, even between discrete sensors. However, it has some Limitations**:** If the touch area is large (e.g., a whole fingertip over several sensors), the centroid may not accurately represent the user's intended edge or direction of movement. This is why the virtual scroll wheel design proposes using the leading edge of the touch instead of the centroid for scroll detection.

The present invention can improve on centroid calculation by using leading edge detection for more natural scroll wheel emulation. In Settings the user can turn off edge-based scrolling and switch to traditional centroid based scrolling if desired.

The proposed edge-based scrolling and pressure-sensitive zoom features can coexist without conflict if properly implemented.

Pressure Threshold Activation**:** Set a force threshold (e.g., >10g) to activate zoom mode. Below this threshold, only edge-based scrolling is active.

Example: Light swipes trigger scrolling; firmer presses activate zoom.

Directional Lockout**:** Ignore edge-based scroll inputs while pressure exceeds the zoom threshold to prevent conflicting commands.

Haptic Latency: <20ms from touch to vibration, matching Apple Watch haptics.

Haptic Feedback Differentiation would be as follows: Scroll Feedback**:** Short, sharp pulses (0.1N·m) for detents. Zoom Feedback**:** Continuous vibrations (0.05N·m) with intensity proportional to pressure. Transition Cue**:** A distinct double-pulse when crossing the pressure threshold into zoom mode. Mode Toggle**:** Allow disabling pressure zoom for users who prefer gesture-based zoom (e.g., pinch on touchpad).

Accordingly, the foregoing disclosure is intended to be illustrative, but not limiting, of the scope of the invention which is set forth in the following claims.

What is claimed is:

1. A computer input device, comprising: Housing with protruding disk segment (≤4.02mm height). Mutual capacitance touch strip along the disk's arc. Modular haptic assembly (LRA + silicone damping layer). MEMS accelerometer detecting PCB flexure for tilt/pressure.
2. The device of claim 1, further including: Pressure threshold >10g activating zoom mode. Haptic feedback proportional to applied force. Leading-edge tracking algorithm disabling centroid calculation
3. Modular haptic assembly compatible with laptops (≤4.02mm protrusion) and mice via sloped PCB mounting
4. A computer input device for scrolling an image, the device comprising: housing of a laptop, mouse, or other input device having an opening with a protruding disk segment.
   The key feature distinguishing virtual scroll wheels is the touch sensitive surface along the arc of a disk segment. The disk segment being equal in size to a semicircle or smaller, for a given implied diameter of a physical scroll wheel. In the prior art only flat touch strips have been proposed. The curved touch strip on the virtual scroll wheel provides the look and feel of a physical scroll wheel.
5. There can be a recessed area in the upper surface of the laptop body at the two ends of the protruding disk segment to provide more access to the arc of the disk segment by the index finger.
6. The device in Claim 1, where part of the chord of the disk segment is bonded to a haptic motor containing an LRA. The modular haptic engine originally used in smartwatches is compatible with mice/laptops and has haptic profiles which can be adjusted in software.
7. There is a thin layer of vibration damping material between the haptic motor and the PCB to isolate haptic feedback.
8. Tilt-to-horizontal scroll is enabled using a MEMS accelerometer detecting PCB flexure caused by applied force, enabling tilt-to-horizontal scrolling without physical pivot points.
9. Force from the touch arc is transmitted to the PCB and thus the MEMS accelerometer by a rigid metal post with a silicone sleeve.
10. The virtual scroll wheel is comprised of a disk segment with a mutual capacitance touch strip along its arc. One end of each RX (Receive) line and each TX (Transmit) line is routed to a dedicated pin on the controller chip. Only one end is connected, the other end terminates at the edge of the electrode pattern. The TX electrode runs along the length of the strip and the RX electrodes are arranged perpendicularly along the strip's length. Typical configuration has 1 TX line running the length of the strip and multiple RX lines segmented along the strip to provide position resolution. The number of RX lines determines the granularity of position sensing. More RX lines mean more precise touch location detection along the strip. The typical number of RX lines in a touch strip is 5-20. Preferably at least 16 or more RX lines would be used in a virtual scroll wheel.

Note that touch strips with RX-only (Self-Capacitance) would not be used since they have higher ghost touch risk, are susceptible to noise, have lower position resolution, and can be less stable in responsiveness.

11. The electrodes along the arc of the disk segment are evenly spaced, making touch interpretation by the software easier.
12. The sensitivity (i.e. how much the image on the screen moves in response to the amount of movement of the finger) can be adjusted in the software. There is no optical encoder wheel or other complicated parts.
    Note that the software settings for sensing touch position and movement can be customized based on the curvature of the virtual scroll wheel and the extent to which the user moves their index finger. This will be different than on a flat touch strip. An adaptive sensitivity algorithm can enable more precise scrolling. Note that the type and amount of haptic feedback can also be customized.
13. The device of Claim 1, further including edge detection. In one embodiment given that the user's index finger is large and touches a large portion of the virtual scroll wheel simultaneously, if the centroid calculation is used to determine the scrolling distance, the movement of the "center" will be limited and may not be representative of the desired amount of movement. It would be computationally easier and more representative of the desired amount of scrolling if it were determined by only changes in the position of the leading edge of the contact area (i.e. the point where the leading edge of the index finger comes in contact with the virtual scroll wheel). Thus, change in the precise leading edge is used to determine how much and in which direction to scroll the screen, for more responsive and intuitive scrolling. Note that this embodiment only applies to vertical scrolling. The user can turn this feature off if they prefer traditional centroid based scrolling.

All the figures for the patent application are given below.

Fig. 1

Stack Order (Top to Bottom)

Touch Arc (with touch-sensitive electrodes)

Haptic Motor (LRA bonded to part of chord of disk segment)

Silicone Damping Layer (to isolate haptic feedback)

Rigid Post (bypasses haptic motor, connects touch arc to PCB)

PCB (MEMS accelerometer soldered onto PCB with controller next to it)

Fig. 2

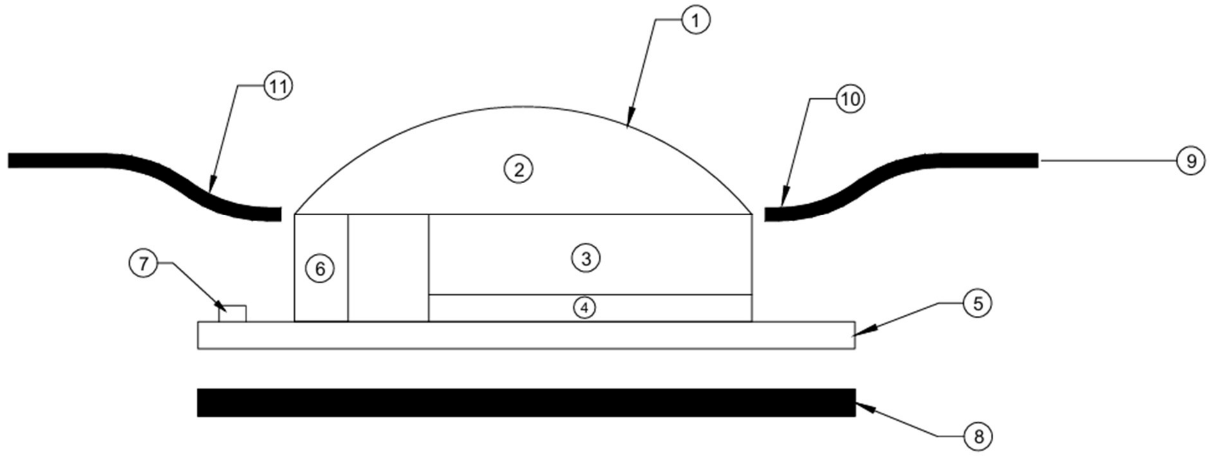

Fig. 3

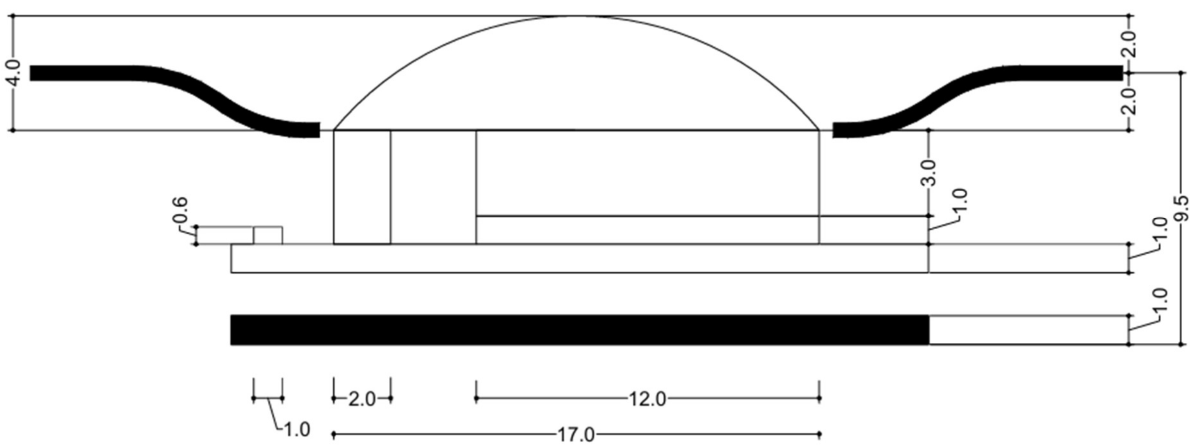

Fig. 4

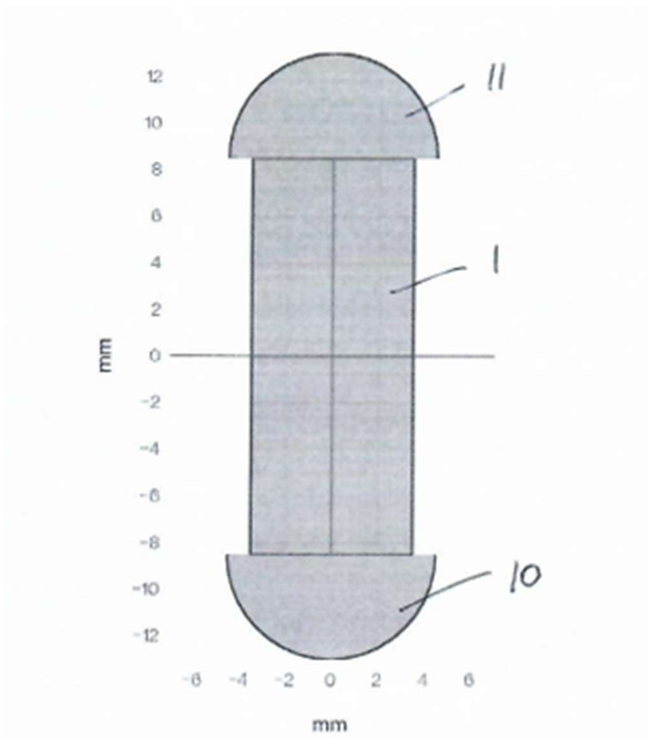

Fig. 5

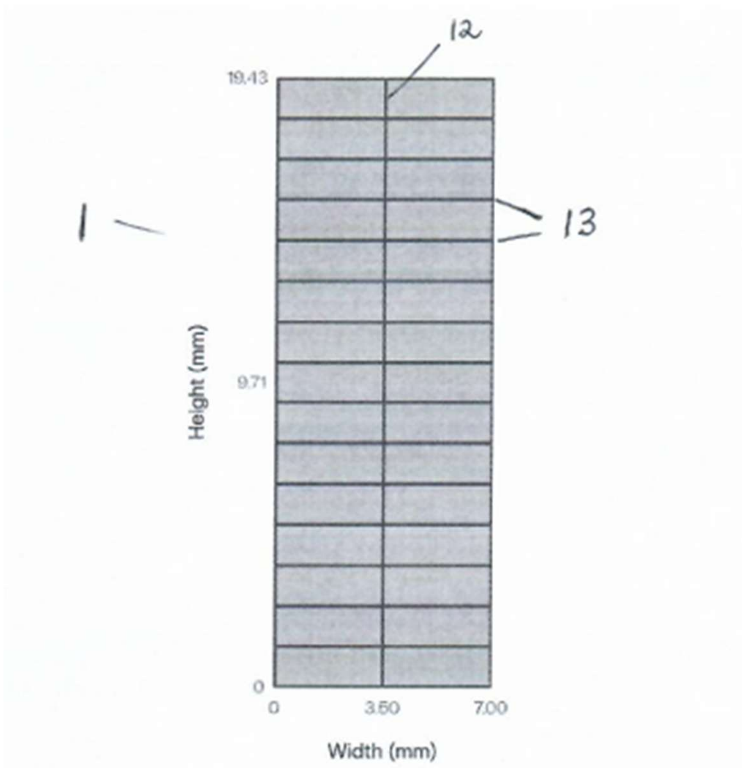

Fig. 6

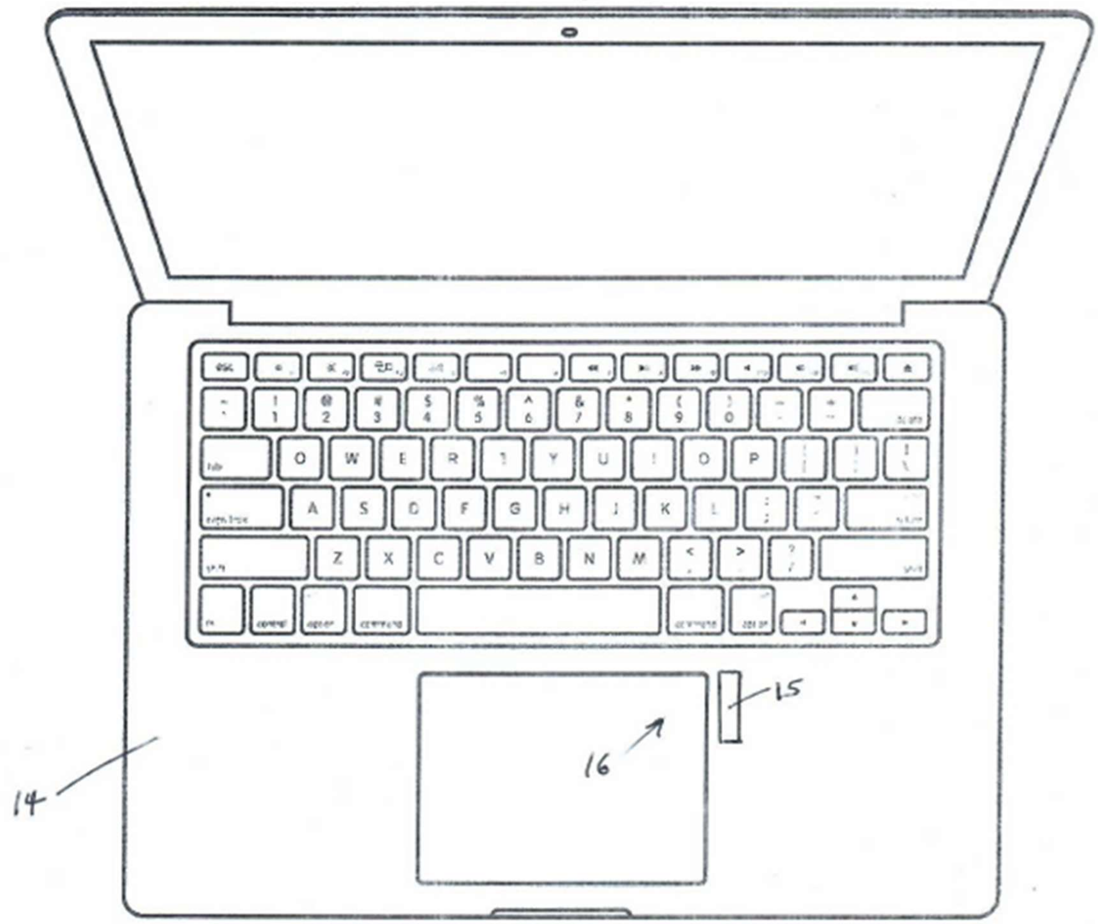

Fig. 7

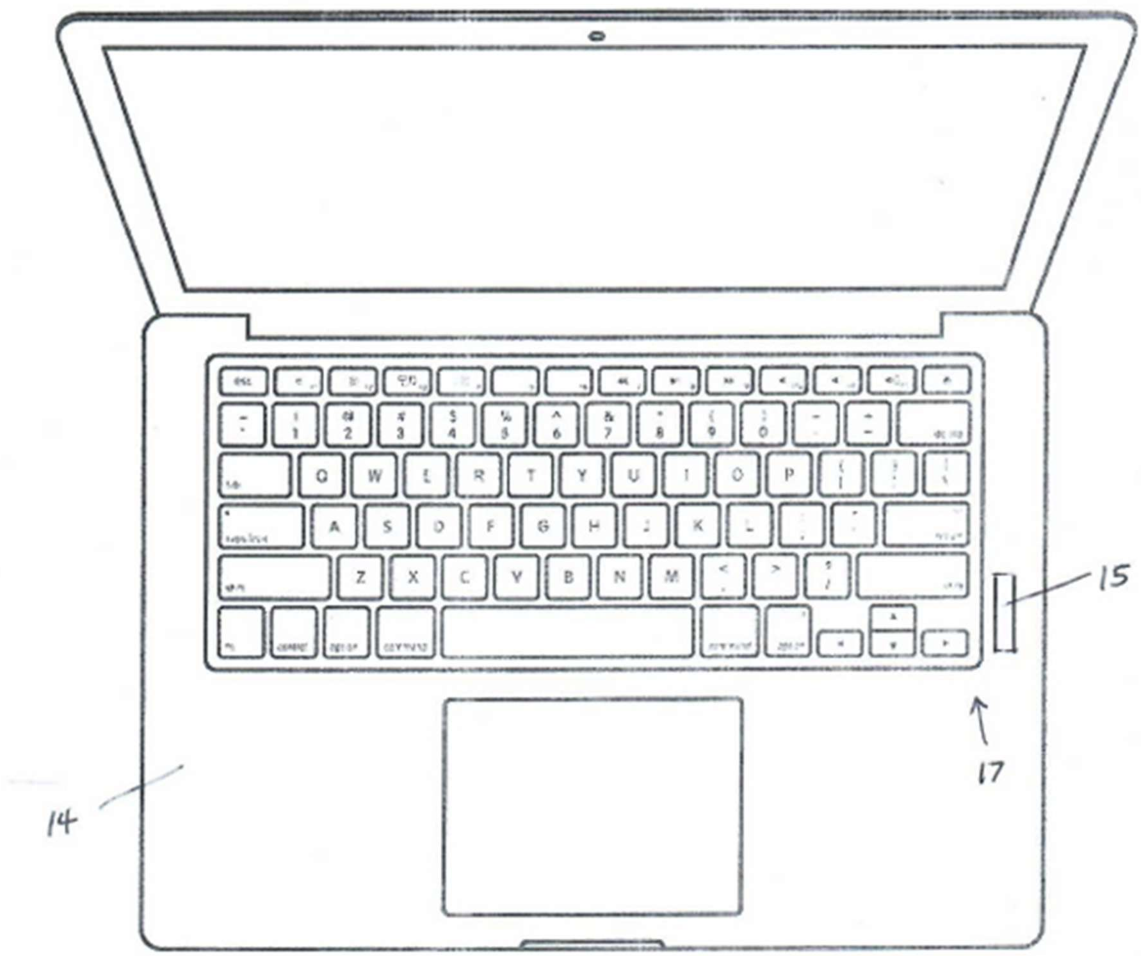

Fig. 8

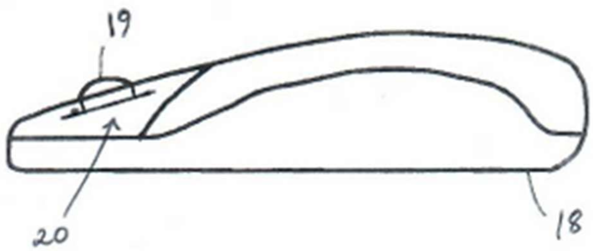

Fig. 9

Prior Art Differentiation Table

Feature	This Invention	Conventional Wheels	Flat Touch Strips
Tactile Feedback	Variable LRA pulses	Mechanical detents	Basic vibration
Input Resolution	0.5mm (16+ electrodes)	1.5° optical encoder	2mm touch zones
Form Factor	4mm protrusion	15-22mm wheels	Flat surface

Fig. 10

Conflict Mitigation Table

Scenario	Solution
Accidental zoom during scroll	Pressure threshold prevents false triggers
Scroll during zoom	Directional lockout ignores scroll inputs
Simultaneous activation	Prioritize zoom if pressure > threshold

Fig. 11

Exploded LRA mounting assembly

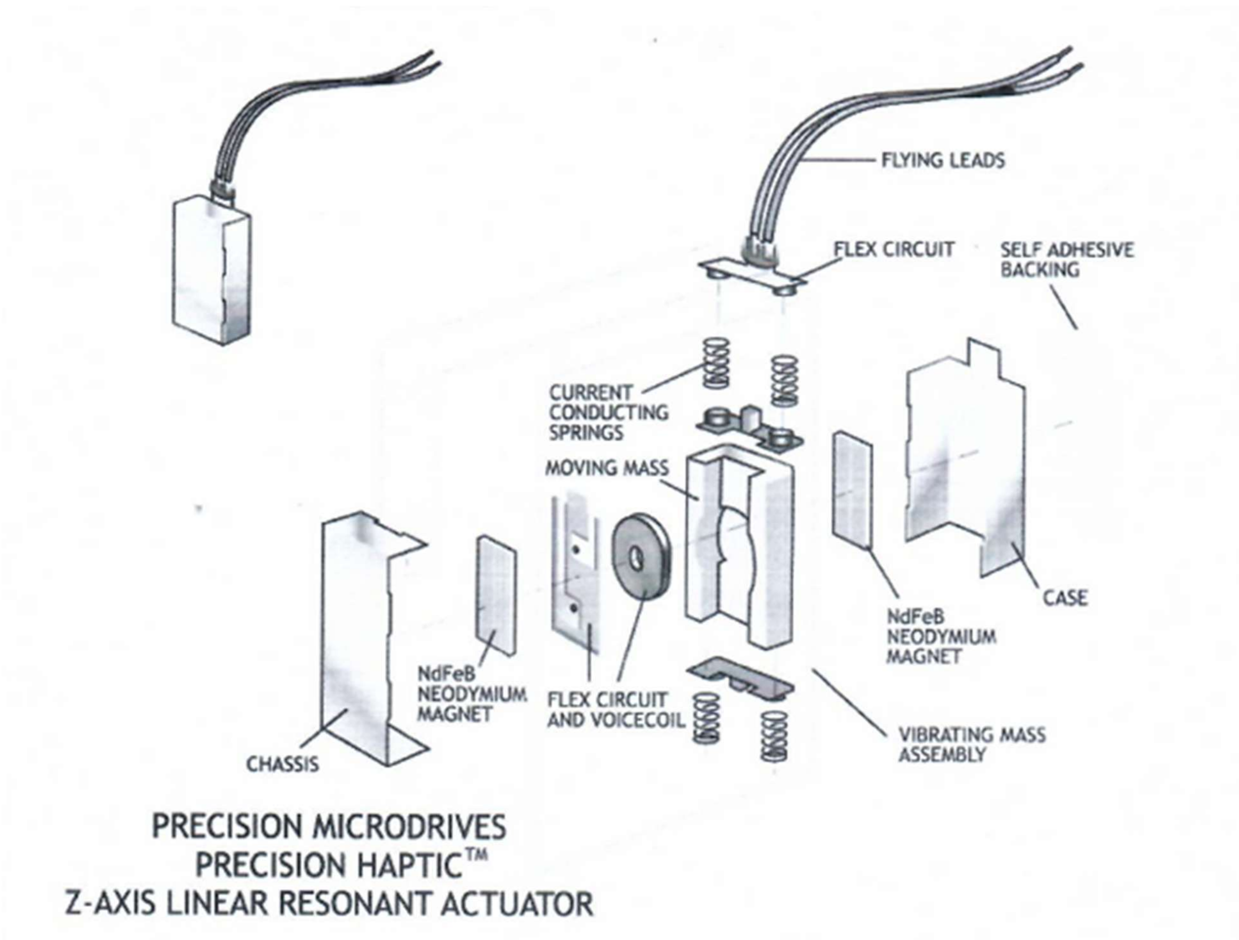

Fig. 12

System block diagram with DSP pipeline

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┌──────────────────────────────────────────────────────────────────────────────────────
──────────────────────────┐
│                             Virtual Scroll Wheel System                            │
├─────────────────────────────────────┬──────────────────────────────────────┬───────
──────────────────────────┤
│ **Touch Sensing**         │ **DSP Pipeline**        │ **Output Control**            │
│                           │                          │                              │
│    ┌──────────────────────────┐      │    ┌─────────────────────────────┐    │
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┌──────────────────────────────────────┐      │
│   │ Mutual           │      │   │ Signal           │   │   │ Haptic Feedback      │
│   │ Capacitance      ◀──TX──┤ Conditioning &   │   │   │ Controller           │
│   │ Electrodes       │      │   │ Filtering        │   │   │ (PWM Generation)     │
│   │ (Arc)            ├────RX──▶ (Noise removal,  │   │   │                      │
│   └──────────────────────────┘      │  │ Baseline adjust) │   │   │
│                          │  └───────────────────────────────┘   │   │
┌────────────────────────────────┐  │     │
│   ┌──────────────────────────┐      │           ▼            │   │  │ LRA Motor Driver
│  │     │
│   │ MEMS             │      │  ┌──────────────────────────────┐   │   │  │ (Haptic
Profiles) │  │     │
│   │ Accelerometer    ├────I2C─▶ Touch Detection  │   │   │
└────────────────────────────────┘  │     │
│   └──────────────────────────┘      │  │ (Position, Edge) │   │   │        ▼
│                          │  └───────────────────────────────┘   │   │
┌────────────────────────────────┐  │     │
│                          │        ▼           │   │   │ Vibration        │  │
│                          │   ┌──────────────────────────────┐   │   │   │ Damping Layer
│  │     │
│                          │   │ Gesture          │   │   │
└────────────────────────────────┘  │     │
│                          │   │ Recognition      │   │   │               │     │
│                          │   │ (Scroll, Tilt)   │   │   │               │     │
│                          │   └──────────────────────────────┘   │   │
│                          │          ▼            │   │               │     │
│                          │   ┌──────────────────────────────┐   │   │
│                          │   │ Adaptive         │   │   │               │     │
│                          │   │ Sensitivity      │   │   │               │     │
│                          │   │ Algorithm        │   │   │               │     │
│                          │   └──────────────────────────────┘   │   │
│                          │          ▼            │   │               │     │
│                          └──────────────────────────────────────┘
└──────────────────────────────────────┘      │
│                                    │                                       │
│                                    ▼                                      │
│                          ┌──────────────────────────────┐
│                          │ Host Communication  │                           │
│                          │ (USB/HID Reports)   │                           │
│                          └──────────────────────────────┘
└──────────────────────────────────────────────────────────────────────────────
──────────────────────────┘
```

Fig. 13

Touch pattern recognition flowchart

```
┌──────────────────────────────────────────────────┐
│  Start Touch Recognition       │
└──────────────────────────┬───────────────────────┘
               ▼
┌──────────────────────────────────────────────────┐
│ Initialize Touch Sensor        │
│ - Mutual capacitance mode     │
│ - 16+ RX electrodes           │
│ - 1 TX electrode              │
└──────────────────────────┬───────────────────────┘
               ▼
┌──────────────────────────────────────────────────┐
│ Scan Electrode Matrix          │
│ - TX pulse sequence           │
│ - Measure RX capacitance      │
│ - Raw data collection         │
└──────────────────────────┬───────────────────────┘
               ▼
┌──────────────────────────────────────────────────┐
│ Process Raw Data               │
│ 1. Noise filtering             │
│ 2. Baseline subtraction       │
│ 3. Threshold comparison       │
└──────────────────────────┬───────────────────────┘
               ▼
┌──────────────────────────────────────────────────┐
│ Identify Contact Area          │
│ - Activated RX electrodes      │
│ - Calculate span:             │
│   Δ = Max(RX) - Min(RX)       │
└──────────────────────────┬───────────────────────┘
               ▼
┌──────────────────────────────────────────────────┐
│ Determine Scroll Direction     │
│ - Compare to previous scan    │
│ - Δ > threshold? → Yes/No     │
└──────────────────────────┬───────────────────────┘
               │
     ┌───────────────────┴───────────────────┐
     ▼                       ▼
┌───────────────────────┐ ┌────────────────────────────┐
│ No Action      │      │ Calculate Leading │
│ Return         │      │ Edge Position     │
└───────────────────────┘      │ - If scroll down:   │
                    │   Leading = Max(RX) │
                    │ - If scroll up:     │
                    │   Leading = Min(RX) │
                    └────────────────┬────────────────┘
                           ▼
                  ┌────────────────────────────────────────────┐
                  │ Compute Scroll Distance   │
                  │ Distance = (Current       │
```

```
│  Leading - Previous) ×      │
│  Sensitivity Factor         │
└───────────────┬──────────────────┘
           ▼
┌──────────────────────────────────┐
│  Adaptive Sensitivity       │
│  - If touch_duration > 500ms:  │
│    Enable precision mode    │
│    (0.1mm resolution)       │
└───────────────┬──────────────────┘
           ▼
┌──────────────────────────────────┐
│  Generate Haptic Feedback   │
│  - PWM frequency based on   │
│    scroll distance & speed│
│  - Activate LRA motor       │
└───────────────┬──────────────────┘
           ▼
┌──────────────────────────────────┐
│  Send HID Report            │
│  - USB/HID protocol         │
│  - Scroll delta value       │
└───────────────┬──────────────────┘
           ▼
        ┌───┴───┐
        │ END │
        └───────┘
```