

Adaptive Bionic Interface for Real-Time Postural Correction and Clinical Monitoring via IoMT

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Abstract— This paper presents the development of an adaptive bionic interface integrated into a vest for real-time postural correction and neuromuscular reeducation. The proposed solution addresses the limitations of passive approaches by closing the sensorimotor loop through the monitoring of spinal geometry using Inertial Measurement Units and sensor fusion algorithms. The system, based on the mbed LPC1768 microcontroller, uses a state machine to perform a personalized calibration of “neutral posture” and calculate angular deviations in real time. To promote conscious motor learning and avoid false alarms, the device activates haptic feedback (112 mA vibration) only when the postural error exceeds 10° for more than 3 s, incorporating a 3° hysteresis for actuator stability. The architecture includes Internet of Medical Things connectivity via a WiFly module and a Node-RED interface, enabling remote clinical monitoring and longitudinal analysis. Experimental verification and LTspice simulations demonstrate a deterministic response to postural error, demonstrating the technical feasibility and algorithmic stability of the closed-loop prototype under simulated postural errors, establishing a foundation for future clinical validation.

Keywords—*Adaptive Bionic Interface, Real-time Postural Correction, IMUs, Haptic Feedback, IoMT, Wearable Systems*

I. INTRODUCTION

The increase in sedentary lifestyles, combined with long workdays in office environments and the repetitive nature of industrial tasks, has exacerbated the prevalence of poor posture in contemporary society. This condition is aggravated by the intensive use of mobile devices, asymmetries on using computer mice, muscle weakness, emotional stress, and functional abnormalities such as kyphosis or scoliosis. Clinical studies indicate a significant gender disparity in this issue, with women representing the group with the highest incidence of postural deviations (63.9%) compared to men (36.1%) [1].

Maintaining poor posture over time is not merely an aesthetic issue but a direct cause of degenerative physiological mechanisms. These include excessive pressure on the intervertebral discs—which can result in herniated discs, disc degeneration, or spinal stenosis—as well as chronic muscle fatigue and reduced lung capacity [2], [3]. Although the market

offers commercial solutions, such as passive correction vests or mobile apps based on simple inertial sensors, these approaches have critical limitations: they lack personalization and fail to promote sustained, conscious motor learning.

Poor posture and associated musculoskeletal disorders constitute a public health concern with severe repercussions in Portugal. Currently, approximately 37% of the Portuguese adult population suffers from chronic pain, with lower back pain specifically affecting 43% of women and 30.9% of men over the age of 15. Alarming statistics reveal that one in three Portuguese people experience back pain daily, reflecting the severity of continuous exposure to ergonomic risks.

The impact of this reality goes beyond individual suffering, generating massive socioeconomic costs. Globally, the sedentary lifestyle associated with these conditions contributes to 14% of annual mortality [4]. In the national context, it is estimated that physical inactivity and the resulting health problems represent an annual cost of approximately 900 million euros for Portugal. This figure is driven by a systematic increase in workplace absenteeism, high costs associated with clinical treatments, and direct losses in productivity. Therefore, the development of low-cost, highly effective tools—such as wearable bionic interfaces—is imperative to mitigate the economic burden of this silent epidemic and promote the neuromuscular health of the population.

The remainder of the paper is organized as follows. Section II addresses the system architecture and hardware design, focusing on the selection of Inertial Measurement Units (IMUs) for data acquisition and the central processing capabilities of the mbed LPC1768 platform. Section III describes the circuit simulation and prototyping phase, including the use of LTspice to validate the power controller and the design of the “analogue brain” featuring MOSFET and flyback protection. Section IV presents the firmware and control strategy, specifically the implementation of the Finite State Machine (FSM) and the logic parameters—such as thresholds, persistence, and hysteresis—used to filter biomechanical noise. Section V discusses the human-machine interface (HMI) and the system's integration into the Internet of Medical Things (IoMT) ecosystem via Node-

RED for remote clinical monitoring. Section VI analyses the experimental results and discussion, highlighting the baseline stability during calibration and the system's dynamic response to critical postural errors. Section VII discusses the lessons learned from the development and validation of the adaptive bionic interface. Finally, Section VIII provides the concluding remarks and proposals for future work, summarizing the effectiveness of the bionic interface as a tool for neuromuscular rehabilitation.

II. SYSTEM ARCHITECTURE AND HARDWARE DESIGN

A. Sensor Description and Data Acquisition

The foundation of the bionic system is the use of Inertial Measurement Units (IMUs), selected for their ability to convert the physical phenomenon of poor posture into quantifiable variables [5]. Each IMU incorporates a triaxial accelerometer (for linear acceleration and gravity), a triaxial gyroscope (angular velocity of flexion/extension), and a magnetometer (absolute orientation stabilization). These units are positioned at planned anatomical points, such as the upper thoracic region and cervicothoracic junction, ensuring that the measured orientation accurately represents the alignment of the spine. The system's electronic design and the corresponding three-dimensional visualization of the developed hardware are shown in Fig. 1.

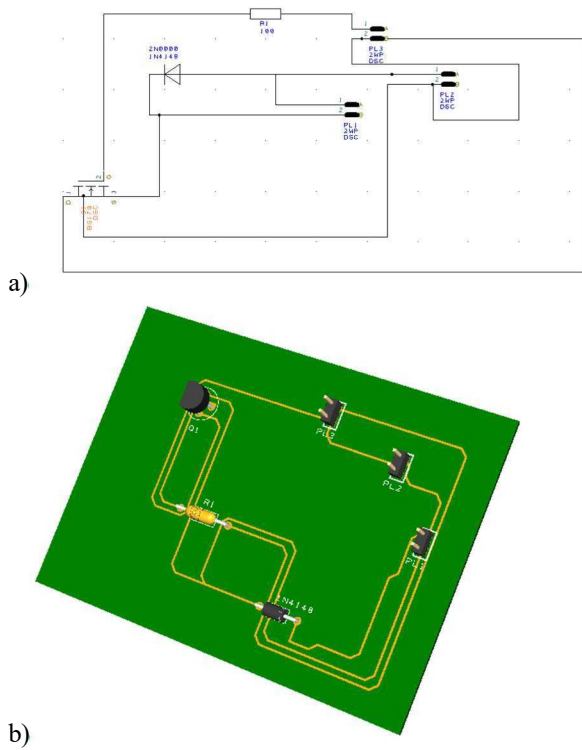


Fig. 1. PCB design: (a) Electronic schematic in DesignSpark; (b) 3D visualization of the hardware module.

The instrumentation chain operates via a standard digital bus (I²C or SPI), with a sampling rate within the range 50-100 Hz. This sampling rate is ideal for capturing human postural dynamics, whose band of interest lies below 15 Hz, thereby optimizing the wearable device's power consumption. The raw signals undergo local processing using sensor fusion algorithms (complementary or Kalman filters) to mitigate noise and inertial drift, converting the readings into stable orientation angles (pitch

and roll) [6]. The system then calculates the postural error in real time by comparing the current orientation with an anatomical baseline established during an initial 10 s calibration procedure.

B. Central Processing and IoMT Connectivity

The system's central processing and intelligence reside in the mbed LPC1768 platform, which functions as the bionic "brain" responsible for coordinating all interfaces between the human body and technology. Integrated into the PCB via connectors J1 and J2, the mbed utilizes the Mbed OS 6 ecosystem to manage a deterministic multitasking framework, which is essential for ensuring the temporal precision required in biomedical applications. This platform coordinates data acquisition via I²C or SPI digital buses (with sampling rates between 50 and 100 Hz) and applies sensor fusion algorithms, such as Kalman or complementary filters, to convert raw readings from accelerometers and gyroscopes into stable orientation angles (pitch and roll) [7]. The microcontroller executes the decision logic which, upon detecting and validating a persistent postural error, activates haptic feedback by sending a 3.3V signal through digital pin p21—protected by a 100 Ω resistor to safeguard the integrity of the microcontroller's port—to the gate of the BS170 MOSFET.

To expand functionality beyond a local alert and integrate the system into the Internet of Medical Things (IoMT) ecosystem, the mbed is paired with a WiFly module, establishing a robust Wi-Fi communication bridge that overcomes the short-range limitations of previous protocols, such as Bluetooth Low Energy, BLE [8]. This integration allows the device to work as a smart node, transmitting real-time processed parameters—including three-dimensional trunk orientation, cumulative postural error, duration in risky postures, and muscle effort indices—to external servers or cloud databases. This IoMT architecture not only closes the sensorimotor loop locally to prompt immediate user correction but also enables longitudinal and remote clinical monitoring. Hence, the mbed/WiFly combination transforms the garment into a co-adaptive interface and a tool for continuous clinical intervention, allowing healthcare professionals to track the progress of the patient's postural re-education in a transparent, data-driven manner.

Although BLE offers superior energy efficiency, Wi-Fi (via the WiFly module) was selected to enable direct, infrastructure-based cloud telemetry without requiring an intermediate smartphone gateway. Operating at a 20 Hz streaming rate, each data packet consists of approximately 80 bytes (containing system state, 3D angles, and error indices), resulting in a continuous bandwidth requirement of 1.6 kb/s. This throughput is comfortably supported by Wi-Fi with negligible packet loss (<0.5% within local indoor coverage of up to 30 meters). The higher power consumption of the Wi-Fi transceiver (~110-140 mA) is compensated by the dedicated external 3.7 V battery, ensuring a continuous prototype operation of approximately 8 hours, which is suitable for standard daily work shifts.

III. CIRCUIT SIMULATION AND PROTOTYPING

The transition from conceptual design to physical implementation required rigorous validation of the signal and power processing stages. Using LTspice software, a current

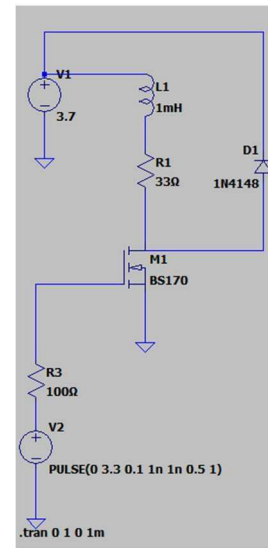
controller for the electromagnetic actuator was simulated to validate the system's dynamic behavior prior to PCB fabrication [9]. The haptic controller circuit and the current stabilization results obtained in a simulation environment are shown in detail in Fig. 2. The simulation confirmed that, in response to a 3.3 V control signal (simulating the microcontroller's decision after detecting a postural error), the power interface responds deterministically, stabilizing the motor current at 112 mA during precise 0.5 s pulses [10]. This rectangular pulse response is essential to ensure that the tactile stimulus is crisp and induces a conscious postural correction in real time.

To translate these results into a functional, miniaturized prototype, the PCB design (developed in DesignSpark) incorporated critical Electromagnetic Compatibility (EMC) strategies [11]. Since the system switches 112 mA currents near sensitive sensors (IMUs) that communicate via I²C/SPI (50–100 Hz), data integrity was ensured by segregating the signal and power electronics. The power components and the flyback diode were positioned as close as possible to the motor to minimize the current loop area and prevent inductive noise from corrupting the angular readings. Additionally, a continuous ground plane was used to provide a low-impedance return path, reducing radiation and crosstalk.

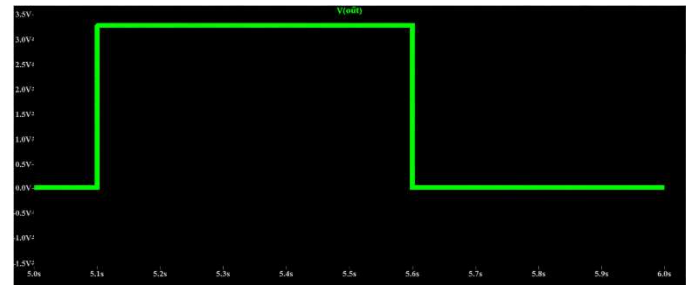
A. Haptic Actuator Driver Circuit and Flyback Protection

The core of the bionic intervention lies in what we define as the system's haptic drive interface, consisting of the strategic combination of the BS170 MOSFET (Q1) with a 1N4148 flyback diode (D1). In this architecture, the BS170 acts as a high-speed, low-impedance N-channel electronic switch, responsible for converting the processed digital data into actual physical stimuli. The control line begins at the mbed's digital pin p21, where the 3.3 V signal is filtered through a 100 Ω resistor (R1) designed to protect the microcontroller's port from current spikes during switching. While the MOSFET ensures that the stimulus amplitude stabilizes deterministically at 112 mA, the flyback diode plays a vital role in preserving hardware integrity. Connected in parallel with the actuator, the 1N4148 dissipates the electromagnetic energy stored in the motor's inductive coil at the exact moment the current is cut off, preventing reverse over voltages that could cause irreversible thermal damage to the transistor.

This hardware configuration is independently powered by an external 3.7 V battery (J3), ensuring that the motor load does not interfere with the stability of the signal electronics. The precision of this analogue interface is what allows the calculated postural error to be translated into the biological domain via crisp 0.5 s pulses, which the user perceives as an immediate and painless "body alert." By ensuring that the stimulus is delivered in a stable, safe, and electromagnetic-noise-free manner—thanks to the close positioning of the power components to minimize the current loop—this architecture ensures that the sensorimotor loop closes effectively. Thus, the technology transcends its role as a mere measurement device to establish an active closed-loop biofeedback pathway, assisting the user in conscious postural correction through a seamlessly integrated physical and digital bridge [12].



a)



b)

Fig. 2. Power controller simulation in LTspice: (a) Haptic actuator circuit with flyback protection; (b) Results showing current stabilization at 112 mA.

IV. FIRMWARE AND CONTROL STRATEGY

A. Finite State Machine Implementation

Firmware developed in C++ on the Mbed OS 6 ecosystem supports system's intelligence and operational autonomy, ensuring the temporal determinism essential for a biomedical interface. The control logic was structured using a Finite State Machine (FSM) that operates at a constant frequency of 20 Hz (50-ms cycles), allowing for the precise capture of postural variations without compromising energy consumption [13]. The FSM coordinates the transition between three fundamental states. In the Calibration state, which lasts for the first 10 s, the software calculates the arithmetic mean of the inertial readings to define a personalized anatomical baseline, adapting the sensor to the user's neutral posture. After this phase, the system automatically transitions to the Monitoring state, where it continuously calculates the postural error based on the angular difference between the current orientation and the reference orientation. Finally, the Stimulation state is activated whenever a critical error is detected, sending a 3.3 V signal to digital pin p21 to trigger the haptic actuator. The physical implementation of the mbed LPC1768 processing unit and the prototype of the data acquisition interface are shown in Fig. 3.

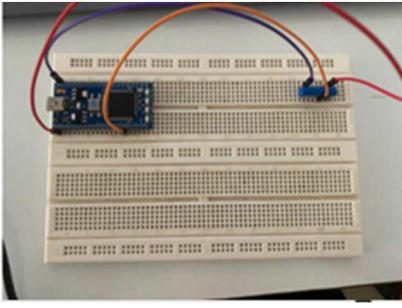


Fig. 3. Physical implementation of the mbed LPC1768 processing unit and prototyping of the data acquisition interface with error emulation.

B. Technical Control Parameters and Decision Logic

To elevate the system from a simple monitor to an effective re-education tool, the control strategy incorporates rigorous technical parameters that filter out biomechanical noise. The critical threshold of 10° was defined as the boundary for potentially harmful postural deviations [14]. To avoid false triggers caused by transient physiological movements, e.g., momentarily bending over, a 3 s persistence period was implemented; the stimulus is only validated if the error continuously exceeds the threshold during this interval. Additionally, to mitigate mechanical instability and the phenomenon of motor chattering (rapid activation/deactivation) when the user fluctuates near the limit, the firmware uses a 3° hysteresis. This means that the 112 mA feedback, once activated, is only stopped when the user corrects their posture to a value below 7° (threshold minus hysteresis). This robust logic ensures that the sensorimotor feedback loop closes in a stable manner, promoting sustained and conscious motor learning [15].

V. HUMAN-MACHINE INTERFACE AND IoMT

The transition from the system to the IoMT ecosystem is achieved through an HMI developed in Node-RED, which acts as the link between raw biophysical data and clinical monitoring [16]. This platform enables the conversion of complex biomechanical variables into indicators that are understandable to both the patient and the medical team, facilitating a longitudinal analysis of postural re-education and enabling remote intervention by healthcare professionals. The data processing workflow and information management architecture for the IoMT ecosystem are illustrated in the flowchart in Fig. 4.

The HMI's data flow follows a continuous processing architecture consisting of three main stages: serial reception, algorithmic processing, and dashboard visualization [17]. The cycle begins at the Serial In node, which actively listens to the data stream from the microcontroller at a frequency of 20 Hz, capturing asynchronous strings containing the system's logical state and angular values. These raw packets are fed into a custom JavaScript Function Node, where the demultiplexing logic segments the message using the `.split(",")` method. At this stage, the algorithm performs data integrity validation and applies a mathematical scaling correction, dividing the angle and error values by 100 to restore the decimal precision of anatomical degrees that had been converted to integers in the firmware for transmission stability.

Finally, the processed data is distributed across Dashboard components, which function as a "digital mirror" of the user's clinical status. The interface organizes the information into three output channels: the instantaneous tilt angle and postural error are displayed on analogue gauges and time-trend graphs, with fixed scales ranging from 0° to 90° and $\pm 30^\circ$, respectively, while the operational status (Calibration, Monitoring, or Stimulation) is shown in an adaptive text node. This configuration allows for real-time observation of the deterministic transition between passive monitoring and active stimulation at 112 mA, validating the system's effectiveness in mitigating critical deviations and ensuring an interface immune to scale noise, optimized for the clinical rehabilitation context [18].

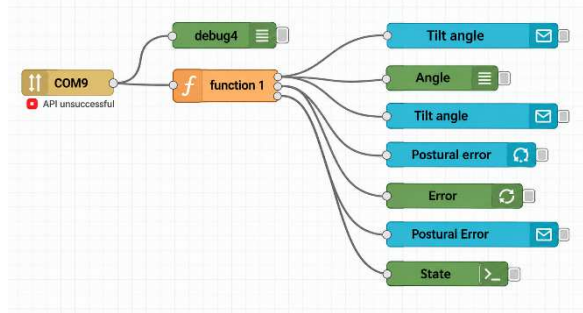


Fig. 4. A structured flowchart in Node-RED for IoMT data management and clinical visualization.

VI. EXPERIMENTAL RESULTS AND DISCUSSION

A. Baseline Stability and Calibration Validation

Experimental verification of the system began with an analysis of the automatic calibration routine, during which, in the first 10 s of operation, the software accumulated and calculated the arithmetic mean of the simulator's readings to establish the anatomical baseline. The results displayed on the clinical dashboard revealed a perfectly stabilized trend line at 0° , which demonstrates the algorithm's effectiveness in neutralizing scanning noise and initial mechanical fluctuations.

This stability is essential to ensure that the IoMT device ignores minor assembly deviations or thermal variations in the sensors, preventing false alarms that could compromise the user's confidence in the rehabilitation system [19].

B. Dynamic Response and Threshold Triggering

The firmware's dynamic response was tested by simulating progressive dorsal kyphosis through manual rotation of the potentiometer, which resulted in an abrupt decline in the error curve until it stabilized at a negative value of -13.16° . This specific result is crucial for validating the design, since the absolute value deterministically exceeds the 10° tolerance threshold configured for the detection of risky postures. The visual transition from the calibration phase to the activation of the alert in response to a critical postural error is shown on the dashboard interface in Fig. 5.

The system demonstrated algorithmic robustness by validating this error through the 3 s persistence filter, ensuring that the stimulus is triggered only by sustained deviations and not by transient physiological movements, while the 3° hysteresis logic ensured that the system remained stable without intermittent motor activations.

C. Sensorimotor Loop Closure and Physical Output

The recording of the -13.16° error served as definitive proof of the closure of the sensorimotor loop, demonstrating the direct translation of a digital deviation into an actual physical intervention. The detection of this error above the threshold forced the state machine to transition to stimulation mode, activating digital pin p21 of the mbed microcontroller to supply 3.3 V to the gate of the BS170 MOSFET [20]. Specifically, the negative angle (-13.16°) denotes forward spinal flexion relative to the calibrated 0° baseline. As displayed on the Node-RED interface, the visual alert triggers once the trajectory continuously exceeds the 10° threshold throughout the 3 s persistence window, directly validating the FSM logic.

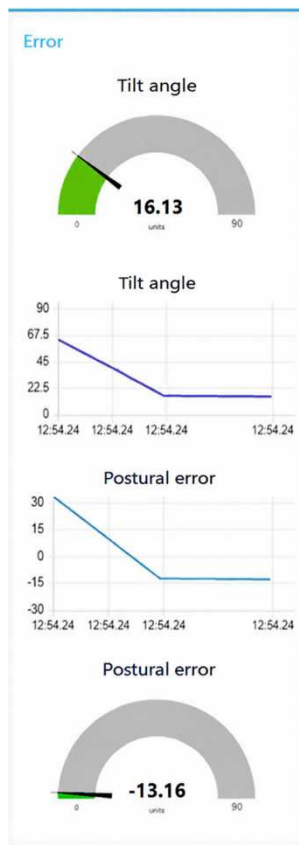


Fig. 5. Experimental results on the Dashboard: transition between the neutral posture (calibrated at 0°) and the detection of a critical error of -13.16° .

VII. LESSONS LEARNED

The development and validation of the adaptive bionic interface provided several critical insights into the integration of high-current actuators with sensitive biomedical sensors:

- Electromagnetic Compatibility (EMC) in Wearables:

A key technical takeaway was the necessity of segregating signal and power electronics. Because the system switches 112 mA currents in close proximity to IMUs communicating via I²C/SPI, the use of a continuous ground plane and placing flyback diodes as close as possible to the motor were essential to prevent inductive noise from corrupting angular readings.

- Filtering Biomechanical Noise:

Standard threshold detection is insufficient for human postural monitoring due to transient movements. The implementation of a 3 s persistence period and a 3° hysteresis was vital to prevent "motor chattering"

and ensure that haptic feedback only responds to sustained, harmful deviations, thereby maintaining user trust in the device.

- **The Role of Deterministic Simulation:** Validating the haptic actuator driver circuit via LTspice prior to PCB fabrication proved indispensable. The simulation allowed for the refinement of the current controller, ensuring a "perfect square wave" response that translated digital logic into crisp, recognizable physical stimuli for the user.

- **Communication Protocol Selection:** While Bluetooth Low Energy is common in wearable devices, the choice of a WiFly module for Wi-Fi connectivity was superior for this IoMT application. It allowed the device to function as a robust smart node, overcoming range limitations and facilitating the high-frequency (20 Hz) data streaming required for real-time clinical dashboards in Node-RED.

- **Personalization through Calibration:** The use of an initial 12:54 s calibration phase to establish an arithmetic mean for the anatomical baseline was critical. This step successfully neutralized initial mechanical fluctuations and assembly deviations, ensuring the system was tailored to each user's unique "neutral posture".

VIII. CONCLUDING REMARKS AND FUTURE WORK

This research enabled the conceptual development and technical validation of an innovative bionic interface designed to mitigate the effects of chronic poor posture through a co-adaptive approach. Unlike traditional passive solutions, this interface establishes an active closed-loop biofeedback pathway, monitoring and responding to spinal misalignment in real time. Through the integration of IMUs and sensor fusion algorithms, the system objectively quantifies spinal misalignment relative to a personalized reference posture, converting complex digital data into an immediate haptic stimulus proportional to the detected error.

This closed sensory loop is fundamental for postural re-education, as the 112 mA tactile feedback acts as a "bridge" that enhances body awareness and facilitates sustained motor learning processes. The tactile feedback acts to encourage a conscious correction, with the potential to support the adoption of healthier postural habits over time. The robustness of the hardware platform, validated by deterministic responses and electromagnetic compatibility strategies, demonstrates its operational reliability under laboratory conditions.

Finally, integration with the IoMT ecosystem and the Node-RED platform expands the utility of this device from a mere local alert to a robust tool for longitudinal clinical monitoring. By enabling remote monitoring by healthcare professionals, this bionic interface presents itself as a promising platform for remote monitoring, with the potential to support neuromuscular rehabilitation programs once extensive human-subject validation is completed.

ACKNOWLEDGMENT

This work is funded by national funds through FCT – Fundação para a Ciência e a Tecnologia, I.P., and, when eligible, co-funded by EU funds under project/support UID/50008/2025 – Instituto de Telecomunicações, with DOI identifier -

<https://doi.org/10.54499/UID/50008/2025>, UIDB/0151/2025, UIDP/0151/2025 (DOI: <https://doi.org/10.54499/UID/00151/2025>), and UID/PRR/00151/2025 (DOI: <https://doi.org/10.54499/UID/PRR/00151/2025>), Centre for Mechanical and Aerospace Sciences and Technologies. This research was also supported by COST CA20120 INTERACT - Intelligence-Enabling Radio Communications for Seamless Inclusive Interactions, and by the Portuguese, National Distributed Computing Infrastructure (INCD) through the FCT Advanced Computing Projects FCT/CPCA/2025/01. Authors also acknowledge the support from ORCIP2 project funded by CENTRO2030-2025-10 - SACCCT – Apoio às Infraestruturas do Roteiro Nacional de Infraestruturas Científicas. Catarina de Sá Baio Pires acknowledges the fruitful discussions with Prof. António Espírito Santo on the Node-RED software code development.

REFERENCES

- [1] S. Yuan and L. Zhou, "GTA-Net: An IoT-integrated 3D human pose estimation system for real-time adolescent sports posture correction," *Alexandria Engineering Journal*, vol. 112, pp. 585–597, Jan. 2025, doi: 10.1016/j.aej.2024.10.099.
- [2] M. D. Martin, C. M. Boxell, and D. G. Malone, "Pathophysiology of lumbar disc degeneration: a review of the literature," *FOC*, vol. 13, no. 2, pp. 1–6, Aug. 2002, doi: 10.3171/foc.2002.13.2.2.
- [3] S. Haldeman, F. J. Kohlbeck, and M. McGregor, "Risk Factors and Precipitating Neck Movements Causing Vertebrobasilar Artery Dissection After Cervical Trauma and Spinal Manipulation:," *Spine*, vol. 24, no. 8, pp. 785–794, Apr. 1999, doi: 10.1097/00007632-199904150-00010.
- [4] I.-M. Lee, E. J. Shiroma, F. Lobelo, P. Puska, S. N. Blair, and P. T. Katzmarzyk, "Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy," *The Lancet*, vol. 380, no. 9838, pp. 219–229, Jul. 2012, doi: 10.1016/S0140-6736(12)61031-9.
- [5] A. A. Gopalai and S. M. N. A. Arosha Senanayake, "A Wearable Real-Time Intelligent Posture Corrective System Using Vibrotactile Feedback," *IEEE/ASME Trans. Mechatron.*, vol. 16, no. 5, pp. 827–834, Oct. 2011, doi: 10.1109/TMECH.2011.2161486.
- [6] R. E. Kalman, "A New Approach to Linear Filtering and Prediction Problems," *Journal of Basic Engineering*, vol. 82, no. 1, pp. 35–45, Mar. 1960, doi: 10.1115/1.3662552.
- [7] E. Fléty and F. Bevilacqua, "Wireless Inertial Measurement Units in Performing Arts," *Sensors*, vol. 25, no. 19, p. 6188, Oct. 2025, doi: 10.3390/s25196188.
- [8] B. Wei and C.-H. Min, "Edge Computing Enabled IMU Motion-Sensing Wireless Sensor Network for Posture Detection," in *2025 28th International Conference on Computer and Information Technology (ICCIT)*, Cox's Bazar, Bangladesh: IEEE, Dec. 2025, pp. 4331–4335. doi: 10.1109/ICCIT68739.2025.11490523.
- [9] A. Rihar *et al.*, "Emerging Technologies for Advanced Power Electronics and Machine Design in Electric Drives," *Applied Sciences*, vol. 14, no. 24, p. 11559, Dec. 2024, doi: 10.3390/app142411559.
- [10] Z. Wang, A. Guez, and A. Das, "Dynamic systems and machine learning approach to online EEG signals processing for different applications," Doctor of Philosophy, Drexel University, Philadelphia, Pennsylvania, United States, 2023. doi: 10.17918/00010608.
- [11] L. Chen *et al.*, "Development and Practical Advances in Integrated Circuit Electromagnetic Reliability Over the Last Decade," *IEEE Trans. Rel.*, vol. 75, pp. 819–832, 2026, doi: 10.1109/TR.2025.3647435.
- [12] S. Ahola, A. Piirainen, and L. H. Skjaerven, "The phenomenon of movement quality: a phenomenographic study of physiotherapy students' movement experiences," *European Journal of Physiotherapy*, vol. 19, no. 2, pp. 59–68, Apr. 2017, doi: 10.1080/21679169.2016.1261366.
- [13] N. Hayami *et al.*, "Development and Validation of a Closed-Loop Functional Electrical Stimulation-Based Controller for Gait Rehabilitation Using a Finite State Machine Model," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 30, pp. 1642–1651, 2022, doi: 10.1109/TNSRE.2022.3183571.
- [14] C. R. Reid, P. McCauley Bush, W. Karwowski, and S. K. Durrani, "Occupational postural activity and lower extremity discomfort: A review," *International Journal of Industrial Ergonomics*, vol. 40, no. 3, pp. 247–256, May 2010, doi: 10.1016/j.ergon.2010.01.003.
- [15] J. Xu *et al.*, "Configurable, wearable sensing and vibrotactile feedback system for real-time postural balance and gait training: proof-of-concept," *J NeuroEngineering Rehabil.*, vol. 14, no. 1, p. 102, Dec. 2017, doi: 10.1186/s12984-017-0313-3.
- [16] I.-V. Nițulescu and A. Korodi, "Supervisory Control and Data Acquisition Approach in Node-RED: Application and Discussions," *IoT*, vol. 1, no. 1, pp. 76–91, Aug. 2020, doi: 10.3390/iot1010005.
- [17] W. He, M. J. A. Baig, and M. T. Iqbal, "An Open-Source Supervisory Control and Data Acquisition Architecture for Photovoltaic System Monitoring Using ESP32, Banana Pi M4, and Node-RED," *Energies*, vol. 17, no. 10, p. 2295, May 2024, doi: 10.3390/en17102295.
- [18] Q. Zeng *et al.*, "Materials and System Design for Self-Decision Bioelectronic Systems," *Advanced Materials*, vol. 38, no. 9, p. e21164, Feb. 2026, doi: 10.1002/adma.202521164.
- [19] F. Pastore, R. W. Anwar, N. H. Jabeur, and S. Ali, "Intelligent Fusion: A Resilient Anomaly Detection Framework for IoMT Health Devices," *Information*, vol. 17, no. 2, p. 117, Jan. 2026, doi: 10.3390/info17020117.
- [20] Y. Moghe, "DC Current Measurement Systems for Neurostimulator Implants," UNSW Sydney, 2014. doi: 10.26190/UNSWORKS/16900.