



A SYSTEM DESIGN FOR SCOLIOSIS DETECTION

Cansel Ficici

Elektical and Electronics
Enginnering, Ankara University,
ogretmenoglu@ankara.edu.tr

Kutay Yıldırım

Elektical and Electronics
Enginnering, Ankara University,
kutayildirim@gmail.com

İsmail Can Yılmaz

Elektical and Electronics
Enginnering, Ankara University,
can0786881@gmail.com

Arif Koçoğlu

Biomedical Device Technologies
Department, Baskent University,
arif@baskent.edu.tr

Onur Koçak

Computer & Biomedical
Engineering, Baskent University,
okocak@baskent.edu.tr

Ziya Telatar

Biomedical Engineering, Baskent
University,
ztelatar@baskent.edu.tr

Abstract— Scoliosis, characterized by lateral curvature of the spine, can lead to significant health complications if not detected early. Conventional diagnostic methods, such as radiographic imaging, require exposure to ionizing radiation and may not be accessible in resource-limited settings. This study presents a non-invasive and portable scoliosis screening system that integrates ADXL345 triaxial accelerometers into a wearable corset. The system performs three established physical assessments—Shoulder Level Test, Adam's Forward Bend Test, and Spinal Angulation Test—by collecting posture data and estimating spinal curvature angles. Sensor outputs were processed using exponential moving average filtering and smoothing techniques to minimize noise. Estimated Cobb angles and other posture metrics are visualized through a user interface developed in C# with the .NET framework. Validation against measurements obtained with a conventional scoliometer demonstrated good agreement, demonstrating the system's potential utility as a radiation-free alternative for scoliosis screening.

Keywords— scoliosis; cobb angle; accelerometer; posture analysis; non-invasive screening

I. INTRODUCTION

Scoliosis is defined as a lateral curvature of the spine greater than 10°, as measured on radiographs [1]. The condition is characterized by a sideways curvature and vertebral rotation, affecting approximately 2% of the global population [2]. The risk is significantly higher in individuals with a family history of scoliosis, with estimates of up to 20%, suggesting a hereditary component [3]. Clinical manifestations can include chronic back pain, shoulder and lumbar instability, and in severe cases, reduced thoracic volume that impairs pulmonary function [4].

Treatment strategies vary depending on curve severity, progression potential, and patient age. Observation is often sufficient in mild cases, bracing is typically recommended for moderate curvatures, and surgery may be required in progressive or severe deformities.

Current diagnostic systems, however, present notable shortcomings. Standard radiographic methods expose patients to ionizing radiation, which is a concern in children and adolescents who require frequent follow-ups. Moreover, radiographs are costly and not always available in rural or resource-limited settings. These limitations highlight the urgent need for alternative diagnostic approaches that are safe, cost-effective, and widely accessible.

The types of scoliosis can be classified as congenital, neuromuscular, or idiopathic [5]. The most common form, idiopathic scoliosis, has no specific cause identified to date [5]. The International Society on Scoliosis Orthopedic and Rehabilitation Treatment (SOSORT) has proposed three main classification types for idiopathic scoliosis: chronological, angular, and topographic [5].

Idiopathic scoliosis (IS) can also be classified according to age of onset: infantile (birth to two years), juvenile (three to nine years), and adolescent (10 years and older) [6]. Adolescent idiopathic scoliosis (AIS) is the most common pediatric spinal deformity [7].

In one study conducted in India, involving 119 patients diagnosed with scoliosis between December 2006 and December 2012, thoracolumbar curvature was the most common type, observed in 43.6% of cases [8]. Bunnell proposed a simple handheld device called a scoliometer, which is frequently used to measure and assess the angle of trunk rotation during the Adams Forward Bend Test and for screening purposes [9].

For examination with the scoliometer, the patient is asked to bend forward until a curve appears in the thoracic region. The scoliometer is then placed and moved along the spine to measure the highest point of the thoracic curve. The patient is subsequently asked to bend forward until the lower back (lumbar) curve is visible, and again the scoliometer is placed along the spine to measure the highest point of the curve [10].

Bunnell defined the following screening cut-off criteria [9] :

$0^\circ \leq \text{ATR} \leq 3^\circ$ Normal

$4^\circ \leq \text{ATR} \leq 6^\circ$ the trunk rotation is intermediate

$7^\circ \leq \text{ATR}$ high possibility of having scoliosis

The scoliometer-measured ATR has proven to be a reproducible and repeatable examination. In this test, an ATR of 7° or higher has shown a sensitivity of 83.3% and specificity of 86.8% [11].

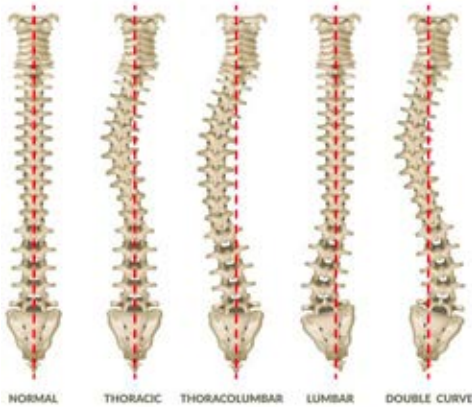


Figure 1. Types of Scoliosis of Spine [12]

The severity of spinal curvature can be determined by measuring the Cobb angle, which is defined as the angle between two perpendicular lines traced from the upper edge of the uppermost involved vertebra and the lower edge of the lowermost involved vertebra.

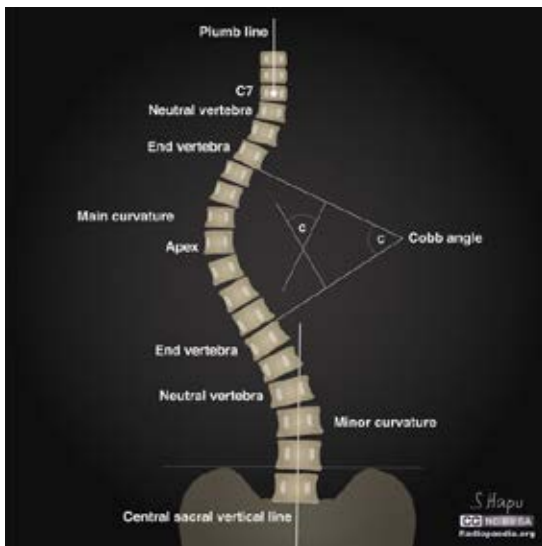


Figure 2. Illustration of the Cobb angle used for scoliosis assessment. [13]

The aim of this project is to design a sensor-based system to support the early diagnosis of scoliosis. The system focuses on obtaining accurate and stable posture data to assess spinal alignment and angulation. Three specific tests were performed within the scope of this project: Shoulder Level Test, Adam's Forward Bend Test, and Spinal Angulation Test. In addition to sensor-based data collection, a user-friendly interface was

developed using C# and the .NET framework to effectively visualize real-time data. The interface displays the results of scoliosis diagnostic tests in tabular form and provides visual feedback by coloring the back, spine, and shoulder areas on a human figure according to the measurement results.

Consequently, this project aims to provide a practical, portable, and cost-effective alternative to existing scoliosis screening methods.

II. MATERIALS AND METHODS

3.1 Materials

The system developed in this study to support the early diagnosis of scoliosis consists of both hardware and software components. For the hardware, an Arduino Uno microcontroller board was used to collect and process sensor data. A total of nine ADXL345 triaxial accelerometers were used for posture analysis. These sensors were integrated into a corset corresponding to specific anatomical points on the patient's back. The connections between the Arduino board and the sensors were established using jumper cables. Plastic clamps were used to secure the cable connections and partially prevent tangling. The wearable corset ensured accurate positioning of the sensors while minimizing measurement errors due to movement.

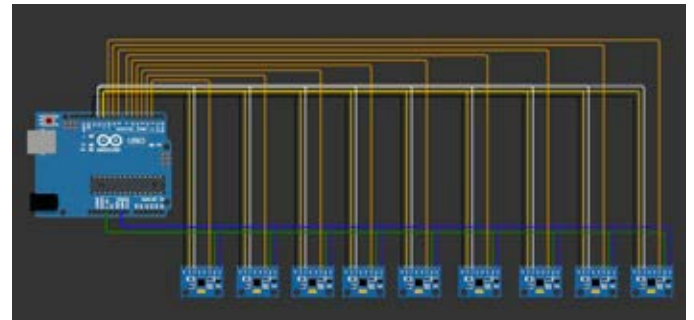


Figure 3. Connection of Arduino and ADXL345

For the software development environment, Microsoft Visual Studio was used for the development of the system interface. For programming and uploading the microcontroller code, the Arduino IDE was employed. Interface development and data processing were performed using the C# programming language and the .NET Framework.

The developed interface was designed to effectively visualize scoliosis diagnostic measurements and provide a user-friendly experience. The results of the Shoulder Level Height Test, Adam's Forward Bend Test, and Spinal Angulation Test are presented in tabular format on the interface. The Cobb angle is calculated from sensor data and displayed on the interface. Dynamic color coding is applied to a representative human figure based on the measurement results.

For Cobb angle measurement, $0-10^\circ$ is displayed in green, $10-25^\circ$ in yellow, $25-45^\circ$ in orange, and values above 45° in red. For the Shoulder Level Test, the higher shoulder side is displayed in blue. The developed interface is shown in Figure 4.

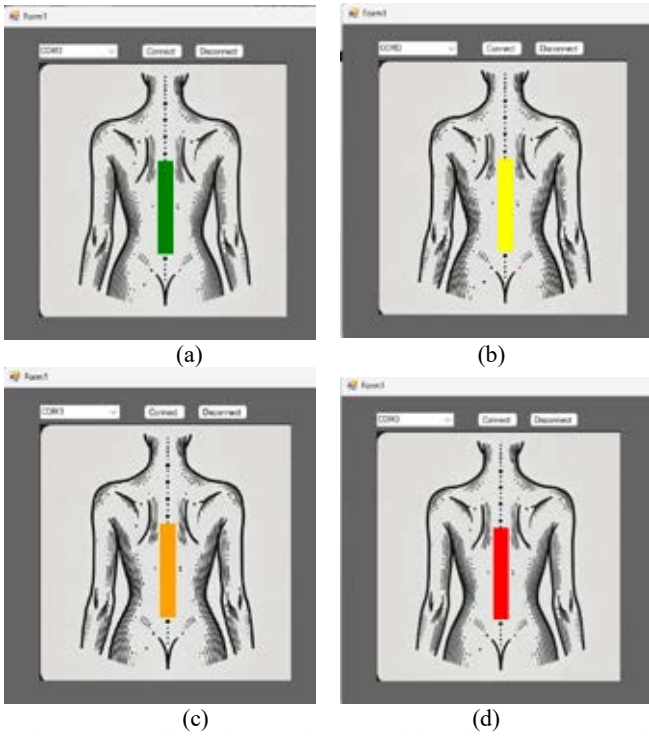


Figure 4 (a) : Cobb Angle < 10 , (b): 10 < Cobb Angle < 25, (c): 25 < Cobb Angle < 45 , (d): 45 < Cobb Angle

3.2 Data Collection and Processing

The Cobb angle was estimated from angular data obtained from sensors instead of conventional radiographic images. Specifically, differences in inclination between sensors placed on the upper and lower parts of the spine were analysed to derive values representing the Cobb angle. This approach integrates traditional measurement principles with sensor technology.

In addition to the Cobb angle, two other clinical tests were implemented using sensor data. The Shoulder Level Test was performed by calculating the difference in orientation between sensors placed on the left and right scapulae. The angular discrepancy in the sagittal plane reflects shoulder level asymmetry, a common indicator of scoliosis.

The Cobb angle, widely used in scoliosis assessment, was estimated from accelerometer data using the following formula:

$$\text{Cobb Angle} = (\arctan(x_2/y_2) - \arctan(x_1/y_1)) + (\arctan(x_4/y_4) - \arctan(x_5/y_5))$$

Here, (x_i, y_i) represent the projections of the orientation vector from different sensor positions along the X and Y axes. The angle differences are combined to reflect the spinal curvature, corresponding to the Cobb angle.

In this test, two sensors are placed over the left and right scapulae to measure their respective orientation angles in the sagittal (YZ) plane. Each angle is calculated using the

arctangent of the ratio between the vertical (Y) and dorsal (Z) acceleration components

$$\theta = \arctan\left(\frac{y}{z}\right)$$

The difference between these two angles provides an objective measure of scapular asymmetry:

$$\Delta\theta = \arctan(y_6/z_6) - \arctan(y_7/z_7)$$

A greater absolute value of $\Delta\theta$ indicates a higher degree of scapular imbalance, which may correspond to underlying spinal deformity such as scoliosis. Conversely, when $\Delta\theta$ approaches zero, it suggests a more symmetric and upright posture. This method enables a quantifiable, sensor-based assessment of scapular alignment, complementing clinical observations and supporting early detection of postural deviations.

Additionally, the Y-axis values from two upper sensors (y_8 and y_9) are compared directly to detect possible asymmetry or displacement. This comparison provides qualitative data on alignment differences, which may support other scoliosis indicators.

3.3 System Testing and Comparative Measurements

To evaluate the accuracy and reliability of the developed system, practical tests were conducted on multiple participants. First, measurements were obtained from each of the 19 participants using the sensor-based system, and the posture data and estimated Cobb angles were recorded in the system interface. Manual scoliosis measurements were then performed on the same participants using a scoliometer, a method widely used in clinical applications. Finally, the data obtained from both methods were compared, and the agreement between the system's measurement results and the traditional method was evaluated.

This experimental study was carried out with three voluntary participants. No interventions posing electrical safety risks were performed on the subjects, and they were duly informed regarding this issue. Written informed consent was obtained from all participants. Ethical approval will be secured for the forthcoming clinical validation phase of the study.

III. RESULTS AND FINDINGS

This section presents the findings from scoliosis detection tests conducted with the developed sensor-based system on multiple individuals under standardized conditions to evaluate its accuracy, functionality, and consistency. Three different physical test scenarios—Shoulder Level Test, Adam's Forward Bend Test, and Spinal Angulation Test—were applied to each participant, and the corresponding sensor data were collected using a custom-designed corset equipped with ADXL345 accelerometers.

For each test, posture deviations and spinal angulations were analyzed, and the estimated Cobb angles were calculated from the sensor data. The results were compared with manual

measurements obtained using a scoliometer to assess the system's measurement reliability. The summarized findings are presented in the tables below, illustrating the performance of the proposed method across different participants and test types. In addition, Figure 5 shows the final version of the system design. As shown in Figure 5, the system was worn by the participants during measurement acquisition.

TABLE I. RESULTS OF SPINAL ANGULATION TEST

Person	Cobb Angle	Scoliometer
Person-1	6.80	3
Person-2	4.79	2
Person-3	6.61	2

TABLE II. RESULTS OF FORWARD BENDING TEST

Person	Cobb Angle
Person-1	4.14
Person-2	6.94
Person-3	10.49

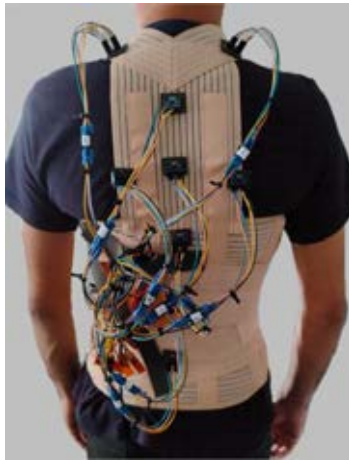


Figure 5. The System Final Design

In the bending test performed in thin individuals, healthier data were obtained compared to the tests performed in overweight individuals.

In a study of 300 healthy adults aged 18–85, the Scapular Balance Angle (SBA) averaged $2.505^\circ \pm 2.340^\circ$. Values above 7.185° were defined as abnormal. Since SBA quantifies the angle between the inferior angles of the scapula and the spine, it corresponds directly to shoulder blade asymmetry measured in our system [14].

III. CONCLUSION

In this study, a prototype scoliosis assessment system based on accelerometer sensors was designed and implemented. The system, comprising both hardware and software components, employs triaxial accelerometers positioned at specific anatomical points on the back to estimate the Cobb angle and evaluate posture. A custom-developed interface was used to present sensor data and provide visual feedback.

Tests conducted on multiple participants allowed comparison between the sensor-based results and those obtained using a standard scoliometer. The findings demonstrate that the system

can produce measurements comparable to conventional methods. This approach may offer a practical, radiation-free alternative for scoliosis screening in settings where radiographic imaging is unavailable or not preferred.

Future improvements may focus on reducing the hardware size and expanding the diversity of the participant sample to further validate and enhance system performance. By ensuring compliance with industrial usability standards, the developed system is envisioned as a practical pre-diagnostic tool that may complement the radiological imaging techniques currently regarded as the gold standard for scoliosis diagnosis. In the present study, subjects remained stationary during the experimental data acquisition process, and all potential sources of electronic noise were eliminated. Future work will focus on trials conducted outside the laboratory environment to further enhance and validate the performance of the system.

REFERENCES

- [1] V. Giannoglou and E. Stylianidis, "Review of advances in Cobb angle calculation and image-based modelling techniques for spinal deformities," *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. III-5, pp. 129–136, 2016, doi: 10.5194/isprsannals-III-5-129-2016.
- [2] S. Adibatti, K. R. Sudhindra, and J. M. Shivaram, "Design and performance analysis of Cobb angle measurement from X-ray images," *Bulletin of Electrical Engineering and Informatics*, vol. 12, no. 6, pp. 3530–3540, 2023.
- [3] H.-H. Ma, C.-L. Tai, L.-H. Chen, C.-C. Niu, W.-J. Chen, and P.-L. Lai, "Application of two-parameter scoliometer values for predicting scoliotic Cobb angle," *Biomedical Engineering Online*, vol. 16, no. 1, p. 136, Dec. 2017, doi: 10.1186/s12938-017-0427-7.
- [4] C. Chen, *et al.*, "Automating Cobb angle measurement for adolescent idiopathic scoliosis using instance segmentation," 2022. [Online]. Available: <https://arxiv.org/pdf/2211.14122>. Accessed: Aug. 10, 2025.
- [5] I. Karpel, A. Ziębiński, M. Kluszczyński, and D. Feige, "A survey of methods and technologies used for diagnosis of scoliosis," *Sensors*, vol. 21, no. 24, p. 8410, 2021, doi: 10.3390/s21248410.
- [6] F. G. Ü. Demir, "Skolyoz sınıflaması," *JAMER*, vol. 8, no. 1, pp. 1–13, 2023.
- [7] Y. Ishikawa, T. Kokabu, K. Yamada, Y. Abe, H. Tachi, H. Suzuki, T. Ohnishi, T. Endo, D. Ukeba, K. Ura, M. Takahata, N. Iwasaki, and H. Sudo, "Prediction of Cobb angle using deep learning algorithm with three-dimensional depth sensor considering the influence of garment in idiopathic scoliosis," *Journal of Clinical Medicine*, vol. 12, no. 2, p. 499, 2023.
- [8] N. Gupta, R. S. B. G., and A. Shetty, "Vertebral and intraspinal anomalies in Indian population with congenital scoliosis: A study of 119 consecutive patients," *Asian Spine Journal*, vol. 10, no. 2, pp. 276–281, Apr. 2016, doi: 10.4184/asj.2016.10.2.276.
- [9] Bunnell, W. P. (1984). An objective criterion for scoliosis screening. *JBJS*, 66(9), 1381–1387.
- [10] T. Kuru Çolak, "Adolesan idiyatik skolyozda Schroth yöntemine göre 3 boyutlu egzersizlerin etkinliği," M.S. thesis, Sağlık Bilimleri Enstitüsü, İstanbul Üniversitesi, İstanbul, Türkiye, 2020. [Online]. Available: <https://nek.istanbul.edu.tr/ekos/TEZ/49328.pdf>. Accessed: Aug. 10, 2025.
- [11] D. M. Coelho, G. H. Bonagamba, and A. S. Oliveira, "Scoliometer measurements of patients with idiopathic scoliosis," *Brazilian Journal of Physical Therapy*, vol. 17, no. 2, pp. 179–184, Mar.–Apr. 2013, doi: 10.1590/S1413-35552012005000081.
- [12] "Skolyoz (omurga eğriliği)," *Terapi Room*. [Online]. Available: <https://terapiroom.com/en/skolyoz-omurga-eigriligi/>. Accessed: Aug. 10, 2025.
- [13] "Cobb angle," *Radiopaedia*. [Online]. Available: <https://radiopaedia.org/articles/cobb-angle>. Accessed: Aug. 10, 2025.
- [14] J. Contreras, D. Gil, J. de Dios Errázuriz, P. Ruiz, C. Díaz, P. Águila, and F. Soza, "Valores de referencia del ángulo de balance escapular en población sana," *Revista Española de Cirugía Ortopédica y Traumatología*, vol. 58, no. 1, pp. 24–30, 2014, doi: 10.1016/j.recot.2013.09.009.