

mHealth-Based Wearable System for Real-Time Monitoring and Prevention of Spinal Postural Disorders [†]

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Abstract

Musculoskeletal disorders caused by poor posture are a major global health concern, contributing to spinal deformities and chronic pain. This study presents a mobile health (mHealth) enabled smart orthosis for real-time monitoring and correction of spinal posture. The wearable system integrates inertial measurement units along the spine to capture curvature data, processed through computational models to detect postural deviations. A connected mobile application enables real-time feedback, continuous monitoring, and remote assessment. Laboratory validation demonstrated reliable sensor performance. The proposed mHealth solution supports early diagnosis, long-term monitoring, and prevention of posture-related disorders, promoting personalized spine care and patient engagement in daily life.

Keywords: mHealth; wearable sensors; spinal posture monitoring; inertial measurement units (IMUs); smart orthosis

1. Introduction

Musculoskeletal disorders (MSDs) represent a major global health burden, significantly affecting quality of life (QoL) and functional capacity across all age groups. Beyond physical impairment, MSDs are associated with psychological and social limitations, contributing to reduced productivity and increased healthcare costs [1,2]. Recent global analyses confirm that MSDs remain among the leading causes of disability worldwide, with increasing prevalence linked to sedentary lifestyles and prolonged digital device use [1].

Spinal pathologies such as lordosis, scoliosis, and kyphosis are highly prevalent and may lead to progressive structural deformities and dysfunction of internal organs if not detected early. Low back pain (LBP) continues to be the leading cause of years lived with disability globally, with many acute cases progressing to chronic conditions, highlighting the importance of early intervention and monitoring [1]. In the context of mobile health (mHealth), continuous monitoring technologies are increasingly used to support early diagnosis and preventive care.

Maintaining proper spinal curvature during daily activities is essential for biomechanical stability and efficient load distribution. However, traditional posture assessment methods rely on clinical observation and episodic measurements, limiting their ability to



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capture real-world behavior. Recent advances in wearable technologies enable continuous monitoring of human movement in natural environments, supporting personalized rehabilitation strategies [3].

In recent years, wearable inertial sensing systems have gained significant attention in digital health due to their portability, affordability, and accuracy. Studies demonstrate that inertial measurement units (IMUs) integrated into wearable systems can reliably assess spinal kinematics and detect postural deviations [4]. Moreover, integration with mobile applications enables real-time feedback, remote patient monitoring, and increased patient engagement core components of mHealth ecosystems [5,6].

Despite these advances, most existing solutions focus on localized spinal regions (e.g., cervical or lumbar), rather than providing a full-spine assessment. Additionally, limitations such as lack of personalization, discomfort, and reduced long-term adherence remain significant barriers to adoption. Recent reviews emphasize the need for user-centered, scalable wearable systems that support continuous monitoring and real-world usability [7].

Another key challenge in postural health is the lack of preventive strategies. Patients often seek treatment only after pain onset, when correction becomes more difficult. Digital health approaches increasingly emphasize prevention through continuous monitoring, behavioral feedback, and early intervention using wearable and mobile technologies [8].

In this context, intelligent wearable orthoses integrated within mHealth platforms represent a promising solution. These systems combine continuous sensing, real-time feedback, and remote communication with healthcare providers, enabling personalized rehabilitation and long-term monitoring. By leveraging inertial sensors and mobile applications, such solutions support early diagnosis, continuous assessment, and prevention of posture-related disorders in everyday life.

This study aims to contribute to this field by proposing a smart orthosis designed for real-time monitoring of the entire spinal curvature using inertial sensors, within a mobile health framework.

2. Materials and Methods

2.1. Architecture and Design

In this study, an intelligent orthosis was developed at the laboratory level to support postural correction by monitoring the entire curvature of the spine. The design focuses on creating a measurement system that is easy to use in controlled and structured environments, thereby enabling accurate and reliable posture assessment. The proposed device is intended to provide real-time feedback to patients, facilitating the detection and correction of improper postural habits [9].

Users' daily postural habits can be collected in real time by this orthosis device. Because the monitoring is carried out in real time and the orthosis includes alarm elements for the patient, real-time feedback can be provided. To be able to reach these points in monitoring, inertial sensors and flex sensors were used in the designed devices [10]. The spine must be monitored both statically and dynamically. In statics for calculating angle accelerometers are reliable, while gyroscopes are reliable in dynamic conditions [11,12].

By permanently determining the variation of the curves of the spine using inertial sensors, we can also provide real-time feedback to the patient. The block diagram of the smart orthosis proposed by us includes flex sensors, inertial sensors, a GPS/GSM module, and a Bluetooth module, which are all controlled by a central unit.

To increase the reliability of the device, 3-axis inertial sensors with a high resolution of up to 13 bits, reduced noise, and a measurement range between ± 0.5 g, ± 1 g, ± 2 g, and ± 4 g were used. Inertial sensors were used to monitor the position of the spine in static and dynamic through the sensory functions of activity (presence and movement) and

inactivity (absence of movement). For the sensors selected for use, the acceleration level can be defined by the user for any axis. This element was necessary to obtain values close to the true values from a postural point of view.

The three inertial sensors were placed on the level of vertebrae C7, T10, and L5 (see Figure 1). This location was chosen to be able to define, with the help of sensors, the full range of vicious positions such as kyphosis, scoliosis, or lordosis.

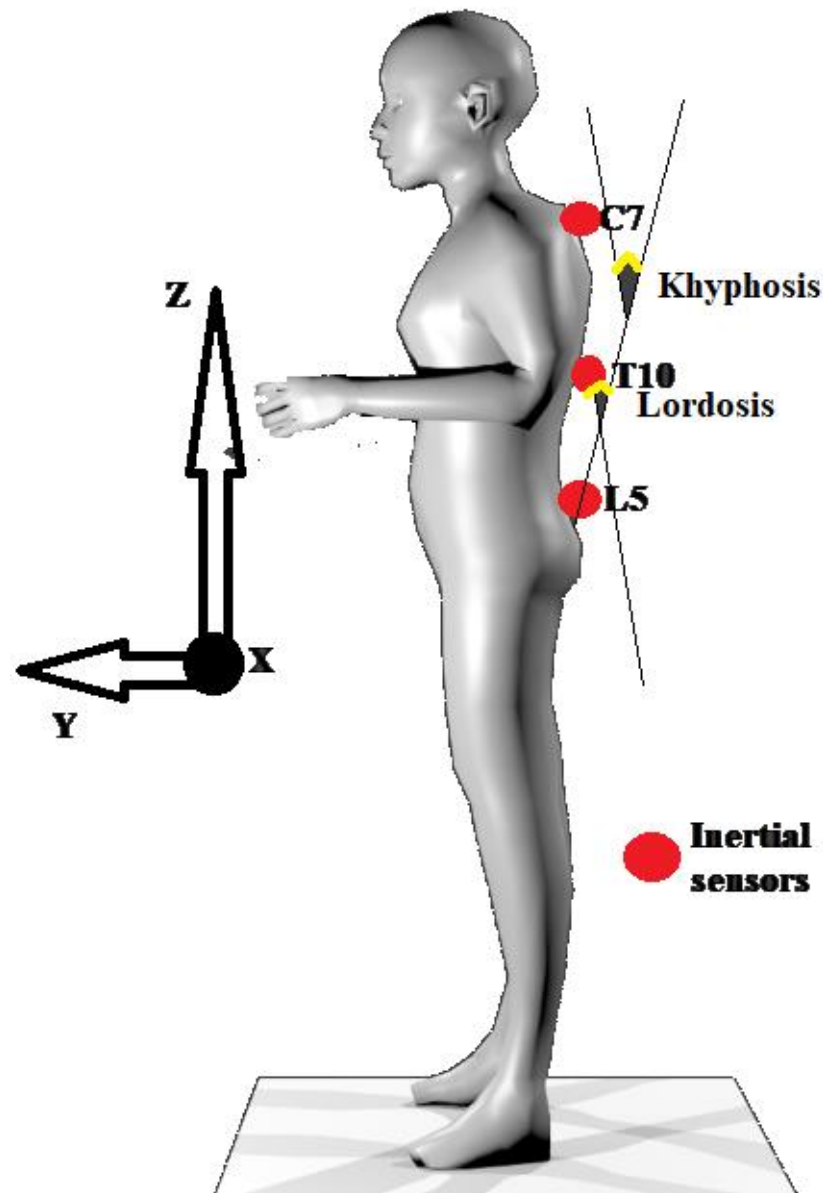


Figure 1. Position of inertial sensors in the experiment.

To build a device that can make recordings with the patient in both static and dynamic, along with the three inertial sensors, a flex type sensor was used. The flex sensor was positioned along the entire length of the spine to increase the accuracy of the recordings, but also to be able to measure the degree of mobility for each vertebra. These records are needed to assess the correct position of the spine in dynamics.

The system architecture is complemented by a mobile application that serves as the user interface, enabling real-time visualization of postural data, feedback delivery, and remote monitoring within an mHealth framework.

2.2. Principle of Operation

The central processing unit acquires and integrates data from the inertial sensors, flex sensors, and GPS/GSM module (see Figure 2). The flex sensor is employed to quantify spinal curvature, enabling the identification of both normal alignment and postural deviations, while inertial sensors enhance the accuracy of posture detection under static and dynamic conditions. The GPS/GSM module facilitates data logging and enables remote communication by transmitting alert notifications to the physician or physiotherapist monitoring the patient's progression.

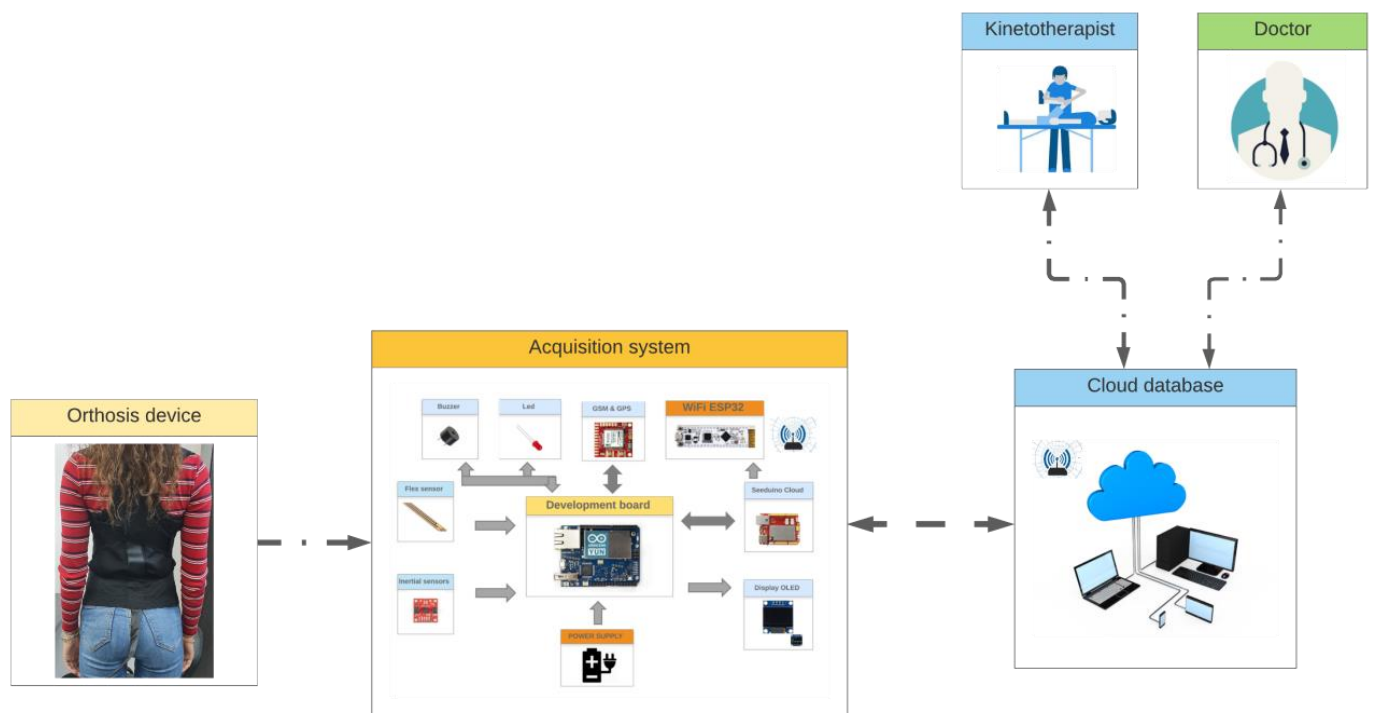


Figure 2. Data acquisition and communication architecture of smart orthosis.

The features we intended to implement in creating this smart orthosis (see Figure 3), used as a posture corrector, include wearing comfort, ease of use, and size reduction.

2.3. Mobile Application and User Interface

To complement the wearable sensing system, a mobile health (mHealth) application was developed to serve as the primary user interface for real-time interaction, data visualization, and feedback delivery. The application is designed to enhance user engagement and enable continuous monitoring of spinal posture outside clinical environments.

The mobile application communicates with smart orthosis via a Bluetooth module, allowing real-time transmission of sensor data acquired from the inertial and flex sensors. These data are processed and displayed through an intuitive graphical interface, providing users with immediate information regarding spinal alignment and postural deviations. The system enables continuous tracking of posture during daily activities, supporting both static and dynamic assessments.

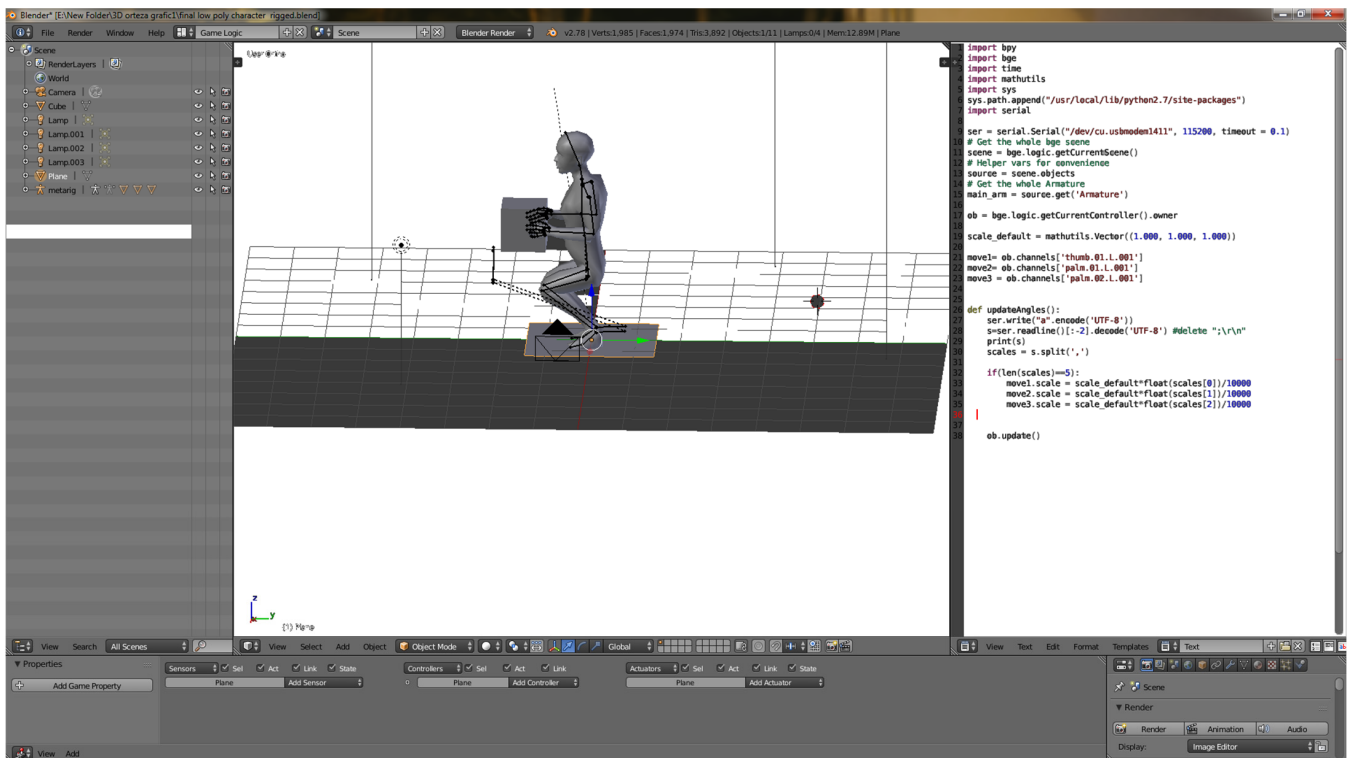


Figure 3. (a) Screenshot representing the physiological model simulated in the Blended program and the code sequence linking the microprocessor placed on the smart orthosis and the program. (b) Subject with smart orthosis on it, lifting a 5 kg box.

3. Results

Following the tests performed, the research team studied whether the materials used in making this smart orthosis prevent the maintenance of a correct posture, are uncomfortable to wear, or do not comply with biocompatibility rules. The materials used proved to be perfectly compatible and do not change their physical and chemical properties during use.

3.1. Simulation

A 3D simulation was performed to test, at the laboratory level, the functionality of the connected device, with the help of the Blender program. We used this program to perform a real-time simulation of the instantaneous values of the sensors. Each object in the simulation program was made individually, and the forces and axes were simulated considering the real values (the weight of the raised object and the ratio between the weight and height of the subject by calculating the body mass index).

The simulated model of the patient, specifically of the spine, is formulated by integrating the dynamic equations and the physiological parameters to determine the forces and movements. For simulation, a code sequence was created to communicate between the device's microprocessor and the simulation program.

Following the simulation, a concordance was observed between the movements of the simulated character and those of the real subject, in real time, as can be seen in Figure 3. The simulated character can be modified according to each subject, considering its real physical characteristics.

The purpose of this simulated character is to enable its later use in the development of a mobile application. The utility stems from the fact that the patient can see a virtual character simulated and transposed in real time on a smartphone.

Spine stability indices were determined by determining the dynamic equations that determine the forces, moments, velocities, and accelerations of the spine. We chose to calculate these indices to determine how robust the lumbar spine is against disturbances when pushing or lifting objects. The dynamic forces for lifting are evaluated as follows:

$$\sum M = m * h^2 * \alpha \quad (1)$$

$$F_p * h * \cos(\theta_f) - F_0 * h * \cos(\theta_f) + N * h * \cos(\theta_g) - mg * h * \cos(\theta_g) = m * h^2 * \alpha \quad (2)$$

where the angular acceleration α , is integrated to acquire an equation for angular velocity. Inertial sensors, such as accelerometers or magnetic sensors, which can be incorporated into portable systems, can be used to monitor the associated movement of human activities. N and mg are the normal force and the force due to gravity. The angle θ_g is the angle between the forces related to mg and the normal forces and the perpendicular axis.

3.2. Signal Processing and Filtering

In the processing and filtering part, we filtered the data received from the inertial sensors, which is sampled at 65 Hz, using a 15 Hz Low-Pass Filter. This initial filtering process eliminates noise and common artifacts from the motion data recorded on each axis of the 3 inertial sensors. Data collected from sensors via Bluetooth are transmitted to the feature extraction module.

From the point of view of the numerical values obtained following the test of lifting an object in the correct position versus in the vicious position, these are mediated and displayed in Table 1.

An important aspect that we have considered was the length of time the patient wears the orthosis. This aspect is very important, given our intentions to design this device as a preventive tool for certain diseases of the spine. Not only for prevention but also for some treatments, it is very important to know how long the patient wore the smart orthosis during the day. This parameter is very important if we wish to begin clinical trials and determine if the patient has difficulty in wearing the orthosis daily. Determining the number of hours for which the orthosis was worn is achieved by segmenting the data

from the bending sensor. The calculation formula used is simple: Duration of orthosis wear = Number of samples/Sampling Frequency.

Table 1. Numerical values collected with the help of attached sensors, obtained from two subjects in the calibration position, maintaining their current postural position and after the postural correction (see Figure 4).

Values	Subject	Calibration			Incorrect Position of Spine			Correct Position of Spine		
Values of Inertial sensor	Subject 1	X = 12	X = 22	X = 15	X = 240	X = 230	X = 224	X = 364	X = 220	X = 200
		Y = 177	Y = 180	Y = 168	Y = 15	Y = 22	Y = 18	Y = 37	Y = 42	Y = 39
		Z = 000	Z = 000	Z = 000	Z = 257	Z = 178	Z = 156	Z = 350	Z = 320	Z = 371
	Subject 2	X = 15	X = 16	X = 15	X = 230	X = 225	X = 221	X = 193	X = 224	X = 195
		Y = 165	Y = 170	Y = 165	Y = 30	Y = 32	Y = 19	Y = 45	Y = 39	Y = 37
		Z = 000	Z = 000	Z = 000	Z = 177	Z = 168	Z = 149	Z = 365	Z = 349	Z = 369
Values of Flex sensor	Subject 1	787	895	834	689	759	679	674	694	705
	Subject 2	914	865	862	625	715	856	694	562	652

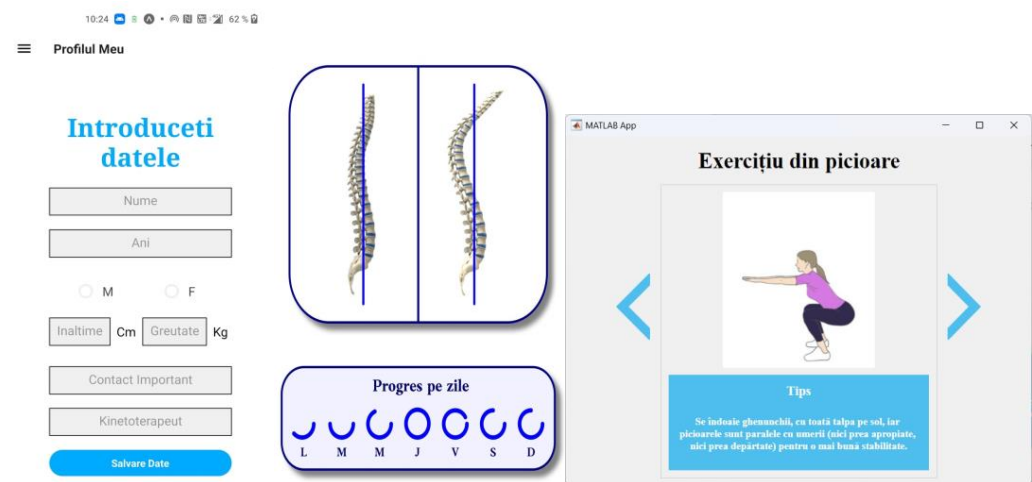


Figure 4. Mobile application interface for real-time posture monitoring, feedback, and data visualization.

A key functionality of the application is the implementation of a real-time feedback mechanism. When deviations from a predefined optimal posture are detected, the system generates visual and/or notification-based alerts to prompt the user to correct their position. This feature plays a critical role in promoting behavioral changes and preventing the development of postural disorders.

In addition to real-time monitoring, the application includes data logging capabilities, making it possible to store and visualize historical posture data. This functionality facilitates long-term assessment of patient progress and supports personalized rehabilitation strategies. The recorded data can be accessed by healthcare professionals, enabling remote monitoring and evaluation of the patient's condition through telemedicine approaches.

Furthermore, the application integrates a virtual representation of the user's posture, based on the processed sensor data, allowing intuitive visualization of spinal movements and alignment. This feature enhances user understanding of postural habits and provides an interactive tool for improving posture awareness.

Overall, the developed mobile application extends the functionality of the smart orthosis by providing a comprehensive mHealth platform that supports real-time feedback, continuous monitoring, and remote clinical supervision, thereby contributing to personalized and preventive spine care.

4. Discussion

The results obtained in this study demonstrate that the proposed smart orthosis can monitor spinal curvature in real time during both static and dynamic activities. The integration of inertial and flex sensors allowed accurate detection of postural changes, while the system architecture ensured reliable data acquisition and transmission. These findings are consistent with recent studies highlighting the effectiveness of wearable inertial sensing technologies for posture assessment and rehabilitation.

A key contribution of this study is the integration of the wearable system within a mobile health (mHealth) framework. The developed mobile application enables real-time visualization, feedback, and data recording, transforming the system from a simple monitoring device into an interactive tool for postural correction. This approach aligns with current trends in digital health, where patient-centered technologies are used to promote engagement, self-management, and preventive care.

Compared to existing solutions, which are often limited to monitoring specific spinal regions, the proposed system provides a more comprehensive evaluation of the entire spinal curvature. This represents an important advancement, as posture-related disorders typically involve complex interactions across multiple spinal segments. Additionally, the use of a wearable orthosis ensures portability and usability in real-life conditions, overcoming limitations associated with clinical or laboratory-based assessment methods.

Another important aspect is the potential of the system to support preventive health-care strategies. As highlighted in recent literature, postural disorders are frequently addressed only after the onset of pain. By providing continuous monitoring and real-time feedback, the proposed solution encourages early correction of improper posture, potentially reducing the risk of developing chronic musculoskeletal conditions. The inclusion of data logging and remote access functionalities further supports long-term monitoring and telemedicine applications.

The mobile application plays a central role in enhancing user adherence and usability. By offering intuitive visualization of posture and immediate feedback, it facilitates behavioral changes and increases patient awareness. Moreover, the possibility for health-care professionals to remotely access patient data enables personalized intervention and follow-up, which are essential components of modern mHealth systems.

Despite these promising results, several limitations should be considered. The current validation was performed under laboratory conditions on a limited number of subjects, which restricts the generalizability of the findings. Future studies should include larger and more diverse populations, including patients with diagnosed spinal pathologies, to evaluate clinical effectiveness. Additionally, long-term usability and user compliance should be investigated in real-world scenarios.

Further developments may focus on improving system miniaturization, enhancing sensor accuracy, and integrating advanced data analysis techniques such as machine learning algorithms for automated posture classification and prediction. The incorporation of cloud-based data management and secure data-sharing protocols could further strengthen the telemedicine capabilities of the system.

In conclusion, the proposed mHealth-based wearable system represents a promising solution for the real-time monitoring, prevention, and management of postural disorders. By combining wearable sensing technologies with mobile applications, the system supports personalized, continuous, and accessible spine care, with potential applications in both clinical rehabilitation and everyday health monitoring.

5. Patents

LUCA CĂTĂLINA [RO]; CORCIOAVĂ CĂLIN PETRU [RO]; FUIOR ROBERT [RO], UNIV DE MEDICINA SI FARMACIE GRIGORE T POPA DIN IASI [RO], SMART ORTHOSIS FOR ACTIVE POSTURAL CORRECTION, IPC A61F5/02; G08B21/24; Publication RO138506A0-30 December 2024.

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Abbreviations

The following abbreviations are used in this manuscript:

MSDs	Musculoskeletal disorders
QoL	quality of life
LBP	Low back pain
IMUs	inertial measurement units

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