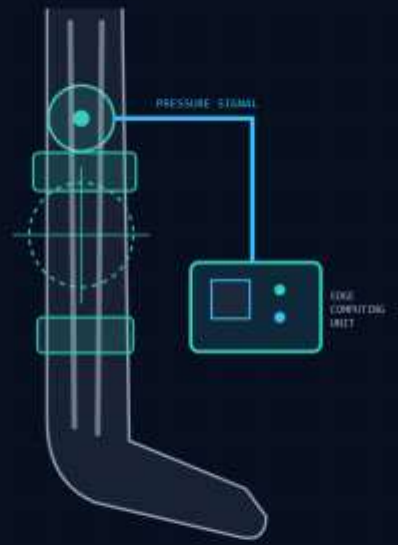


The Ortho-Monitorizer: Real-Time Pressure and Compliance Monitoring using Edge Computing

A retrofittable, low-cost solution for post-traumatic orthotic rehabilitation in resource-constrained environments.

The Dual Clinical Threats of Prolonged Orthosis Wear



Threat 1: Tissue & Nerve Damage

Sustained localized load on the superficial fibular head progresses from reversible neurapraxia to permanent foot drop [1].



Threat 2: Unseen Non-Compliance

High rates of premature removal due to discomfort re-introduce motion across healing fractures, delaying bone union [2].

The Clinical Blindspot: Both complications evolve silently at home between scheduled follow-ups [3].

Background Study: Clinical Justification for Active Monitoring

Literature Synthesis & Diagnostic Matrix

P × t

Pressure-Time Dynamics

Skin tolerates high pressure briefly, but low sustained pressure causes tissue ischemia. The primary clinical threat is **duration**, not just peak force. **(Kosiak [4])**

ADH

The Psychology of Compliance

Physical discomfort, heat, and inconvenience are the primary drivers of non-wear, severely compromising post-traumatic joint recovery. **(Houwen-van Opstal et al. [6])**

CPN

Time-Sensitive Vulnerability

The common peroneal nerve runs superficially over the fibular head with minimal soft-tissue protection. Early detection of compression prevents permanent motor loss. **(Wright & Yacoubian [1]; Li [5])**

OBJ

Objective vs. Subjective Tracking

Self-reporting vastly overstates actual wear time **(Devanand & Kedgley [3])**. Real-time, objective feedback actively shifts patient wear behavior compared to passive logging alone. **(Aulisa et al. [2])**

Bridging the Gap: The Diagnostic Comparison Matrix

Current Practice

(LUTH Standard)

- **Assessment:** Subjective, retrospective clinical interviews and visual skin inspection.
- **Infrastructure Needed:** None.
- **Drawback:** Completely fails to capture objective, continuous home-wear data [3].

Traditional Cloud IoMT

- **Assessment:** Continuous remote objective data logging.
- **Infrastructure Needed:** Uninterrupted broadband, cloud servers, active data plans.
- **Drawback:** Fails in Nigeria due to high costs, frequent power outages, and lack of home internet [7].

The Ortho-Monitorizer

- **Assessment:** Real-time, localized adaptive alerting.
- **Infrastructure Needed:** Completely offline (Edge-computed local Wi-Fi AP).
- **Advantage:** Affordable, highly resilient, and strictly compliant with the Nigeria Data Protection Regulation (NDPR) [8].

A Non-Invasive, Modular Retrofit

Zone 1: The Sensor Interface (Inside)

Force-Sensitive Resistor (FSR) tucked inside a thin soft fabric pouch resting directly against the fibular head.

⚠ **Crucial Design Rule:**
Nothing electronic touches the skin directly. Only the soft fabric pouch contacts the patient.



Internalized Routing — Zero Snag / Fire Risk

Zone 2: Safely Enclosed Routing

Internalized, hazard-free cable routing secured completely beneath the AFO shell to eliminate snagging, wire abrasion, and fire risks.

Zone 3: Electronics Enclosure (Outside)

Custom 3D-printed PLA enclosure mounted externally below the knee, housing the processing, power, and telemetry hardware with an external power switch.

System Architecture: Stimulus to Telemetry



Untethered Power Management



Primary Source

18650 Battery: High-capacity Lithium-ion cell providing a 3.7 V nominal output for all-day compliance tracking.



Safe Recharging

TP4056 Module: Allows caregivers to recharge using standard micro-USB chargers without removing the battery.



Manual Control

External Rocker Switch: Hard on/off control bypassing software sleep states for absolute power termination.

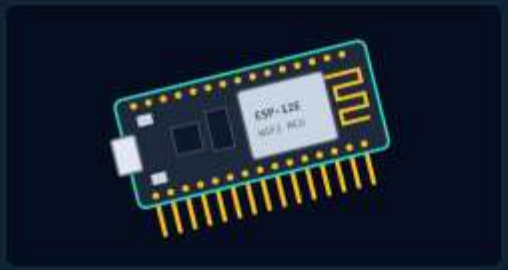


Voltage Step-Up

MT3608 Boost: DC-DC converter steps 3.7 V up to a regulated 5.0 V rail to reliably power the MCU VIN pin.

Core Electronics: Sensing and Edge Processing

The Brain



NodeMCU ESP8266 12-E

Samples sensors at 10 Hz, executes adaptive threshold logic locally, and hosts the Wi-Fi web server without cloud dependencies.

Interface Pressure



Force-Sensitive Resistor (FSR)

Piezoresistive sensor whose resistance drops under load. Wired with a fixed 10 kΩ pull-down resistor to the 10-bit ADC (A0).

Wear-State Motion



MPU6050 6-Axis IMU

Communicates via I²C protocol (D1/SCL, D2/SDA). Tracks 3-axis gravitational magnitude to detect movement vs. stillness [9].

Electrical Schematic & Microcontroller Pin Assignments

TABLE 1: ESP8266 12-E PIN CONFIGURATION

Pin	GPIO	Component Connected	Function
`3V3`	N/A	MPU6050 VCC; FSR	Regulated 3.3 V sensor supply
`GND`	N/A	MPU6050; 10 kΩ; Buzzer	Common ground reference
`A0`	ADC0	FSR + 10 kΩ node	10-bit Analog pressure input
`D1`	GPIO 5	MPU6050 SCL	I²C clock line
`D2`	GPIO 4	MPU6050 SDA	I²C data line
`D5`	GPIO 14	Piezo Buzzer (+)	Digital output for audible alert
`VIN`	N/A	MT3608 OUT+	5.0 V regulated input rail

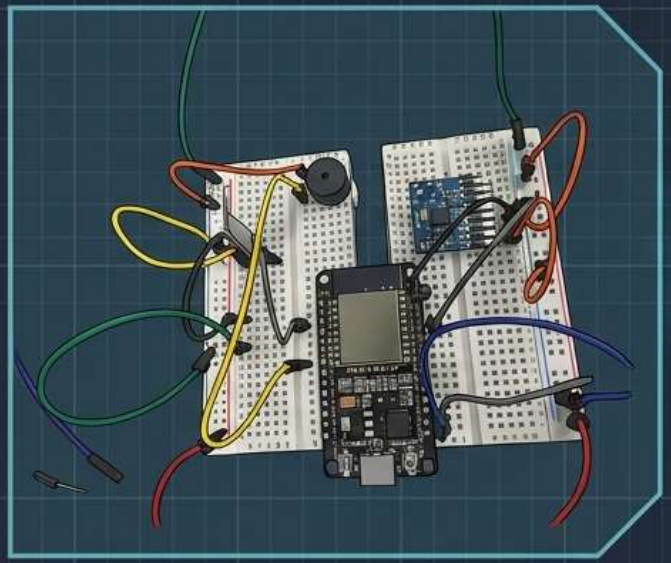
Analog Conditioning

The FSR forms the upper arm of a voltage divider against a fixed `10 kΩ` pull-down resistor connected to `A0`.

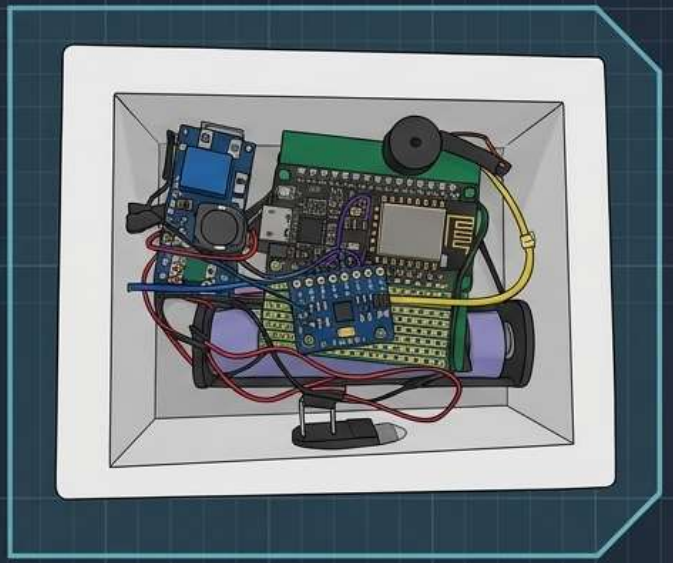
```
V_out = 3.3V × [ R_pulldown / (R_FSR + R_pulldown) ]
```

As compressive force at the fibular head increases, `R_FSR` decreases, driving `V_out` upward toward 3.3 V.

Hardware Assembly for Rehabilitation



Eliminating mechanical failure from ambulation vibration.



Transitioning to a soldered veroboard and isolating delicate buses from sweat and impact via the PLA housing.

The Algorithm: Adaptive Pressure Thresholding

Activation Curve (10-bit ADC Pressure Units vs. Time)



Why Fixed Limits Fail

Raw FSR output varies widely based on individual anatomy, sensor placement, and strap tension. Hardcoded limits cause constant false alarms.

Bespoke Baseline

The 1-hour learning mode silently computes a unique patient mean (μ) and standard deviation (σ) to set $T = \mu + 3\sigma$.

The 30-Second Sustain Rule

Follows Kosiak's pressure-time curve [4]: ignores brief walking spikes and only fires the buzzer if T is breached for 30 continuous seconds.

Independent Wear-State Detection via Kinematics

State: WORN
Dynamic accelerometer variance detected

↓ Sustained Stillness

Transition to REMOVED
Combined 3-axis acceleration magnitude rests at `~1.0 g` (gravitational stillness) for a sustained period.

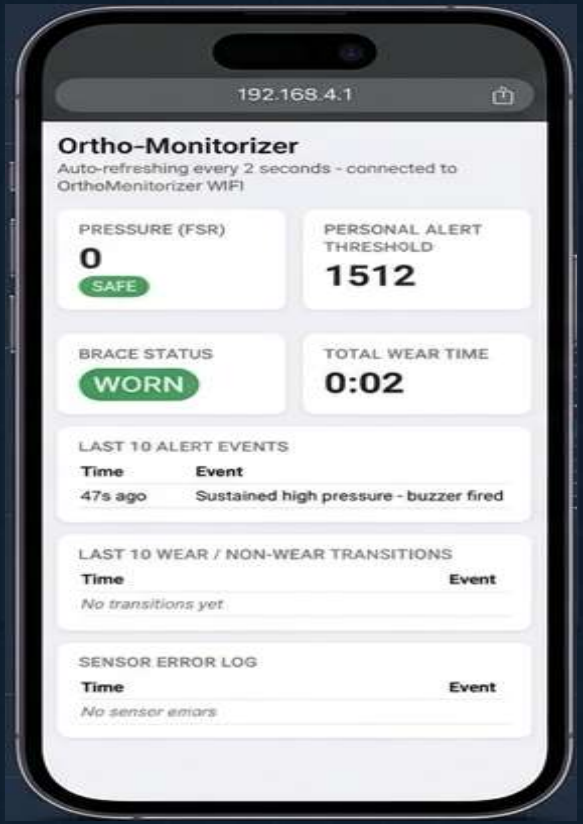
↑ Motion Detected

Transition to WORN
Any sudden mechanical disturbance or limb motion variance immediately flips state back to active wear.

State: REMOVED
Combined magnitude rests at ~1.0 g

Why Independence Matters: If compliance relied solely on pressure, patients could loosen the strap to silence alarms. 3D acceleration guarantees the brace is physically moving with a leg [9].

Edge Telemetry: The Offline Local Dashboard



Zero-Infrastructure Setup

The ESP8266 acts as its own Wi-Fi SoftAP hotspot (`192.168.4.1`). Caregivers connect directly via any standard smartphone browser—no app installation, router, or data plan needed.

Real-Time Live View

Displays dynamic FSR readings with color-coded safety badges (SAFE / WARNING / ALERT), the bespoke personal threshold, live `WORN/REMOVED` status, and cumulative wear time.

Historical Logging

Local RAM storage retains navigable logs of the last 10 pressure alert events and the last 10 wear/non-wear transitions for immediate clinical insight during follow-up visits.

Why Edge Computing is a Clinical Necessity in LMICs

Cloud-Tethered IoMT in Nigeria

- ✗ Frequent Broadband Drops
- ✗ Unaffordable Patient Data Plans
- ✗ Grid Power Outages [7]

Ortho-Monitorizer Local Telemetry

- ✓ 100% Offline Self-Hosted Wi-Fi
- ✓ Zero Recurring Subscription Cost
- ✓ Patient-Controlled Data Privacy [8]

Resilience
Guarantees 100% uptime in underserved areas with poor broadband or power outages [7].

Data Privacy
Strict adherence to the Nigeria Data Protection Regulation (NDPR) by eliminating cloud-breach risks [8].

Immediate Feedback
Real-time localized alerting vastly outperforms retrospective clinic reviews [2].

Bench Testing and Performance Validation

Learning Phase Execution

Successfully logged 60 minutes of baseline data and computed stable bespoke thresholds ($T = \mu + 3\sigma$) on every power cycle.

Sustained Pressure Alert

ADC accurately tracked voltage drops; the localized piezo buzzer fired precisely at 30 continuous seconds of threshold breach.

Motion Detection Reliability

Consistently toggled `WORN/REMOVED` states based on ~1.0 g stillness without false triggering during simulated ambulation.

Telemetry Stability

Seamlessly served the live HTML dashboard to standard Android and laptop browsers without network drops or router dependency.

Frugal Engineering by Force, Not by Choice



NodeMCU ESP8266 12-E	8,000 – 12,000 NGN
Force-Sensitive Resistor (FSR)	10,000 – 12,000 NGN
MPU6050 6-Axis IMU	4,000 – 6,000 NGN

3D-printed PLA enclosure, 18650 cell, TP4056, MT3608 boost converter, and passive components make up the remainder.

Financial Empathy: Priced so trauma patients leaving tertiary centres like LUTH can afford a monitored brace out-of-pocket, contrasting with multi-million Naira imported commercial systems.

Future Pathway: From Prototype to Clinical Trial

PHASE 01

Step 1: Clinical Calibration

Mapping raw 10-bit ADC voltage outputs to precise clinical pressure units (**mmHg**) using research-grade reference sensors and validating against clinical risk scales.

`Bench → Metrology Standard`

PHASE 02

Step 2: Hardware Miniaturization & Storage

Transitioning from veroboard to a custom PCB and adding persistent non-volatile flash storage so learned thresholds and event logs survive power cycles.

`Veroboard → Custom PCB + Flash`

PHASE 03

Step 3: LUTH Clinical Pilot

Implementing a supervised, patient-facing wear trial at Lagos University Teaching Hospital (LUTH) to assess real-world ambulation reliability, sweating impacts, and clinical outcomes.

`Ethics Approval → Patient Trial`

The Ultimate Goal: Transforming unmonitored rigid plastic into an intelligent clinical partner.

`Decreased revision surgeries & shorter hospital stays`

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[9] B. Griffiths, N. Silver, M. H. Granat, and E. Lebel, "Measuring foot abduction brace wear time using a single 3-axis accelerometer," *Sensors*, vol. 22, no. 7, art. 2433, 2022.