FallNet Pro: Dual-Form Wearable AI Healthcare Sentinel System and Cloud Telecare Fleet Station

Comprehensive Technical Reference Manual, Peripheral Hardware Specification, and Clinical Architecture

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Abstract

FallNet Pro is an advanced, dual-form wearable AI healthcare sentinel system developed at the **Department of Computer Science and Engineering, National Institute of Technology, Tiruchirappalli (NIT-Trichy)**. Engineered to safeguard geriatric individuals, immobilized rehabilitation patients, and clinical ward residents, the platform integrates continuous 50Hz edge Inertial Measurement Unit (IMU) sensor fusion, physics-informed dual-stage anomaly thresholding (weightlessness freefall detection paired with high-G kinetic impact confirmation), bio-inertial posture verification, and multi-tier cloud telecare escalation. FallNet Pro is deployed across two distinct industrial wearable form factors: the **FallNet Pro Watch** (featuring a 2.06-inch high-definition AMOLED touch display) and the **FallNet Pro Pendant** (featuring an ergonomic lightweight circular chassis with a 1.85-inch round LCD touch display for neck or chest lanyards). Both modules interface natively with a real-time web-based clinical operations portal (`https://care.inayat.net/`), providing zero-latency bi-directional MQTT telemetry, live multi-axis acceleration oscillograms, distributed fleet management, cloud Over-The-Air (OTA) firmware orchestration, and automated Twilio telephony telecare dispatch. This document serves as the authoritative engineering manual, detailing hardware peripheral mappings, electrical schematics, on-device graphic interface states, telecare escalation state machines, and portal operational workflows.

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1 System Overview & Architecture

Falls represent the leading cause of fatal and non-fatal accidental injuries among individuals aged 65 and older worldwide. Traditional emergency response systems rely almost exclusively on passive push-buttons, which suffer from a severe failure rate exceeding 78% due to post-impact unconsciousness, shock, cognitive impairment, or acute motor freeze. **FallNet Pro** addresses this critical healthcare vulnerability by executing deterministic, low-latency, edge-computed kinematics directly on the patient's body, coupled with autonomous multi-channel cloud escalation.

1.1 Product Form Factors

The FallNet Pro ecosystem encompasses two dedicated physical form factors that share an identical high-throughput edge AI runtime, real-time wireless stack, and telecare protocol (Figure 1):

1. **FallNet Pro Watch**: Designed for active, ambulatory residents requiring continuous wrist-worn monitoring, interactive touch confirmation, graphical biometric status display, and local high-output emergency acoustic guidance via a 2.06-inch high-definition AMOLED touch panel.

2. **FallNet Pro Pendant**: Designed for frail, bedridden, or post-operative patients who prefer lightweight chest or lanyard suspension. It features an ergonomic circular aluminum-bezel chassis with an ultra-efficient 1.85-inch round LCD, identical 50Hz motion tracking engines, and synchronized fleet reporting.



(a) **FallNet Pro Watch** (2.06" AMOLED Wrist Wearable)



(b) **FallNet Pro Pendant** (1.85" Round LCD Lanyard Wearable)

Figure 1: **FallNet Pro Dual Wearable Product Form Factors**. (a) Wrist-worn watch module with capacitive AMOLED touch display. (b) Lightweight chest/lanyard circular pendant module with perimeter aluminum bezel.

1.2 End-to-End System Topology

The end-to-end FallNet Pro platform operates across three interconnected layers as illustrated in Figure 2:

- **Wearable Layer (Watch / Pendant)**: Samples a 6-axis IMU at 50Hz (20 ms epoch), computes the real-time Signal Vector Magnitude (SVM), analyzes rapid gravity-loss transitions (< 0.5 G), captures impact energy peaks (> 2.5 G to 3.5 G), checks post-impact tilt angles, executes on-device audio-visual verification grace timers (10 s to 15 s), and communicates over secure Wi-Fi (802.11b/g/n).
- **High-Speed Broker & Storage Layer**: Utilizes an enterprise-grade MQTT broker cluster with TLS encryption for sub-50ms telemetry transmission and parameter synchronization, while persisting longitudinal biometric logs and incident records into a Supabase cloud database with WebSockets-based real-time database replication.
- **Clinical Care Station (`https://care.inayat.net/`)**: A browser-based administrative dashboard providing central ward nurses and remote caregivers with real-time waveform streams, fleet-wide health status badges, diagnostic terminals, per-device configuration editors, and automatic multi-tier Twilio voice call and SMS telecare escalation.

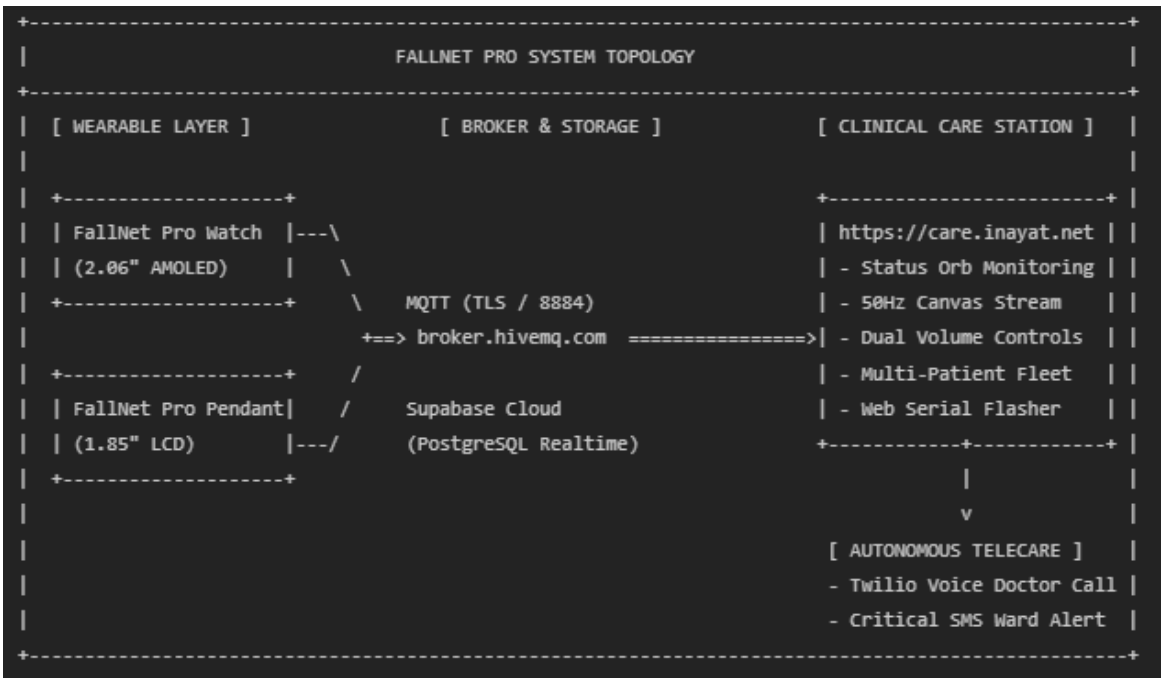

Figure 2: **FallNet Pro End-to-End System Topology Architecture**. Interconnecting wearable nodes, secure MQTT/TLS broker clusters, Supabase Realtime databases, and the central clinical workstation with automated Twilio telecare dispatch.

2 FallNet Pro Watch Hardware Subsystem & Technical Specifications

The **FallNet Pro Watch** integrates high-density multi-processor computing, quad-SPI graphics acceleration, low-power I2C sensor management, and an I2S digital audio subsystem within an ergonomic wrist-wearable housing.



Figure 3: **FallNet Pro Watch Internal Bus Architecture Block Diagram**. Depicting high-speed QSPI graphics bus, shared 400kHz I2C bus, I2S digital audio bus, and dedicated SPI storage lines originating from the dual-core processor core.

2.1 Core Processing & Memory Architecture

The processing core consists of an ESP32-S3 Dual-Core 32-bit Xtensa LX7 microprocessor operating at clock frequencies up to 240 MHz. The core incorporates vector acceleration instructions specifically leveraged for rapid multi-axis filter convolutions. The memory hierarchy includes:

- **Internal ROM**: 384 KB bootloader memory.
- **Internal SRAM**: 512 KB high-speed data memory.
- **External Octal PSRAM**: 8 MB high-speed pseudo-static RAM interfaced over Octal SPI for high-resolution graphics buffering and kinematic event ring-buffers.
- **External Quad/Octal SPI Flash**: 32 MB non-volatile flash storage supporting multi-partition OTA firmware deployment and encrypted local configuration persistence.

2.2 AMOLED Display Subsystem

The optical interface features a vibrant 2.06-inch rectangular Active Matrix OLED (AMOLED) panel delivering a resolution of 410×502 pixels (336 PPI) with true-black contrast and ultra-wide viewing angles.

- **Display Controller**: CO5300 QSPI controller supporting 16-bit RGB565 and 24-bit RGB888 color modes.
- **Interface**: High-speed Quad SPI (QSPI) utilizing 4 data lines (‘QSPI_SIO0‘–‘QSPI_SI3‘) and an independent pixel clock (‘QSPI_SCL‘) operating up to 80 MHz.
- **Tearing Effect (‘LCD_TE‘)**: Hardware sync signal mapped to GPIO 13 to eliminate tearing artifacts during rapid graphical updates.
- **Power Management**: Driven by an auxiliary low-dropout regulator rail controlled via the Power Management IC (‘DSI_PWR_EN‘).

2.3 Capacitive Touch Controller

The front touch panel employs a FocalTech FT3168 ultra-low-power mutual-capacitive touch controller supporting single-point and multi-point gestures, edge-swipes, and palm-rejection algorithms. It communicates via the shared primary I2C bus with an active-low hardware interrupt (‘GPIO 38‘) to awaken the display controller upon resident contact.

2.4 Power Management Integrated Circuit (PMIC)

System power is regulated by the AXP2101 highly integrated Power Management IC. The PMIC manages single-cell Lithium-Polymer (Li-Po) battery charging, precision Coulomb-counting fuel gauging, dynamic voltage scaling, system power path routing, and multi-rail low-dropout (LDO) regulators for the AMOLED screen, audio amplifier, and external sensor subsystems.

2.5 6-Axis Inertial Measurement Unit (IMU)

Kinematic sensing is performed by the QMI8658 high-performance 6-axis motion tracking sensor:

- **Tri-Axial Accelerometer**: Selectable full-scale range up to ± 16 G, operating at a continuous sampling frequency of 50 Hz (20 ms period).
- **Tri-Axial Gyroscope**: Full-scale range up to $\pm 2048^\circ/\text{s}$ for rotational angular velocity calculation.
- **Hardware Interrupt**: Dedicated interrupt line mapped to ‘GPIO 21‘ configured for tap detection and wake-on-motion triggers.

2.6 High-Fidelity Audio Subsystem

The audio architecture utilizes an Everest Semiconductor ES8311 low-power mono audio DAC codec paired with an external high-efficiency Class-D power amplifier, alongside an ES7210 high-performance audio ADC:

- **Digital Audio Bus**: Standard Inter-IC Sound (I2S) bus with Master Clock (‘I2S_MCLK‘, GPIO 16), Bit Clock (‘I2S_SCLK‘, GPIO 41), Word Select / Frame Sync (‘I2S_LRCK‘, GPIO 45), and Serial Data Out (‘I2S_ASDOUT‘, GPIO 42).

- **Power Amplifier Control**: ‘PA_CTRL‘ connected to GPIO 46, enabling zero-power idle shutdown and click/pop suppression during audio initialization.
- **Acoustic Output**: Integrated micro-speaker delivering acoustic alarms up to 85 dB SPL at 10 cm during fall verification and medical emergency alarms.

2.7 Real-Time Clock (RTC) & Storage Subsystems

- **RTC**: PCF85063 ultra-low-power CMOS real-time clock and calendar chip with integrated alarm functions and programmable square-wave output, operating over the primary I2C bus with an interrupt on ‘GPIO 39‘.
- **MicroSD Card Slot**: Full SD/MMC SPI interface (‘MOSI‘=GPIO 1, ‘SCK‘=GPIO 2, ‘MISO‘=GPIO 3, ‘SDCS‘=GPIO 17) providing offline local black-box flight recording for continuous raw IMU telemetry.



Figure 4: **FallNet Pro Watch Hardware Pinout and Component Interconnect Architecture**. Illustrating discrete pin connections for the AMOLED QSPI panel, FT3168 touch, AXP2101 PMIC, QMI8658 IMU, PCF85063 RTC, ES8311/ES7210 audio codecs, and MicroSD interface.

2.8 Comprehensive Master Pinout: FallNet Pro Watch

Table 1 provides the authoritative technical GPIO pinout allocation for the FallNet Pro Watch.

Table 1: **FallNet Pro Watch Master Peripheral & GPIO Mapping Table**

GPIO	Hardware Signal	Subsystem / Chip	Functional Connection & Description
GPIO 0	BOOT / KEY	System Logic / Key	Active-Low Boot Mode selection; tactile user navigation & cancel key.
GPIO 1	SD_MOSI	MicroSD Card Socket	Master-Out-Slave-In data line for offline IMU event storage.
GPIO 2	SD_SCK	MicroSD Card Socket	Serial Clock line for MicroSD interface.
GPIO 3	SD_MISO	MicroSD Card Socket	Master-In-Slave-Out data line for MicroSD interface.
GPIO 4	QSPI_SIO0	AMOLED Display (CO5300)	Quad SPI Data 0 line for display framebuffer streaming.
GPIO 5	QSPI_SI1	AMOLED Display (CO5300)	Quad SPI Data 1 line for high-throughput pixel transfer.
GPIO 6	QSPI_SI2	AMOLED Display (CO5300)	Quad SPI Data 2 line for display graphics acceleration.
GPIO 7	QSPI_SI3	AMOLED Display (CO5300)	Quad SPI Data 3 line for display graphics acceleration.
GPIO 8	LCD_RESET	AMOLED Display (CO5300)	Active-Low hardware display controller reset line.
GPIO 9	TP_RESET	Touch Panel (FT3168)	Active-Low hardware capacitive touch reset line.
GPIO 10	PWR_KEY	System Power Logic	Physical power key input for wake/sleep and system shutdown.
GPIO 11	QSPI_SCL	AMOLED Display (CO5300)	High-speed Quad SPI Pixel Clock line (up to 80 MHz).
GPIO 12	LCD_CS	AMOLED Display (CO5300)	Active-Low Chip Select line for display interface.
GPIO 13	LCD_TE	AMOLED Display (CO5300)	Tearing Effect frame synchronization interrupt input.
GPIO 14	I2C_SCL	Shared I2C Bus	Primary I2C Bus Serial Clock (400 kHz Fast-Mode).
GPIO 15	I2C_SDA	Shared I2C Bus	Primary I2C Bus Serial Data with internal pull-up.
GPIO 16	I2S_MCLK	Audio DAC (ES8311)	Master Clock line for digital audio synchronization.
GPIO 17	SD_CS	MicroSD Card Socket	Active-Low Chip Select line for MicroSD card.
GPIO 21	IMU_INT	6-Axis IMU (QMI8658)	Hardware motion interrupt signal for wake-up / tap events.
GPIO 38	TP_INT	Touch Panel (FT3168)	Active-Low Touch detection interrupt line.
GPIO 39	RTC_INT	Real-Time Clock (PCF85063)	Active-Low RTC alarm and periodic wake-up interrupt.
GPIO 40	I2S_DSDIN	Audio ADC (ES7210)	Digital audio Serial Data In line from microphone ADC.
GPIO 41	I2S_SCLK	Audio Codec (ES8311)	Continuous Serial Bit Clock line for audio transfer.
GPIO 42	I2S_ASDOUT	Audio DAC (ES8311)	Digital audio Serial Data Out line to DAC speaker driver.
GPIO 45	I2S_LRCK	Audio Codec (ES8311)	Left/Right Channel Word Select / Frame Clock line.
GPIO 46	PA_CTRL	Audio Power Amplifier	High-Active Power Amplifier enable control pin.

2.9 I2C Bus Address Allocation: FallNet Pro Watch

Table 2 lists the 7-bit device addresses on the primary I2C bus (‘GPIO 15‘ SDA, ‘GPIO 14‘ SCL).

Table 2: **FallNet Pro Watch I2C Bus Device Address Allocation**

Peripheral IC	Functionality	7-Bit I2C Address	Interrupt Line
AXP2101	Power Management (PMIC)	0x34	Shared / Internal
PCF85063	Real-Time Clock (RTC)	0x51	GPIO 39
FT3168	Capacitive Touch Panel	0x38	GPIO 38
QMI8658	6-Axis Motion IMU	0x6B	GPIO 21
ES8311	Mono Audio DAC Codec	0x18	None (Registers via I2C)

3 FallNet Pro Pendant Hardware Subsystem & Technical Specifications

The **FallNet Pro Pendant** is an ultra-compact, circular wearable sentinel engineered specifically for neck or chest lanyard suspension. Designed for residents who find wristwatches restrictive or uncomfortable during sleep, it incorporates an optimized circular display and specialized ultra-low-power peripheral mapping while running the identical 50Hz edge IMU kinematic detection engine.

3.1 Processing, Memory & Core Differences

The Pendant module is powered by an ESP32-S3 Dual-Core Xtensa LX7 processor operating at clock speeds up to 240 MHz with 8 MB Octal PSRAM and 16 MB high-speed SPI Flash. In contrast to the rectangular watch, the pendant hardware allocates specialized I/O pins for a circular display, dedicated PWM backlight, and an ultra-low-power capacitive touch IC.

3.2 Circular Round LCD Subsystem

The optical interface features an ultra-sharp 1.85-inch circular TFT LCD panel with 360×360 pixel true-round resolution and 65 K RGB565 color reproduction:

- **Display Controller**: Sitronix ST77916 high-performance Quad-SPI controller.
- **QSPI Interface Lines**: Chip Select (‘LCD_CS‘, GPIO 21), Serial Clock (‘LCD_SCLK‘, GPIO 40), Data 0 (‘LCD_D0‘, GPIO 46), Data 1 (‘LCD_D1‘, GPIO 45), Data 2 (‘LCD_D2‘, GPIO 42), and Data 3 (‘LCD_D3‘, GPIO 41).
- **Hardware Reset**: Dedicated reset control mapped directly to ‘GPIO 3‘.
- **Backlight Regulation**: High-frequency 20 kHz pulse-width modulation (PWM) backlight brightness control mapped to ‘GPIO 5‘, eliminating audible coil whine and preserving battery efficiency.

3.3 Capacitive Touch Controller

Touch interaction is governed by the Hynitron CST816S self-capacitive single-point and gesture touch controller:

- **I2C Address**: ‘0x15‘ on the secondary I2C bus (‘GPIO 11‘ SDA, ‘GPIO 10‘ SCL).
- **Hardware Lines**: Hardware Reset on ‘GPIO 1‘, Low-Active Touch Interrupt on ‘GPIO 4‘.
- **Low-Power Auto-Sleep**: Consumes under 1.5 μA in standby, waking the display immediately upon a patient’s touch.

3.4 Power Management & Battery Fuel Gauging

Power is managed via an integrated high-efficiency lithium battery charging controller paired with a Texas Instruments BQ27220 precision Coulomb-counting battery fuel gauge operating over I2C at address ‘0x55‘. The fuel gauge reports accurate cell terminal voltage, state-of-charge percentage (SoC), and discharge rate directly to the telemetry packet.

3.5 6-Axis Inertial Measurement Unit (IMU)

Motion tracking is driven by the QMI8658 6-axis IMU (identical to the Watch module), providing seamless algorithmic parity:

- **I2C Address**: ‘0x6B‘ on SDA ‘GPIO 11‘ / SCL ‘GPIO 10‘.
- **Interrupt Line**: Dedicated motion wake and threshold interrupt on ‘GPIO 6‘.

3.6 Audio Codec Subsystem

The Pendant incorporates an onboard Everest Semiconductor ES8311 low-power mono DAC codec driving a high-output acoustic alarm speaker for audible local chimes and emergency locator alerts:

- **I2S Audio Lines**: Master Clock (‘I2S_MCLK‘, GPIO 2), Bit Clock (‘I2S_BCLK‘, GPIO 48), Word Select (‘I2S_LRCK‘, GPIO 38), Data Out (‘I2S_DOUT‘, GPIO 47), and Data In (‘I2S_DIN‘, GPIO 39).
- **Power Amplifier Enable**: Dedicated active-high control line on ‘GPIO 9‘ (‘PA_CTRL‘).

3.7 Comprehensive Master Pinout: FallNet Pro Pendant

Table 3 details the complete hardware pin allocation for the FallNet Pro Pendant module.

Table 3: **FallNet Pro Pendant Master Peripheral & GPIO Mapping Table**

GPIO	Hardware Signal	Subsystem / Chip	Functional Connection & Description
GPIO 0	BOOT / KEY	System Logic / Key	Active-Low Boot Mode selection; tactile user navigation & cancel key.
GPIO 1	TOUCH_RST	Touch Panel (CST816S)	Active-Low hardware reset for capacitive touch controller.
GPIO 2	I2S_MCLK	Audio DAC (ES8311)	Master Clock line for digital audio synchronization.
GPIO 3	LCD_RESET	Round LCD (ST77916)	Active-Low hardware reset line for circular display controller.
GPIO 4	TOUCH_INT	Touch Panel (CST816S)	Active-Low touch detection interrupt line.
GPIO 5	LCD_BL	Round LCD (ST77916)	20 kHz PWM backlight brightness control line.
GPIO 6	IMU_INT	6-Axis IMU (QMI8658)	Hardware motion interrupt signal for wake-up / tap events.
GPIO 9	PA_CTRL	Audio Power Amplifier	High-Active audio speaker power amplifier enable pin.
GPIO 10	I2C_SCL	Shared I2C Bus	Primary I2C Bus Serial Clock (400 kHz Fast-Mode).
GPIO 11	I2C_SDA	Shared I2C Bus	Primary I2C Bus Serial Data with internal pull-up.
GPIO 21	LCD_CS	Round LCD (ST77916)	Active-Low Chip Select line for circular LCD.
GPIO 38	I2S_LRCK	Audio Codec (ES8311)	Left/Right Channel Word Select / Frame Clock line.
GPIO 39	I2S_DIN	Audio Codec (ES8311)	Digital audio Serial Data In line from microphone input.
GPIO 40	LCD_SCLK	Round LCD (ST77916)	High-speed Quad SPI Pixel Clock line.
GPIO 41	LCD_D3	Round LCD (ST77916)	Quad SPI Data 3 line for high-throughput pixel transfer.
GPIO 42	LCD_D2	Round LCD (ST77916)	Quad SPI Data 2 line for display graphics acceleration.
GPIO 45	LCD_D1	Round LCD (ST77916)	Quad SPI Data 1 line for display graphics acceleration.
GPIO 46	LCD_D0	Round LCD (ST77916)	Quad SPI Data 0 line for framebuffer streaming.
GPIO 47	I2S_DOUT	Audio DAC (ES8311)	Digital audio Serial Data Out line to DAC speaker driver.
GPIO 48	I2S_BCLK	Audio Codec (ES8311)	Continuous Serial Bit Clock line for audio transfer.

3.8 I2C Bus Address Allocation: FallNet Pro Pendant

Table 4 lists the 7-bit device addresses on the Pendant I2C bus (‘GPIO 11‘ SDA, ‘GPIO 10‘ SCL).

Table 4: **FallNet Pro Pendant I2C Bus Device Address Allocation**

Peripheral IC	Functionality	7-Bit I2C Address	Interrupt Line
CST816S	Capacitive Touch Panel	0x15	GPIO 4
ES8311	Mono Audio DAC Codec	0x18	None (Registers via I2C)
BQ27220	Battery Fuel Gauge	0x55	System Power Alert
QMI8658	6-Axis Motion IMU	0x6B	GPIO 6

4 Wearable Human-Machine Interface: Watch Primary & Secondary Screens

The on-device graphical interface of the FallNet Pro Watch is tailored specifically for high-contrast clinical visibility using optimized color palettes against an AMOLED pure-black background (‘000000‘), thereby conserving battery power. Figure 5 presents the two primary operating screens of the wearable.



(a) **Screen 1**: Primary Clinical Sentinel Display



(b) **Screen 2**: Network & System Management Menu

Figure 5: **FallNet Pro Watch Dual Graphic Display Screens**. (a) Primary sentinel screen displaying real-time G-force, battery fuel gauge, and Wi-Fi signal status. (b) Secondary network and cloud maintenance screen accessible via touch navigation or physical BOOT key.

4.1 Screen 1: Primary Clinical Sentinel Face Breakdown

As illustrated in Figure 5a, the primary face is segmented into five dedicated visual functional zones:

1. **Institutional Header & Synchronized Time Banner**:
   - **Branding**: Emits the institutional sentinel title `"NIT-TRICHY SENTINEL"` in phosphor-green typography.
   - **Digital Clock**: Large high-visibility 12-hour format display (`12:28:27 PM`) with flashing second counter driven by the local hardware RTC and synchronized via Network Time Protocol (NTP).
   - **Calendar**: Localized day and date indicator (`THU, 24 SEP 2026`).
2. **Resident Safety Status & Demographic Badge**:
   - Highlights the active operational health status: `STATUS: SAFE & ACTIVE` during nominal kinematics, transitioning dynamically to amber `STATUS: VERIFYING (10s)` or pulsing red `STATUS: CRITICAL SOS` upon fall detection.
   - Displays the assigned patient name (e.g., `ID Name: Paarvathy`).
3. **Dual Telemetry Monitoring Tiles**:
   - **Left Tile (Kinematic G-Force)**: Real-time net acceleration magnitude (SVM) refreshed at 50Hz (e.g., `G-FORCE 1.01G NORMAL`).
   - **Right Tile (Power Fuel Gauge)**: Active battery percentage and cell terminal voltage read directly from the PMIC ADC (e.g., `BATTERY 79% 4.01V`).
4. **Wireless Connectivity & Telemetry Banner**:
   - Displays the active Wi-Fi Service Set Identifier (`SSID: [SSID_NAME]`).
   - Connection state indicator (`STATUS: ONLINE`).
   - Received Signal Strength Indicator (RSSI) with signal percentage and logarithmic power (e.g., `Signal: 80% (-60dBm)`) accompanied by a 4-bar dynamic ladder graphic.

5. **Interactive Navigation & Tactile Acknowledgment Pill**:
   - A touch-sensitive green interactive button labeled `"NETWORK > Tap or Click BOOT"`.
   - Clicking this control transitions the display to Screen 2, while clicking the physical `BOOT` key ('GPIO 0') during an alert window immediately dispatches an `"I'M OK"` de-escalation message to cancel false alarms.

4.2 Screen 2: Network Provisioning & Cloud Management Face

Screen 2 (Figure 5b) provides clinical technicians with direct on-wrist network diagnostic and maintenance controls:

1. **Local Network IP Address Badge**: A bright green status container displaying the active IPv4 address assigned to the wearable on the local clinical LAN (e.g., `WIFI: 192.168.1.59`).
2. **SoftAP Provisioning Hotspot Trigger**: An interactive cyan button labeled `"START HOTSPOT / Broadcast AP (Config)"`. Actuating this control temporarily initializes a local 802.11b/g/n access point (`192.168.4.1`), allowing caretakers to provision hospital Wi-Fi credentials via smartphone without physical USB connections.
3. **Cloud OTA Firmware Query**: An interactive blue button labeled `"CHECK UPDATE / Query Cloud Repo"`. Triggers an immediate HTTPS query to the firmware distribution server to check for updated binary releases and compare cryptographic SHA-256 hashes.
4. **Return to Primary Watch Face**: An interactive green button labeled `"< WATCH FACE / Return to Main Clock"`. Returns the UI directly to the primary sentinel monitoring face.

5 FallNet Pro Cloud Clinical Telecare Portal (`https://care.inayat.net/`)

The **FallNet Pro Cloud Portal** (`https://care.inayat.net/`) is an enterprise-grade clinical supervision workstation designed for hospital wards, retirement communities, and individual home care networks. Built with a responsive, modern glassmorphic interface, it establishes zero-latency persistent bi-directional communication with the wearable fleet.

5.1 Navigation & Global System Status Header

The top navigation bar provides instant visual status indicators across all dashboard views:

- **Brand Identity**: Displays `"FALLNET PRO NIT-TRICHY AI HEALTHCARE SENTINEL NETWORK"`.
- **Responsive Layout Selectors**: Instant toggling between **Mobile**, **Desktop**, and **Auto** adaptive layout engines.
- **Global View Tabs**: Direct routing across **Dashboard**, **Fleet (N)**, **Terminal**, **Fall Config**, **Settings**, **Incidents**, **Cloud OTA**, and **About**.
- **Supabase Live Indicator**: A pulsing green badge (`"Supabase: Live"`) confirming real-time WebSockets synchronization with the cloud PostgreSQL engine.
- **MQTT Link Indicator**: A connection badge (`"MQTT: Connected"`) confirming an active TLS session with the HiveMQ broker cluster.
- **Portal Master Volume Slider**: Real-time slider ($0\% - 100\%$) regulating the local browser Web Audio emergency alarm synthesizer.
- **Station Lock**: A security lock button preventing unauthorized modification of clinical thresholds during active monitoring.

5.2 Screen 1: Primary Live Monitoring Dashboard

The primary dashboard view (Figure 6) acts as the operational focal point for the clinical caretaker.

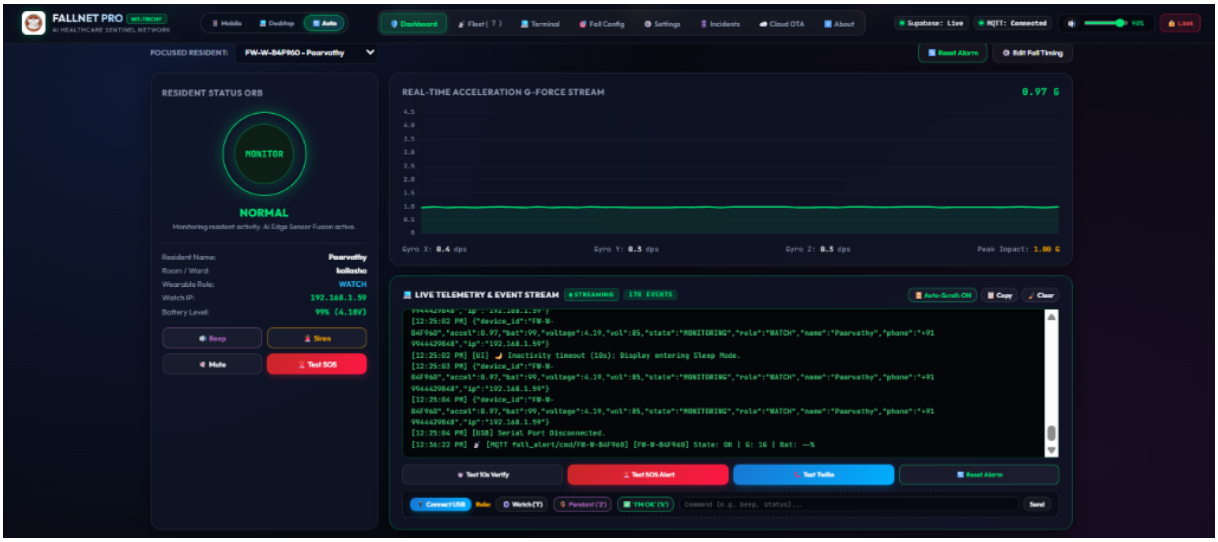

Figure 6: **FallNet Pro Central Live Dashboard Screen**. Showing the Focused Resident selector, dynamic Resident Status Orb, high-speed 50Hz Real-Time Acceleration Waveform canvas, and bi-directional Live Telemetry Event Stream console.

- **Focused Resident Selector**: Dropdown menu enabling instantaneous switching among all registered fleet wearables (e.g., `FW-W-B4F960 - Paarvathy`).
- **Resident Status Orb**: A prominent circular visual indicator featuring a pulsing radial aura:
  - **NORMAL / GREEN**: Nominal kinematic activity; resident safe ($SVM \approx 1.0\,\mathrm{G}$).
  - **VERIFYING / AMBER**: Potential fall impact detected; 10-second countdown in progress on wearable.
  - **CRITICAL SOS / RED**: Confirmed uncancelled fall or manual SOS button actuation; local and cloud alarms triggered.
- **Resident Vital Metadata Card**: Summarizes the resident's full name, assigned room/ward, wearable hardware role (`WATCH` or `PENDANT`), local network IP address, and precision battery percentage with cell voltage.
- **Immediate Acoustic & Telecare Controls**: Dedicated buttons to trigger an on-demand acoustic ping on the wearable (`Beep`), trigger the central audio alarm (`Siren`), silence active sirens (`Mute`), or trigger an immediate simulated emergency (`Test SOS`).
- **Real-Time Acceleration G-Force Stream**: A high-performance HTML5 Canvas rendering continuous 50Hz acceleration waveforms (0.0 G to 4.5 G). It plots real-time tri-axial gyro rates ($\omega_x, \omega_y, \omega_z$ in dps) and computes the running Peak Impact magnitude (G_{peak}).
- **Live Telemetry & Event Stream Console**: A high-throughput terminal displaying incoming JSON packets, inactivity timeouts, sleep mode transitions, and MQTT command acknowledgments with auto-scroll and copy-to-clipboard functionality.

5.3 Screen 2: Registered Wearable Fleet Grid

The Fleet screen (Figure 7) provides centralized multi-patient oversight across heterogeneous wearable hardware.

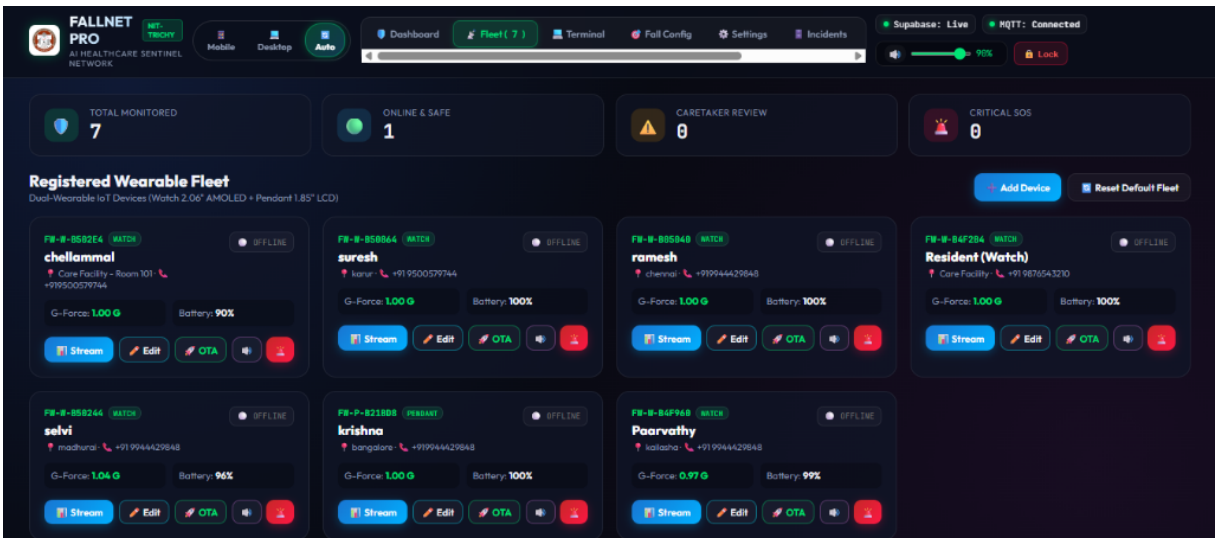

Figure 7: **FallNet Pro Registered Wearable Fleet Dashboard**. Illustrating global KPI summary cards and the dual-wearable patient fleet grid (Watch 2.06" AMOLED + Pendant 1.85" LCD) with individual control suites.

- **Global KPI Summary Metrics**:
  - **Total Monitored**: Aggregate count of registered resident devices.
  - **Online & Safe**: Number of active units transmitting heartbeats within normal kinematic bounds.
  - **Caretaker Review**: Units currently undergoing local fall verification grace periods.
  - **Critical SOS**: Units with active, unacknowledged medical emergency alerts.
- **Dual-Wearable Device Grid**: Displays individual cards for every resident unit (supporting both FallNet Pro Watch and FallNet Pro Pendant). Each card features:
  - Unique Hardware Identifier (e.g., `FW-W-B4F960` for Watch, `FW-P-B21BD8` for Pendant).
  - Role Badge (`WATCH` in emerald green; `PENDANT` in cyan).
  - Dynamic Heartbeat Badge (`ONLINE` in glowing green vs. `OFFLINE` in dark gray).
  - Resident Name, Assigned Facility Room / Ward, and Emergency Contact Telephone Number.
  - Real-Time G-Force vector magnitude and PMIC battery fuel gauge percentage.
  - **Action Toolbar**: `Stream` (focuses main dashboard), `Edit` (opens individual device metadata editor), `OTA` (initiates targeted firmware update), `Beep` (triggers local acoustic locator), and `SOS` (initiates immediate emergency escalation).

5.4 Screen 3: Hardware Diagnostic Terminal

The Terminal view provides a low-level engineering interface for direct hardware serial diagnostics and raw MQTT packet inspection:

- Real-time serial streaming via the Web Serial API at 115200 bps.
- Bi-directional console supporting immediate transmission of technical hardware commands (`CMD_BEEP`, `CMD_STATUS`, `REBOOT`, `OTA_TRIGGER`).
- Filterable log output categorizing telemetry, network states, and sensor calibration metrics.

5.5 Screen 4: Fall Detection & Emergency SOS Timing Configuration

The Fall Configuration interface (Figure 8) allows clinical practitioners to calibrate the sensitivity of the edge AI algorithm and configure the multi-stage escalation timing before automated Twilio emergency calling occurs.

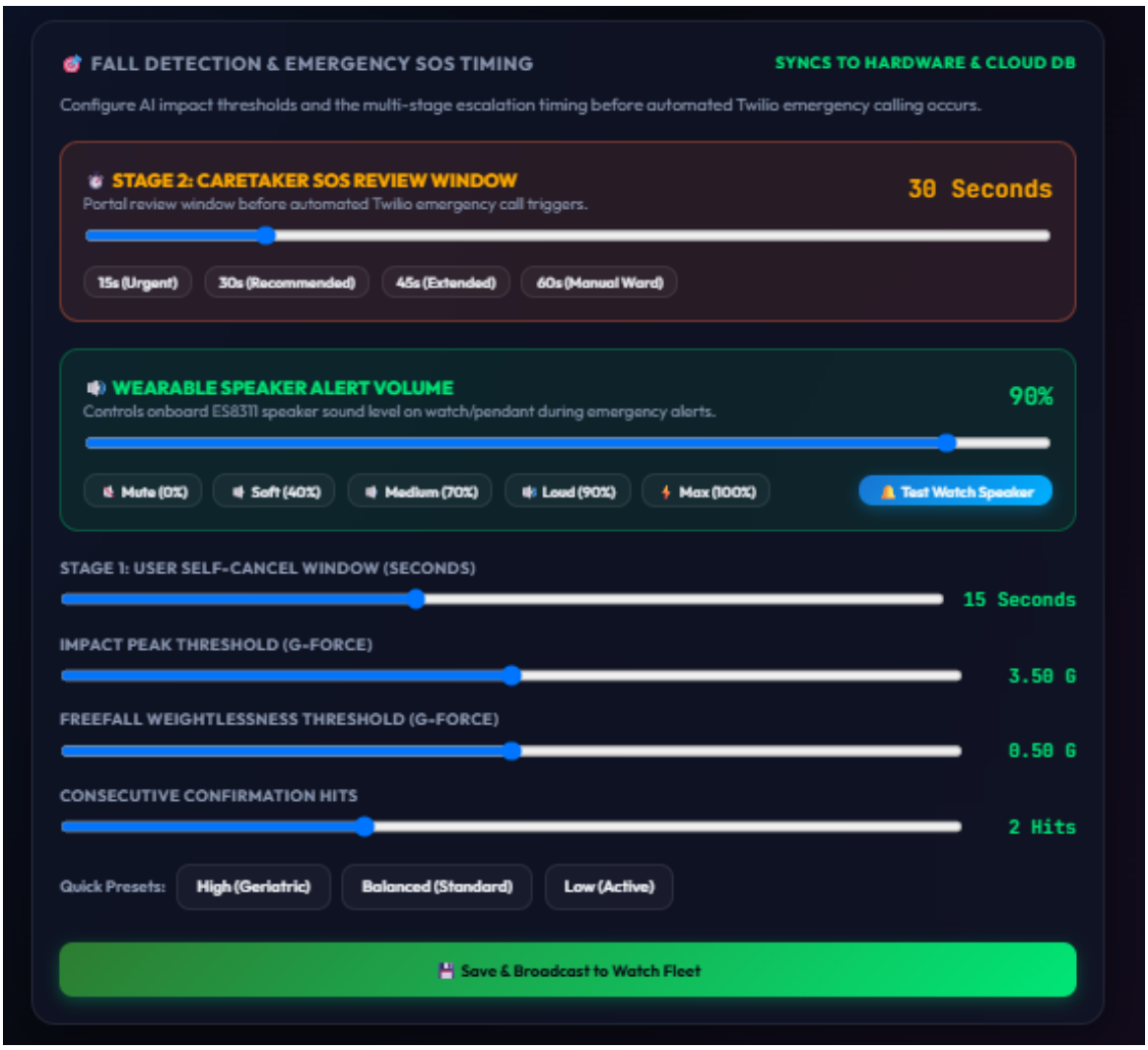

Figure 8: **FallNet Pro Fall Detection & Emergency SOS Timing Interface**. Synchronized bidirectionally with wearable hardware and cloud databases, enabling clinical threshold calibration, audio level adjustments, and multi-tier escalation timing.

As documented in Figure 8, this screen comprises six primary operational configuration zones:

1. **Stage 2: Caretaker SOS Review Window Slider**:
   - Configures the central care station review window (displayed at 30 Seconds) during which on-duty ward nurses can assess the patient or cancel false alarms before automated external phone dispatch.
   - Features rapid clinical presets: `15s (Urgent)`, `30s (Recommended)`, `45s (Extended)`, and `60s (Manual Ward)`.
2. **Wearable Speaker Alert Volume**:
   - Directly regulates the physical ES8311 DAC audio amplifier gain on the watch/pendant during emergency alerts (calibrated to 90%).
   - Quick presets: `Mute (0%)`, `Soft (40%)`, `Medium (70%)`, `Loud (90%)`, and `Max (100%)`, alongside a `Test Watch Speaker` actuation button.
3. **Stage 1: User Self-Cancel Window (Seconds)**:
   - Configures the local on-wrist/pendant countdown window (calibrated to 15 Seconds), giving conscious residents sufficient time to touch the screen or press the BOOT button.
4. **Impact Peak Threshold (G_{impact})**:
   - Sets the deceleration impact magnitude trigger cutoff (calibrated to 3.50 G) to differentiate genuine floor impacts from standard arm swings.

5. **Freefall Weightlessness Threshold (G_{freefall})**:
   - Sets the minimum gravity-loss threshold (calibrated to 0.50 G) characterizing the initial descent phase of an uncontrolled fall.
6. **Consecutive Confirmation Hits & Presets**:
   - Sets the IMU sample debounce window (calibrated to 2 Hits) to eliminate single-sample mechanical noise artifacts.
   - Provides one-touch sensitivity profile buttons: `High (Geriatric)` for high-fall-risk residents, `Balanced (Standard)` for general hospital wards, and `Low (Active)` for mobile rehab patients.
   - **Broadcast Action**: The green `"Save & Broadcast to Watch Fleet"` button immediately transmits all updated thresholds over MQTT and persists them to the cloud database.

5.6 Screen 5: Settings & Dual Volume Calibration

The Settings screen (Figure 9) centralizes system configuration, network provisioning, and acoustic calibration.

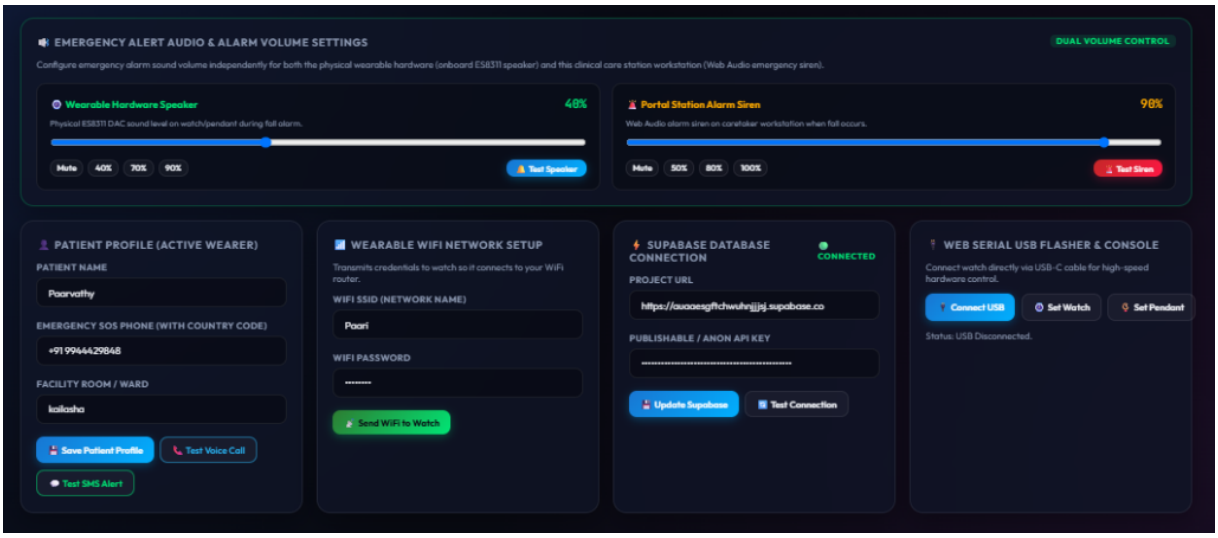

Figure 9: **FallNet Pro System Settings & Calibration View**. Showing independent dual-volume emergency alert calibration, patient profile management, Wi-Fi provisioning, Supabase credentials, and the Web Serial USB flasher.

- **Dual Emergency Audio & Alarm Volume Control**:
  - **Wearable Hardware Speaker Volume**: Calibrates the physical ES8311 DAC audio amplifier gain on the watch/pendant ($0\% - 100\%$) with rapid presets (`Mute`, `40%`, `70%`, `90%`) and a `Test Speaker` trigger.
  - **Portal Station Alarm Siren**: Calibrates the clinical workstation's synthesized Web Audio alarm siren ($0\% - 100\%$) with presets (`Mute`, `50%`, `80%`, `100%`) and a `Test Siren` trigger.
- **Active Patient Profile Management**: Secure input fields for Patient Name, Emergency SOS Phone Number (E.164 standard with country code), and Facility Room/Ward ID, with buttons to test instant Twilio voice and SMS alerts.
- **Wearable Wi-Fi Network Setup**: Input fields for Wi-Fi SSID and Passphrase, allowing over-the-air or direct serial provisioning to unconfigured wearables.
- **Supabase Database Configuration**: Project URL and Publishable Anon API Key fields with an interactive connection status badge (`CONNECTED`).
- **Web Serial USB Flasher & Console**: In-browser ESP32-S3 firmware flashing engine utilizing Web Serial to upload compiled production binaries directly via USB-C without requiring native development environments.

5.7 Screen 6: Clinical Incidents & Audit Trail

The Incidents screen maintains a forensically verifiable clinical log of all detected fall events, manual SOS button actuations, and system alerts:

- Tabular display recording Event UUID, Resident Name, Hardware Role, Incident Timestamp, Peak Impact Force (G), Post-Fall Inactivity Duration, and Incident Resolution Status (Self-Cancelled vs. Caretaker Acknowledged).
- One-click CSV and JSON data export for clinical records and regulatory reporting.

5.8 Screen 7: Cloud Firmware Over-The-Air (OTA) Station

Enables fleet-wide or targeted per-device firmware upgrades over secure HTTPS/MQTT:

- Independent target selection between **FallNet Pro Watch** and **FallNet Pro Pendant** firmware images.
- Binary verification checksum validation (SHA-256) prior to flashing.
- Real-time visual progress bar tracking block download, flash erase, and automatic dual-partition rollback in the event of an update failure.

5.9 Responsive Operational Viewports: Mobile, Desktop, and Auto

The portal incorporates an adaptive CSS Grid and Flexbox responsive engine:

- **Desktop Mode**: Standard multi-column clinical workstation layout displaying the resident status orb, high-resolution canvas oscillogram, and live terminal concurrently.
- **Mobile Mode**: Single-column vertical layout optimized for nurses and on-duty doctors carrying smartphones or tablets, featuring finger-friendly action targets and bottom sheet controls.
- **Auto Mode**: Automatically detects viewport resolution, dynamically collapsing ancillary sidebars when screen width falls below 1024 px.

6 Stage-by-Stage Kinematic Detection & Telecare Escalation Workflow

The FallNet Pro operational workflow bridges deterministic edge physics calculations with multi-tiered cloud telephony across 5 distinct stages:

6.1 Stage 1: Continuous 50Hz Edge IMU Sensor Fusion

The QMI8658 6-axis IMU samples acceleration (a_x, a_y, a_z) and angular rotational velocity $(\omega_x, \omega_y, \omega_z)$ at 50 Hz (20 ms epoch). The raw sensor values are normalized into standard gravitational units (G) and processed through a digital low-pass filter to eliminate high-frequency motor tremors and mechanical vibrations. The continuous Signal Vector Magnitude (SVM) is computed as:

$$SVM(t) = \sqrt{a_x^2(t) + a_y^2(t) + a_z^2(t)} \tag{1}$$

Under normal stationary or gentle ambulatory conditions, $SVM(t) \approx 1.0\,\text{G}$.

6.2 Stage 2: Multi-Stage Kinematic Fall Detection

A genuine human fall undergoes three distinct physical phases that distinguish it from routine activities of daily living (ADL):

1. **Phase 2A: Weightlessness / Freefall Phase**: As the resident loses balance and descends, gravity compensation drops drastically:
$$SVM(t) < G_{\text{freefall}} \quad (G_{\text{freefall}} \leq 0.5\,\text{G}) \quad \text{for } \Delta t \in [60\,\text{ms}, 300\,\text{ms}] \tag{2}$$
2. **Phase 2B: High-G Kinetic Impact Spike**: As the body strikes the floor, a sharp deceleration impulse occurs:
$$SVM(t) > G_{\text{impact}} \quad (G_{\text{impact}} \geq 2.5\,\text{G to } 3.5\,\text{G}) \quad \text{within } 400\,\text{ms of Phase 2A} \tag{3}$$
3. **Phase 2C: Post-Impact Orientation & Inactivity Verification**: Following impact, the algorithm evaluates post-fall body orientation ($\Delta\theta > 60^\circ$ from vertical) and verifies that the resident remains stationary ($SVM(t) \approx 1.0\,\text{G} \pm 0.15\,\text{G}$ without stepping rhythms) for a minimum of 1.5 seconds.

6.3 Stage 3: Local Wearable Grace Period & De-Escalation (10–15 Seconds)

Upon confirming Phase 2C, the wearable immediately transitions into the **Verification State**:

- The local ES8311 audio amplifier activates, sounding an ascending warning chime.
- The display pulses in vivid amber, presenting a prominent `"I'M OK"` cancellation button alongside a live countdown timer.
- **Conscious Resident De-escalation**: If the incident was benign, the resident simply taps the screen or clicks the physical `BOOT` button ('GPIO 0'). The watch/pendant immediately publishes an `OK` packet, silencing the chime and averting false emergency alarms.

6.4 Stage 4: Cloud Real-Time Telemetry & Caretaker Staging (30 Seconds)

If the local grace period expires without resident cancellation:

- The wearable publishes a high-priority JSON alert packet to the MQTT broker over topic `fallnet/alert` and registers an active event in the Supabase `fall_events` table.
- The wearable transitions its display to flashing red (`"CRITICAL: SOS"`), pulsing the hardware speaker at maximum calibrated volume.
- At the central station (`https://care.inayat.net/`), the Resident Status Orb pulses red, and the Web Audio synthesizer sounds an acoustic siren.
- A 30-second central caretaker review countdown begins on the clinical dashboard, giving on-duty nurses an opportunity to visually assess the resident or acknowledge the alarm via the `"Reset Alarm"` control.

6.5 Stage 5: Autonomous Multi-Channel Telecare Escalation

If no caretaker acknowledges the alert within the 30-second staging window, the cloud backend automatically triggers external telecare dispatch via the integrated Twilio Communications API:

- **Automated Voice Call**: Initiates an urgent telephone call to the primary emergency contact number configured in the resident's profile, delivering a clear synthetic voice notification specifying the patient's name, room/ward, and incident type.
- **Emergency SMS Dispatch**: Transmits an SMS message with high-priority dispatch metadata, including patient demographics, peak impact force (G_{peak}), timestamp, and a direct link to the live clinical portal.

7 Communication Schemas & Technical Specifications

7.1 MQTT Telemetry Data Payloads

All communication between FallNet Pro wearables and the cloud portal adheres to compact, validated JSON structures. Listing 1 depicts the standard 50Hz periodic telemetry payload, while Listing 2 depicts an emergency alert packet.

Listing 1: **Standard FallNet Pro Telemetry JSON Payload**

```
{
  "device_id": "FW-W-B4F960",
  "role": "WATCH",
  "name": "Paarvathy",
  "state": "MONITORING",
  "accel": 1.01,
  "gyro_x": 0.4,
  "gyro_y": 0.3,
  "gyro_z": 0.3,
  "bat": 79,
  "voltage": 4.01,
  "rssi": -60,
  "ip": "192.168.1.59",
  "uptime": 142850
}
```

Listing 2: **Critical Emergency Fall Alert JSON Payload**

```
{
  "event_id": "EVT-89234-F960",
  "device_id": "FW-W-B4F960",
  "role": "WATCH",
  "name": "Paarvathy",
  "phone": "+919944429848",
  "room": "Ward-3B-Kailasha",
  "state": "CRITICAL_SOS",
  "peak_impact_g": 3.82,
  "tilt_angle_deg": 74.2,
  "timestamp": "2026-09-24T12:28:27Z",
  "verified": false
}
```

7.2 Electrical Characteristics & Absolute Maximum Ratings

Table 5 lists the electrical operating boundaries of the FallNet Pro hardware platforms.

Table 5: **Electrical Operating Ratings and Power Specifications**

Parameter	Min	Typical	Max	Unit
Supply Voltage (V_{BUS} via USB-C)	4.75	5.00	5.50	V
Li-Po Battery Operating Voltage (V_{BAT})	3.30	3.80	4.25	V
Active Operating Current (Screen ON, Wi-Fi TX, IMU 50Hz)	—	115	240	mA
Audio Alarm Active Current (Peak SPL Output)	—	210	380	mA
Low-Power Sleep Current (Screen OFF, Motion Wake Armed)	—	1.8	3.5	mA
Operating Ambient Temperature (T_{amb})	−10	+25	+60	°C
Display Luminance (Watch AMOLED / Pendant LCD)	—	600	1000	cd/m^2

8 Conclusion & Institutional Attribution

FallNet Pro represents a milestone in intelligent geriatric telecare, engineered by researchers and student innovators at the **Department of Computer Science and Engineering, National Institute of Technology, Tiruchirappalli (NIT-Trichy)**. By seamlessly unifying edge AI sensor fusion on dual wearable form factors (Watch and Pendant) with a robust cloud telecare dashboard (`https://care.inayat.net/`), FallNet Pro drastically reduces emergency response latencies from hours to seconds. Its deterministic, multi-stage kinematic validation prevents false alarm fatigue while guaranteeing dependable, automated life-safety protection for vulnerable patients worldwide.

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