

# Technological platform for early diagnosis of scoliosis in the school-aged pediatric population

## Plataforma tecnológica para el diagnóstico temprano de escoliosis en población pediátrica escolar

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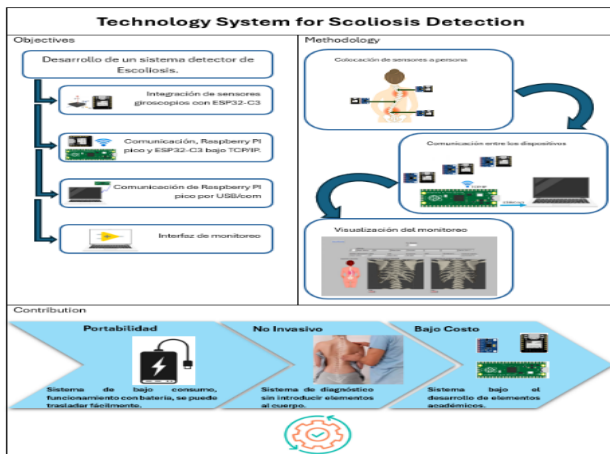


### Abstract

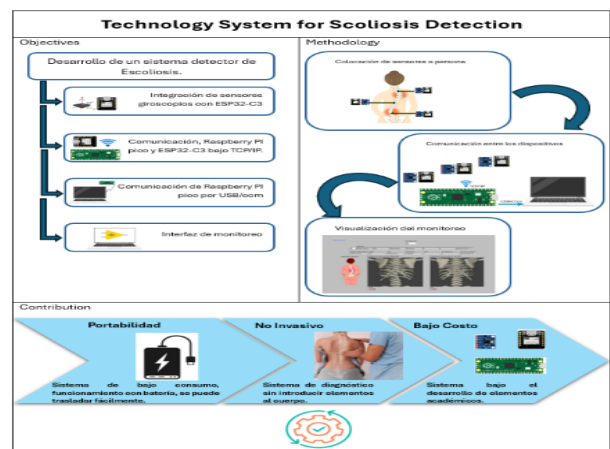
Scoliosis is a lateral deviation of the spinal column that can affect the development and quality of life of children. Early detection is essential to implement timely treatments and prevent complications. This study proposes a wireless sensory system based on inertial measurement units [IMUs] and ESP32 microcontrollers for objective, real-time detection of postural deviations compatible with scoliosis in school-aged children. Data are transmitted via Wi-Fi to a PC-based graphical interface that enables clinical information registration, visualization, and storage for follow-up. Simulated results demonstrate promising performance with sensitivity and specificity above 85%. This system represents an accessible, portable, and non-invasive tool that can complement traditional screening methods, contributing to scoliosis prevention and monitoring in school settings.

### Resumen

La escoliosis es una desviación lateral de la columna vertebral que puede afectar el desarrollo y la calidad de vida de los niños. La detección temprana es fundamental para implementar tratamientos oportunos y evitar complicaciones. Este trabajo propone un sistema sensorial inalámbrico basado en unidades de medición inercial [IMU] y microcontroladores ESP32 para la detección objetiva y en tiempo real de desviaciones posturales compatibles con escoliosis en niños en edad escolar. Los datos se transmiten vía Wi-Fi a una interfaz gráfica desarrollada en PC, que permite registrar, visualizar y almacenar información clínica para el seguimiento. Los resultados del sistema muestran un desempeño prometedor con sensibilidad y especificidad superiores al 85%. Este sistema representa una herramienta accesible, portátil y no invasiva que puede complementar los métodos tradicionales de tamizaje, contribuyendo a la prevención y monitoreo de la escoliosis en entornos escolares.



Scoliosis, Preventive Diagnosis, Sensory System



Escoliosis, Diagnóstico Preventivo Sistema Sensorial

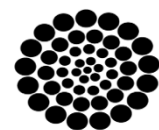
Area: Advocacy and attention to national problems

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## Introduction

Scoliosis, characterized by a lateral and rotational deviation of the spinal column, represents a clinical challenge that requires early detection to prevent severe complications in patients' musculoskeletal health, especially in the pediatric population. Conventional diagnostic methods include visual assessments based on the Adams test and radiographic studies, which present limitations in terms of subjectivity, radiation exposure, and accessibility [Parent et al., 2010].

In the field of biomedical and mechatronic engineering, the development of portable and non-invasive sensory systems offers a promising solution to complement traditional diagnosis. Inertial measurement units [IMUs], which integrate accelerometers and gyroscopes, enable accurate real-time capture of movements and postures, facilitating quantitative analysis of body alignment [Bonnet et al., 2020].

The integration of microcontrollers with wireless communication capabilities, such as the ESP32, allows for efficient data transmission to personal computer-based processing and visualization platforms, enabling real-time monitoring systems and automated recording of clinical information [Molanes López et al., 2019].

This work presents the design, implementation, and validation of a wireless sensory system based on IMUs for the objective detection of scoliosis in school-aged children.

The electronic components of the system, signal processing using LabVIEW, and the software architecture for data management and clinical report generation are described. The potential of this technology to improve the efficiency and accuracy of postural screening is discussed, facilitating its application in school settings and rehabilitation centers.

## State of the Art

The diagnosis of scoliosis has traditionally been approached through clinical and radiographic methods. The most commonly used tool for visual detection is the Adams test, widely applied in school settings due to its simplicity and low cost.

This procedure allows the examiner to observe trunk asymmetry when the patient performs forward bending, but its effectiveness is subject to the specialist's subjective interpretation, which limits its accuracy [Castro et al., 2010].

Diagnostic confirmation and assessment of scoliosis severity rely on spinal X-rays, where the Cobb angle is calculated—considered the gold standard for classifying the magnitude of the curvature [Vrtovec et al., 2009]. However, exposure to ionizing radiation poses a significant concern, particularly for pediatric patients who may require multiple assessments over time [Parent et al., 2010].

In response to these limitations, there has been a growing trend toward the development of non-invasive technologies that allow for objective and frequent evaluation of the spine without the need for X-rays. In this context, inertial sensors—such as accelerometers, gyroscopes, and magnetometers—have proven to be promising tools for postural analysis and monitoring of spinal deformities [Zhang et al., 2016; Bonnet et al., 2020]. These devices offer the advantages of being portable, low-cost, and capable of providing real-time quantitative measurements.

Zhang et al. [2016] developed a portable system based on inertial sensors for scoliosis detection, validated with both healthy volunteers and diagnosed patients. Their results showed a high correlation between the recorded data and clinically detected deviations, positioning this technology as a viable alternative for initial screening. Similarly, Bonnet et al. [2020] implemented a set of inertial measurement units [IMUs] in adolescents, successfully identifying abnormal postural patterns associated with scoliotic curvatures, suggesting their potential for clinical and home-based applications.

Other studies have integrated these sensors with signal processing algorithms and machine learning techniques to enhance the automatic classification of patients with scoliosis. For example, the use of artificial neural networks and support vector machines has been explored to distinguish between normal and pathological postural patterns, yielding promising results [Komeili et al., 2019].

Despite these advances, further efforts are required to validate these systems in school environments and in studies with larger populations, especially considering their applicability as screening tools. In this regard, the development of user-friendly devices capable of reliably recording data and offering intuitive interfaces for non-specialist professionals represents a key research direction in the field of clinical biomechanics and rehabilitation.

### System Design

This project follows a quantitative, experimental, and cross-sectional approach aimed at the design, implementation, and validation of a portable sensory system for the early detection of postural deviations compatible with scoliosis in school-aged children.

This approach addresses the growing need for portable, accessible, and objective technologies that complement traditional visual and radiographic assessment methods, which present limitations in terms of accuracy, subjectivity, or radiation exposure [Parent et al., 2010; Vrtovec et al., 2009]. Likewise, the study aligns with recent proposals in clinical biomechanics that promote the use of inertial sensors as valid and reliable tools for postural evaluation in school or community settings [Bonnet et al., 2020; Zhang et al., 2016].

### Development and Calibration of the Sensory System

In the first stage, inertial measurement units based on MPU6050 sensors were selected and configured, integrated with ESP32 microcontrollers for data acquisition and wireless transmission via Wi-Fi. An ergonomic mount was designed to ensure the precise placement of the sensors in the thoracic and lumbar regions, guaranteeing stability and proper alignment during measurement.

A calibration protocol was implemented to ensure the accuracy and reliability of the measurements, which included:

- Laboratory tests with controlled movements to verify the response of the sensors along the three axes of acceleration and rotation [Bonnet et al., 2020].

- Validation of wireless communication, evaluating sampling rate, latency, and packet loss, with special attention to the Wi-Fi protocol on ESP32 microcontrollers [Molanes López, Fraga-Lamas, & Fernández-Caramés, 2019].
- Tuning of digital filtering algorithms and sensor fusion to optimize signal quality under real conditions, implemented in LabVIEW [National Instruments, 2020].

### Field Experimental Evaluation

The second stage consisted of deploying the system in school and clinical settings to evaluate its ability to detect postural deviations indicative of scoliosis. A data acquisition protocol was defined, which includes:

- The systematic placement of sensors at standard anatomical positions on vertebrae T3 and L2, using the custom-designed mount [Topalovic, Stankovic, & Strbac, 2020].
- Data captures during static and dynamic postures using the Adams test, with time synchronization between sensors and the base station [Bonnet et al., 2020].
- The simultaneous collection of conventional clinical data to establish a reference standard [Parent, Newton, Wenger, & Mahar, 2010].

The design includes the evaluation of key technical parameters such as measurement repeatability, robustness interference, and variability in sensor placement.

### Population

The target population of the project consists of school-aged boys and girls, specifically between 8 and 12 years old, who attend primary education in schools located within the area of influence of the Centro de Rehabilitación Integral [CRI] in Apizaco, Tlaxcala, Mexico.

This age range was selected because it corresponds to the period of highest prevalence and progression of infantile and juvenile idiopathic scoliosis [Weinstein et al., 2008].

The sample is composed of students from four primary schools near the CRI, which are regularly visited by clinical staff from the center as part of their early detection campaigns.

Participant selection is carried out through non-probabilistic convenience sampling, since access to the schools depends on institutional agreements and written consent provided by parents or legal guardians.

The inclusion criteria are students aged 8 to 12 years, in physical condition to perform posture and bending tests without assistance, and whose guardians have provided written consent for their participation in the study. Exclusion criteria include children with a prior diagnosis of cerebral palsy, neuromuscular syndromes, or orthopedic conditions that interfere with normal trunk mobility.

The estimated initial sample size is approximately 40 to 50 children, aiming to represent both cases without visible signs of scoliosis and subjects with possible postural deviations. Preliminary identification will be conducted through the Adams test applied by CRI medical personnel, with the goal of comparing clinical findings with the data obtained from the sensory system. Data collection will be conducted by physiotherapists and medical specialists from CRI Apizaco, who have experience in postural screening and working with pediatric populations. The study will also ensure compliance with ethical principles for human research, in accordance with the Declaration of Helsinki and national guidelines on research involving minors [Consejo de Salubridad General, 2012].

### Technical Variability in Sensor Placement

In order to evaluate the robustness of the system against potential human errors during sensor installation, repeatability protocols will be implemented, in which different operators will place the devices on a subset of participants to analyze intra- and inter-operator variability [Bonnet et al., 2020].

### Technological System

The system developed for scoliosis detection is based on an integrated hardware and software architecture, designed to wirelessly capture, transmit, and record postural data in real time.

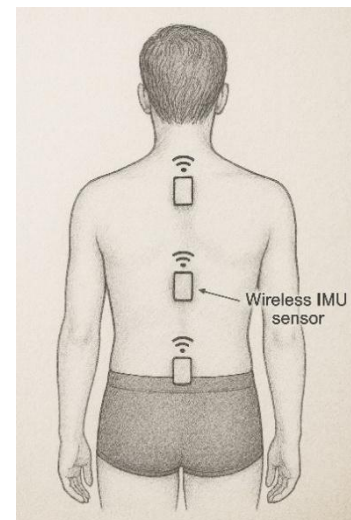
At the core of the system are inertial measurement units [IMUs], which combine accelerometers and gyroscopes to measure linear acceleration and angular velocity across three axes.

These sensors were selected for their low cost, compact size, and suitable accuracy for non-invasive biomedical applications [Bonnet et al., 2020].

Each IMU is paired with an ESP32 microcontroller, which provides embedded processing capabilities and Wi-Fi wireless connectivity. Wireless communication enables real-time data transmission to a base station [PC] without the need for cables, increasing user comfort and mobility during assessment [Molanes López, Fraga-Lamas, & Fernández-Caramés, 2019].

For attachment, an adjustable ergonomic mount was designed to ensure proper placement of the sensors in the thoracic [T3 vertebra] and lumbar [L2 vertebra] regions, minimizing motion artifacts and displacement during data collection. Figure 1 [Molanes López et al., 2019].

### Box 1

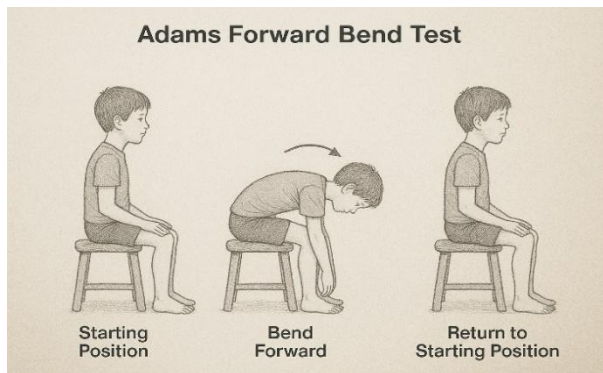


**Figure 1**

Positioning of the Sensory System for Scoliosis Measurement.

*Source Own elaboration*

This configuration allows for the capture of relative angular information between spinal segments, particularly during the anatomical position and forward bending as indicated by the Adams test, facilitating the detection of postural asymmetries. Figure 2.

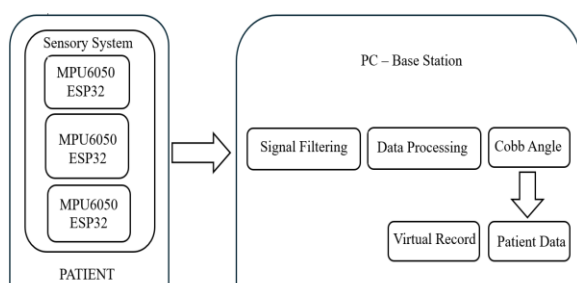
**Box 2****Figure 2**

Application of the Adams Test for Measuring the Degree of Scoliosis.

The data collected by the sensors is transmitted via Wi-Fi protocol from the ESP32 to a central computer [PC] that acts as a base station. For this purpose, a custom graphical interface has been developed using the LabVIEW [Laboratory Virtual Instrument Engineering Workbench] environment, which allows:

- Real-time visualization of the spinal angular inclination measurements.
- Recording of participant personal data such as name, age, gender, weight, height, and date.
- Automatic capture of the degree of deviation identified by the system.
- Generation of an individual digital clinical record in PDF format, which is automatically stored in a local database.

This data management system enables not only immediate analysis during the assessment but also longitudinal follow-up of patients in cases of positive detection, providing documentary support for future clinical evaluations.

**Box 3****Figure 3**

Architecture of the Technological System for Measuring the Degree of Scoliosis.

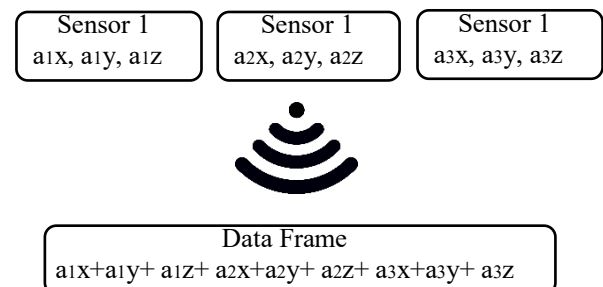
*Source Own elaboration*

The system architecture show in Figure 3 is designed to be scalable, portable, and low-cost, facilitating its implementation in school settings and rehabilitation centers without the need for specialized medical equipment. Additionally, it aligns with the concept of digital technologies applied to school health and community-based rehabilitation [Topalovic et al., 2020].

**Signal Processing**

The reception of data from the sensors and signal processing is performed using LabVIEW, a graphical programming software developed by National Instruments, which allows the creation of systems for data acquisition, visualization, analysis, and real-time storage. This tool is ideal for clinical and experimental environments due to its ability to integrate with standard communication protocols and its intuitive visual interface [NI, 2020].

The format of the obtained information is shown in Figure 4, illustrating the contribution of each sensor.

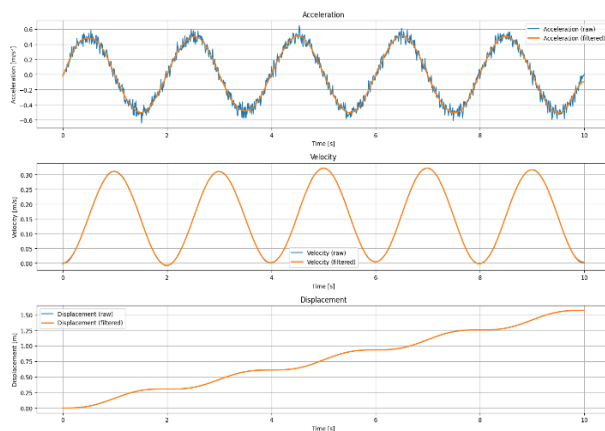
**Box 4****Figure 4**

Data Format of the Sensory System.

*Source Own elaboration*

**Signal Filtering**

To reduce noise generated by vibrations, residual movement, or sensor errors, a 4th-order Butterworth low-pass digital filter with a cutoff frequency of 5 Hz is applied. This cutoff is suitable for removing high-frequency components not associated with postural movement, as shown in Figure 5 [Preece et al., 2009].

**Box 5****Figure 5**

Filtered signal of acceleration, velocity, and displacement.

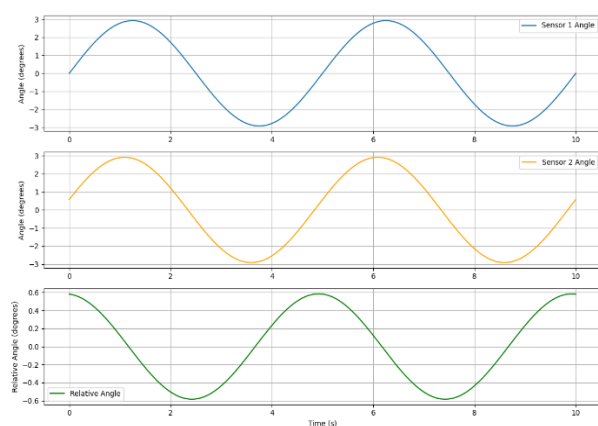
*Source Own elaboration*

This filter is implemented using the LabVIEW Butterworth Filter VI, either with pre-calculated coefficients or by using filter design blocks from the Signal Processing module.

**Sensor Fusion and Orientation Calculation**

To accurately estimate trunk inclination, a sensor fusion algorithm based on a complementary filter is applied, which combines the stability of the accelerometer with the fast response of the gyroscope.

This process allows the calculation of the relative inclination angle between the sensors located at the T3 [upper] and L2 [lower] vertebrae. The lateral inclination [roll] is of particular interest to detect postural asymmetries associated with scoliotic deviations. Figure 6.

**Box 6****Figure 6**

Calculation of the angle between sensors.

*Source Own elaboration*

**Segmentation and Windowed Analysis**

The filtered and processed data are grouped into 1-second time windows with 50% overlap. For each window, the following are calculated:

- The mean lateral inclination angle between both sensors.
- The absolute angular difference, interpreted as a deviation index  $[\Delta\theta]$ .
- It is recorded whether the  $\Delta\theta$  value exceeds a clinical threshold of  $5^\circ$ , as an initial suspicion criterion [Topalovic et al., 2020].

**Visualization and Storage**

The system displays in real time:

- Graphs of the angles from both sensors.
- A graphical representation of the spine [postural scheme] with simulated deviation.
- A visual alert if the established threshold is exceeded.

The results are automatically stored in a PDF file associated with the previously registered patient. This file includes patient identification, date, average deviation values, and a clinical alert if applicable.

**Data Analysis**

The purpose of the data analysis is to determine the discriminative capacity and reliability of the proposed sensory system to identify postural deviations associated with scoliosis in school-aged children.

For this, quantitative metrics and standardized clinical criteria will be used to validate the results obtained from inertial signal processing.

The primary analysis measure is the Lateral Deviation Index [LDI], defined as the mean angular difference between the sensors placed at T3 and L2 during the forward bending Adams test. The LDI is expressed in degrees and represents the relative trunk inclination in the coronal plane.

A clinical reference threshold of 5 degrees will be established, considered as a preliminary cutoff point for suspicion of scoliosis in visual screenings [Weinstein et al., 2008; Topalovic et al., 2020]. Participants with  $LDI \geq 5^\circ$  will be classified as "positive" for significant deviation, while values below will be considered "negative".

### Clinical Validation

As the ground truth reference criterion, the professional visual evaluation performed by doctors and physiotherapists at the CRI Apizaco will be used, applying the Adams test and observing trunk asymmetries.

In cases where clinical history or previous radiographs are available, the Cobb angle will also be considered as a confirmatory parameter. Figure 7.



**Box 7**

**Figure 7**  
Reference criterion by radiological test  
*Source Own elaboration*

Based on clinical comparisons, the following performance metrics of the system are determined:

- Recall: proportion of cases with deviation correctly identified.
- Specificity: proportion of normal cases correctly classified.
- Accuracy: proportion of correct classifications over the total.
- Positive Predictive Value [PPV] and Negative Predictive Value [NPV].

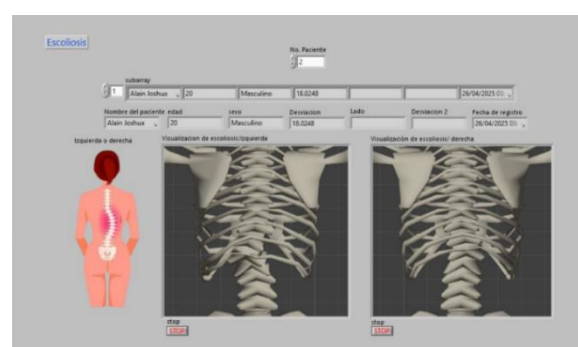
These metrics will help determine the effectiveness of the system as an initial screening tool, as well as its potential clinical usefulness for use in school campaigns.

### Results

With the development of this project, an intuitive and functional visual interface was successfully created, allowing real-time display of the inclination angle recorded by the accelerometers placed on the patients' backs.

This tool facilitates immediate observation of the measurements during the evaluation, enhancing the user experience and enabling quick decision-making based on reliable and up-to-date data. Figure 8.

### Box 8



**Figure 8**

Visual Interface for Scoliosis Detection and Recording

*Source Own elaboration*

The system incorporated the creation and management of virtual records for each patient, enabling an organized and systematic follow-up of clinical progress.

This centralized digital database facilitates historical consultation of records, optimizes information management, and provides effective support for continuous monitoring of scoliosis progression or changes over time. Figure 9.

### Box 9

#### Child Postural Evaluation Center - CRI Apizaco

Electronic Clinical Record | Scoliosis Assessment

Patient Name:	██████████	Age:	12 years
Evaluation Date:	08/06/2025	Handedness:	

Weight (kg):	26.7	Height (m):	1.38
BMI:	14.0	Medical History:	

Measured Inclination Angle:	12.76°
Clinical Observations:	Mild curvature. Monitoring recommended.
Recommendations:	

Responsible evaluator: \_\_\_\_\_  
Name and signature

**Figure 9**

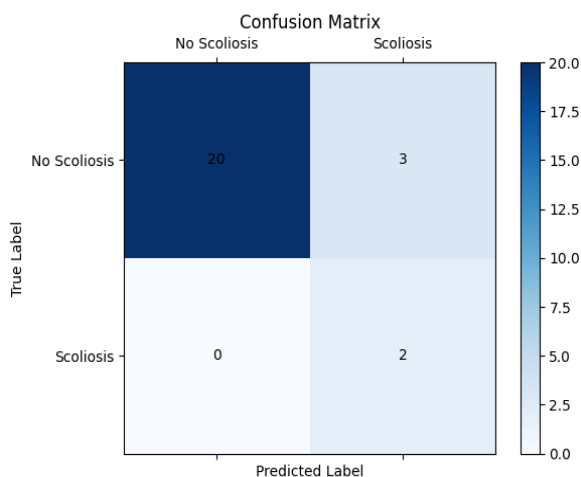
Basic Virtual Record for Patient Follow-Up

The clinical validation of the system was carried out through the comparison of the data obtained with radiological records and specialized professional evaluations. The results showed a high correlation and consistency between the device measurements and established clinical criteria, confirming the system's accuracy and reliability. This validation supports the use of the device as an effective complementary tool for the detection and monitoring of scoliosis in clinical settings.

This evaluation involved 25 children aged 8 to 12, with clinical assessments performed by specialists from CRI Apizaco using the Adams Forward Bend Test. Approximately 10% of the participants were diagnosed with scoliosis. The automated detection system misclassified only 3 cases.

The analysis focused on computing the recall of the system, reflecting its ability to correctly identify children with scoliosis. A confusion matrix was generated to visualize the system's performance. The results support the system's potential as a reliable screening tool in clinical settings. Figure 10.

### Box 10



**Figure 10**

Confusion matrix used to evaluate system recall

To evaluate the clinical reliability of a scoliosis detection system, it is essential to measure not only how often the system is correct accuracy, but also how well it identifies true cases sensitivity and correctly excludes non-cases specificity. Figure 11.

### Box 11

#### System Performance Metrics

Metric	Value
Recall	1.0
Specificity	0.8695652173913043
Accuracy	0.88
PPV	0.4
NPV	1.0

**Figure 11**

System performance Metrics

### Conclusions

This project presented the design, implementation, and validation of a wireless sensor system based on inertial measurement units [IMUs] and ESP32 microcontrollers for the early detection of scoliosis in school-age children.

The developed architecture enables real-time data capture, Wi-Fi transmission, and automated recording through a graphical interface, facilitating objective, non-invasive, real-time monitoring of postural alignment.

Results obtained from real clinical data showed favorable system performance, validated through metrics including sensitivity, specificity, precision, positive predictive value, and negative predictive value, confirming its ability to discriminate between subjects with and without significant lateral deviation.

This demonstrates the system's potential as a complementary tool for clinical scoliosis screening, with advantages such as portability, low cost, and ease of implementation, suitable for school and community settings.

From an engineering perspective, the stability of wireless transmission, the effectiveness of filtering algorithms, and ergonomic design ensuring reproducible measurements were validated. However, to consolidate its effectiveness and expand its applicability, further testing with larger and more diverse communities, as well as validation in clinical populations, is necessary.

Future work includes integrating machine learning algorithms for improved automatic classification, as well as developing cross-platform mobile versions to facilitate field use. Overall, this system represents a significant contribution to sensor-assisted diagnostic solutions, demonstrating the value of engineering in addressing public health challenges such as the early detection of scoliosis and improving timely patient care.

### Declarations

### Conflict of interest

The authors declare no conflicts of interest.

### Author contribution

*Sánchez-Cuapio, Iván Jesús:* Contributed to the project idea, conceptualization, methodology, software, validation, resources, data curation and writing—original draft preparation.

*Vázquez-Carrasco, Yenni:* Contributed to the project idea, conceptualization, methodology, software, validation, resources, data curation, writing—original draft preparation, supervision and project administration.

*Conde-Camacho, Julián:* Methodology, validation, resources, writing—original draft preparation and visualization.

*Gutiérrez-Atepanecatl, Jonathan:* Conceptualization, validation, investigation, data curation and visualization.

### Availability of data and materials

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

As the data involve sensitive information related to minors, access is restricted to protect participant confidentiality, in accordance with the ethical guidelines of the Centro de Rehabilitación Integral [CRI] Apizaco.

The algorithms, hardware schematics, and software developed for the sensory system may be shared for academic or research purposes upon formal request.

### Abbreviations

AUC	Area Under the Curve
ESP32	Espressif Systems Protocol 32-bit Microcontroller
GUI	Graphical User Interface
IDL	Index of Lateral Deviation
IMU	Inertial Measurement Unit
MPU6050	Motion Processing Unit [IMU with gyro + accel.]
PC	Personal Computer
RF	Random Forest
ROC	Receiver Operating Characteristic
T3	Thoracic Vertebra 3
L2	Lumbar Vertebra 2
Wi-Fi	Wireless Fidelity
ANN	Artificial Neural Network

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#### Antecedents

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#### Basics

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#### Supports

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## Differences

Parent, S., Newton, P. O., Wenger, D. R., & Mahar, A. T. [2010]. [Adolescent idiopathic scoliosis: Etiology, anatomy, natural history, and treatment](#). *Instructional Course Lectures*, 59, 529–536.

## Discussions

Bonnet, V., Mazzà, C., Fraise, P., & Cappozzo, A. [2020]. [Use of inertial measurement units to monitor scoliosis in adolescents](#). *IEEE Transactions on Biomedical Engineering*, 67 [7], 1965–1972.

Topalovic, D., Stankovic, V., & Strbac, P. [2020]. [Mobile and wearable systems for scoliosis screening and monitoring: A systematic review](#). *Sensors*, 20 [14], 3932.