An Explainable Framework for Non-Invasive Scoliosis Screening Using Geometric Body Symmetry Analysis

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Abstract — Early identification of scoliosis is essential for preventing the progression of spinal deformities and enabling timely clinical intervention. However, conventional scoliosis assessment primarily relies on radiographic imaging, exposing patients to repeated ionizing radiation during routine follow-up. This paper presents an explainable framework for non-invasive scoliosis screening using conventional posterior body images. The proposed methodology integrates image preprocessing, geometric feature extraction, and the Explainable Scoliosis Risk Score (ESRS) to evaluate external body symmetry and classify subjects into three clinically meaningful categories: Scoliosis Not Present, Mild Scoliosis Risk, and Scoliosis Present. Unlike computationally intensive learning-based approaches, the proposed framework employs explainable geometric analysis to provide transparent and clinically interpretable screening outcomes without requiring deep neural network training or manually annotated datasets. Experimental evaluation on 203 posterior body images demonstrates the effectiveness of the proposed framework in distinguishing different levels of postural asymmetry while maintaining computational efficiency. The generated explainable clinical visualization further improves result interpretability by presenting the extracted anatomical features together with the corresponding screening outcome. Owing to its radiation-free, cost-effective, and explainable design, the proposed framework is well suited for preliminary scoliosis screening in school-based programs, primary healthcare centers, and other resource-constrained clinical environments.

Keywords — *Scoliosis Screening, Explainable Computer Vision, Non-Invasive Assessment, Posterior Body Images, Body Symmetry Index (BSI), Explainable Scoliosis Risk Score (ESRS), Geometric Feature Extraction, Clinical Decision Support.*

I. Introduction

This Early detection of scoliosis is essential for preventing the progression of spinal deformities and improving long-term clinical outcomes. Scoliosis is a three-dimensional spinal disorder characterized by an abnormal lateral curvature of the spine accompanied by vertebral rotation. If left untreated, it may lead to chronic pain, postural imbalance, impaired respiratory function, and reduced quality of life. The Cobb angle measured from spinal radiographs remains the clinical standard for diagnosis and monitoring; however, repeated exposure to ionizing radiation is undesirable, particularly for adolescents requiring regular follow-up examinations [1], [2], [13], [16], [17].

To address this limitation, significant research has focused on non-invasive scoliosis screening using computer vision and optical imaging techniques. Surface topography, raster stereography, body posture analysis, and image-based assessment have demonstrated that external trunk morphology and body symmetry can provide reliable indicators for early scoliosis detection without relying on radiographic imaging [2], [4], [6]–[10], [15]. Although recent learning-based approaches have shown promising performance, many require specialized imaging systems, computationally intensive deep learning models, or large annotated datasets, limiting their practical deployment in resource-constrained healthcare environments [3]–[5].

To overcome these challenges, this paper proposes an Explainable Computer Vision Framework for automated scoliosis screening using conventional posterior body images through geometric body symmetry analysis. Unlike conventional learning-based methods, the proposed framework employs explainable geometric image processing to perform body segmentation, contour extraction, estimated body centerline computation, adaptive anatomical landmark localization, Body Symmetry Index (BSI) estimation, and Explainable Scoliosis Risk Score (ESRS) computation. By combining transparent geometric measurements with an explainable clinical visualization, the proposed framework provides interpretable scoliosis screening without requiring deep neural network training or manually annotated datasets. Owing to its computational efficiency, radiation-free operation, and low implementation cost, the framework is well suited for school-based screening programs, primary healthcare centers, and other resource-constrained clinical environments.

The proposed framework presents a fully automated and explainable approach for non-invasive scoliosis screening using conventional posterior body images. By integrating body segmentation, geometric feature extraction, Body Symmetry Index (BSI) estimation, and Explainable Scoliosis Risk Score (ESRS) computation, the framework provides transparent and clinically interpretable screening outcomes without requiring deep learning models or specialized imaging systems. Its computational efficiency and low implementation cost make it suitable for large-scale community screening, school-based health programs, and primary healthcare applications.

II. Related Work

A. Non-Invasive Scoliosis Screening

Radiographic imaging and Cobb angle measurement remain the clinical standard for scoliosis diagnosis and follow-up. However, repeated exposure to ionizing radiation is undesirable, particularly for adolescents who require continuous monitoring [1], [2], [13]. To address this limitation, researchers have explored non-invasive techniques such as surface topography, raster stereography, optical imaging, and posture analysis for radiation-free scoliosis assessment [6], [7]. Recent advances in digital imaging and smartphone-based screening have further improved the accessibility and affordability of scoliosis screening using conventional body images [4], [8], [9]. Despite these developments, many existing methods still depend on specialized equipment or controlled imaging conditions, limiting their practical use in large-scale screening programs.

B. Computer Vision and Geometric Body Analysis

Computer vision has become an effective tool for automated posture assessment by enabling body contour extraction, anatomical landmark localization, and geometric feature analysis [10], [14]. Recent deep learning approaches have reported promising performance in scoliosis screening using natural body images [3]–[5]. However, these methods generally require large annotated datasets and often operate as black-box models with limited interpretability. In contrast, geometric body symmetry analysis provides transparent measurements, including centerline deviation, shoulder asymmetry, waist asymmetry, and body symmetry, allowing clinicians to better understand the basis of the screening outcome [11], [12].

C. Research Gap

Although previous studies have demonstrated the potential of non-invasive scoliosis screening, many existing approaches depend on specialized imaging systems, computationally intensive deep learning models, or prediction mechanisms with limited interpretability [5], [11], [12]. These limitations increase implementation cost, reduce transparency, and restrict deployment in large-scale screening and resource-constrained healthcare environments. Therefore, there is a need for an efficient and explainable framework that can perform reliable scoliosis screening using conventional posterior body images without requiring complex learning-based models. To address this gap, the proposed framework combines explainable geometric image processing, body symmetry analysis, and Explainable Scoliosis Risk Score (ESRS) estimation to provide transparent, computationally efficient, and cost-effective scoliosis screening suitable for community-based and primary healthcare applications.

III. Proposed Methodology

A. Overall Framework

The proposed framework presents a fully automated and explainable methodology for non-invasive scoliosis screening using conventional posterior body images. Unlike conventional learning-based approaches that require large annotated datasets and computationally intensive model training, the proposed methodology employs geometric image processing and body symmetry analysis to evaluate external postural characteristics associated with scoliosis. By extracting interpretable geometric features instead of relying on black-box prediction models, the framework provides transparent and clinically meaningful screening outcomes [2], [6], [10].

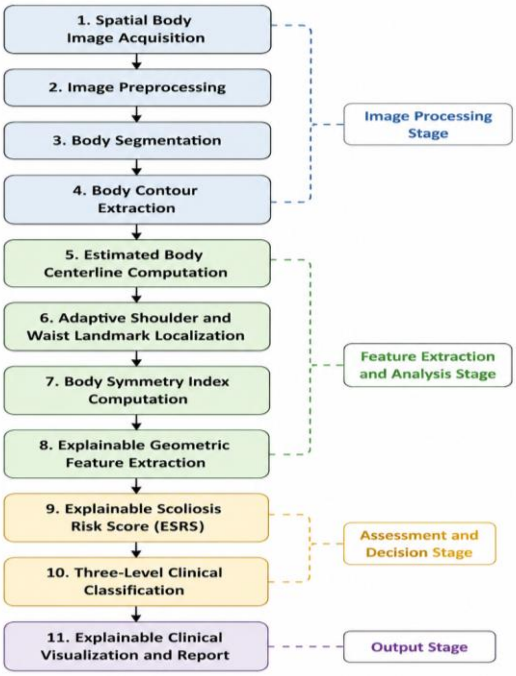

Fig. 1. Overall workflow of the proposed explainable framework for automated scoliosis screening using conventional posterior body images through geometric body symmetry analysis.

As illustrated in Fig. 1, the proposed framework consists of nine sequential stages: (1) posterior body image acquisition, (2) image preprocessing, (3) body segmentation, (4) body contour extraction, (5) estimated body centerline computation, (6) shoulder and waist landmark localization, (7) geometric feature extraction, (8) Explainable Scoliosis Risk Score (ESRS) computation, and (9) three-level scoliosis classification with explainable clinical visualization. Each stage progressively extracts geometric information required for objective and interpretable scoliosis screening.

Initially, a posterior body image is acquired under standardized imaging conditions and pre-processed to obtain a clean binary body mask. The segmented body contour is then extracted to estimate the body centerline and localize the shoulder and waist landmarks. These geometric measurements are subsequently used to compute the Body Symmetry Index (BSI) and the Explainable Scoliosis Risk Score (ESRS). Based on the computed ESRS, each subject is classified into one of three clinically meaningful categories: Scoliosis Not Present, Mild Scoliosis Risk, or Scoliosis Present. Finally, the framework generates an explainable visualization that highlights the extracted anatomical features together with their corresponding quantitative measurements, enabling transparent interpretation of the screening results.

B. Image Acquisition and Preprocessing

The proposed framework utilizes conventional posterior body images acquired under standardized imaging conditions to ensure consistent posture analysis. During image acquisition, subjects stand in an upright position with both arms naturally relaxed alongside the body while facing away from the camera. Images are captured against a plain background under uniform illumination to minimize background interference and ensure consistent image quality.

Each acquired image is resized to a fixed resolution and converted from the RGB colour space to the Hue–Saturation–Value (HSV) colour space. Compared with RGB, the HSV representation separates colour information from illumination, enabling more reliable body extraction under varying lighting conditions [6], [14]. HSV-based thresholding is then applied to isolate the body region and generate a binary body mask, defined as

$$M(x,y) = \begin{cases} 1, & \text{if } I_{HSV}(x,y) \in T, \\ 0, & \text{otherwise}, \end{cases} \quad (1)$$

where $I_{HSV}(x, y)$ denotes the HSV image, T represents the predefined threshold range, and $M(x, y)$ is the generated binary body mask.

To improve segmentation quality, morphological opening and closing operations are performed to remove small artifacts, fill discontinuities, and smooth the body boundary. The refined binary body mask is subsequently used for body segmentation, contour extraction, and geometric feature analysis [14]. Fig. 2 illustrates the preprocessing pipeline and the corresponding binary body mask generated by the proposed framework.

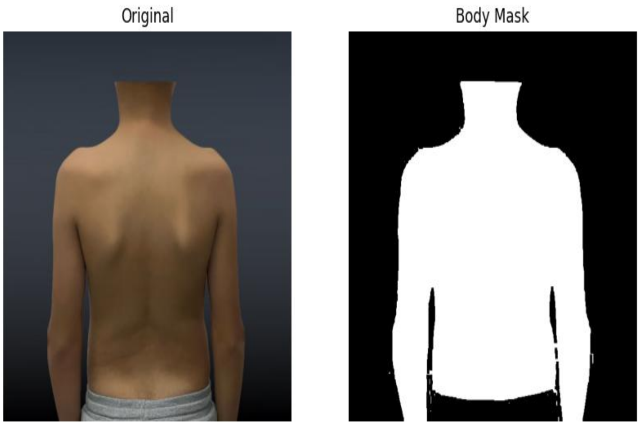

Fig. 2. Original posterior body image and the corresponding binary body mask generated through HSV-based preprocessing, thresholding, and morphological refinement.

C. Geometric Feature Extraction

Following image preprocessing, the refined binary body mask is used to extract geometric features that characterize external body symmetry associated with scoliosis. The body region is segmented from the background, and its external contour is extracted to preserve the anatomical body profile required for subsequent geometric analysis [14]. The extracted contour provides a geometric representation of the body shape and forms the basis for estimating body alignment and anatomical landmarks. Fig. 3 illustrates the segmented body contour.

The extracted body contour is represented as

$$C = \{(x_i, y_i)\}_{i=1}^{N} \qquad (2)$$

where C denotes the extracted body contour, N represents the total number of contour points, and (x_i, y_i) denotes the coordinates of the i^{th} contour point.

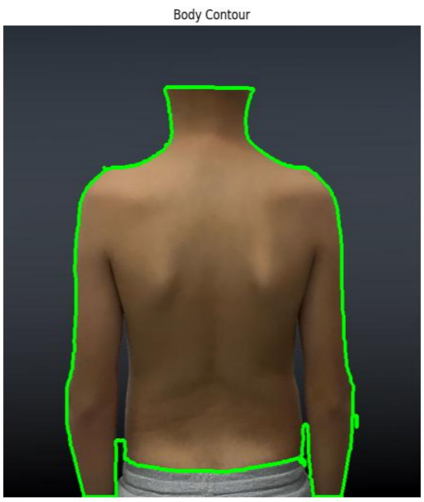

Fig. 3. Segmented body contour extracted from the binary body mask for geometric analysis.

An estimated body centerline is computed by determining the midpoint between the left and right body boundaries at each vertical position. The resulting centerline represents the overall body alignment and provides a reference for identifying postural deviations associated with scoliosis. The centerline coordinate is calculated as

$$x_c(y) = \frac{x_L(y) + x_R(y)}{2} \qquad (3)$$

where $x_L(y)$and $x_R(y)$denote the left and right body boundary coordinates, respectively, and $x_c(y)$represents the estimated centerline coordinate. Fig. 4 presents the estimated body centerline obtained from the segmented body contour.

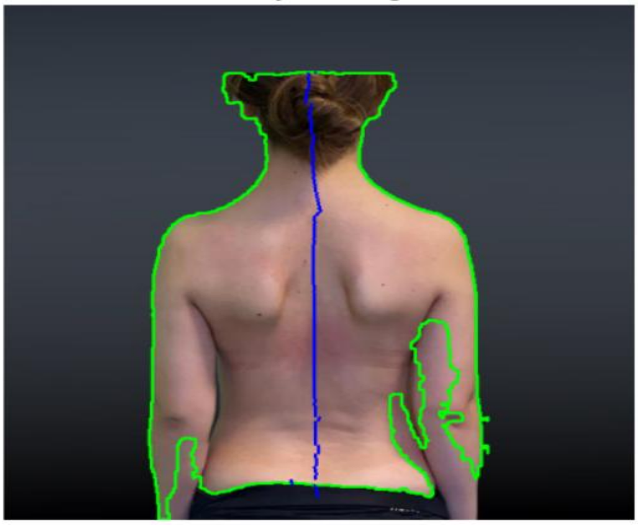

Fig. 4. Estimated body centerline computed from the segmented body contour for posture assessment.

Based on the extracted contour and estimated centerline, the framework automatically localizes the shoulder and waist landmarks using relative body proportions. These landmarks are subsequently used to estimate shoulder asymmetry, waist asymmetry, and the Body Symmetry Index (BSI), providing quantitative measurements of external body symmetry. Higher values of these geometric features indicate greater postural imbalance and an increased likelihood of scoliosis. Fig. 5 illustrates the automatically localized anatomical landmarks used for geometric feature extraction.

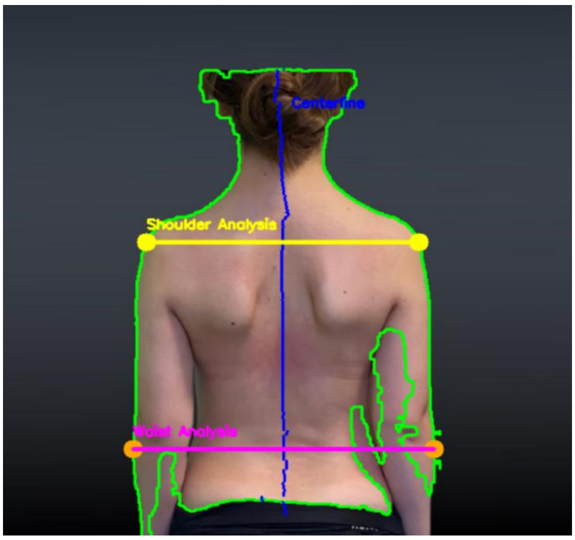

Fig. 5. Automatically localized shoulder and waist landmarks used for geometric feature extraction and body symmetry analysis.

D. Explainable Scoliosis Risk Score (ESRS)

The extracted geometric features are integrated to compute the Explainable Scoliosis Risk Score (ESRS), which provides a transparent and quantitative assessment of scoliosis risk based on external body symmetry. Since the extracted features have different numerical ranges, they are normalized before score computation to ensure balanced contribution from each anatomical measurement.

The proposed framework utilizes four normalized geometric features: estimated body centerline deviation, Body Symmetry Index (BSI), shoulder asymmetry, and waist asymmetry. These features are combined using the weighted formulation

$$ESRS = 50S_C + 25S_B + 15S_S + 10S_W \qquad (4)$$

where S_C , S_B , S_S , and S_W denote the normalized scores of the estimated body centerline deviation, Body Symmetry Index, shoulder asymmetry, and waist asymmetry, respectively. The weighting coefficients are selected according to the relative contribution of each feature to external postural imbalance, with centerline deviation assigned the highest weight because it represents the primary indicator of body alignment.

The computed ESRS is used to classify each subject into one of three clinically meaningful categories according to

$$C = \begin{cases} \text{Scoliosis Not Present,} & ESRS < T_1, \\ \text{Mild Scoliosis Risk,} & T_1 \leq ESRS < T_2, \\ \text{Scoliosis Present,} & ESRS \geq T_2, \end{cases} \qquad (5)$$

where T_1 and T_2 denote the predefined decision thresholds. Because each component of the ESRS corresponds to a measurable anatomical characteristic, the proposed scoring mechanism provides an interpretable assessment of scoliosis risk while avoiding the limitations of black-box prediction models.

E. Explainable Clinical Visualization

To improve the interpretability of the proposed framework, an explainable clinical visualization is generated using the extracted geometric features. The visualization combines the original posterior body image with the estimated body centerline, automatically localized shoulder and waist landmarks, and the corresponding geometric measurements used during scoliosis assessment.

In addition to the visual representation, the framework reports the estimated body centerline deviation, shoulder asymmetry, waist asymmetry, Body Symmetry Index (BSI), Explainable Scoliosis Risk Score (ESRS), and the final screening outcome. By presenting both the geometric measurements and the corresponding prediction, the proposed framework provides transparent and clinically interpretable decision support for non-invasive scoliosis screening. The generated visualization is presented and discussed in the Experimental Results section.

IV. EXPERIMENTAL RESULTS

A. Experimental Setup

The The proposed framework was evaluated using a dataset of 203 posterior body images representing different levels of postural symmetry and scoliosis severity. The framework was implemented in Python using the Google Colaboratory environment. Image processing operations were performed using OpenCV, numerical computation was carried out using NumPy, and Matplotlib was employed for visualization. Each image was processed through the complete analysis pipeline, including preprocessing, body segmentation, contour extraction, centerline estimation, anatomical landmark localization, geometric feature extraction, and Explainable Scoliosis Risk Score (ESRS) computation. The experimental environment is summarized in Table I.

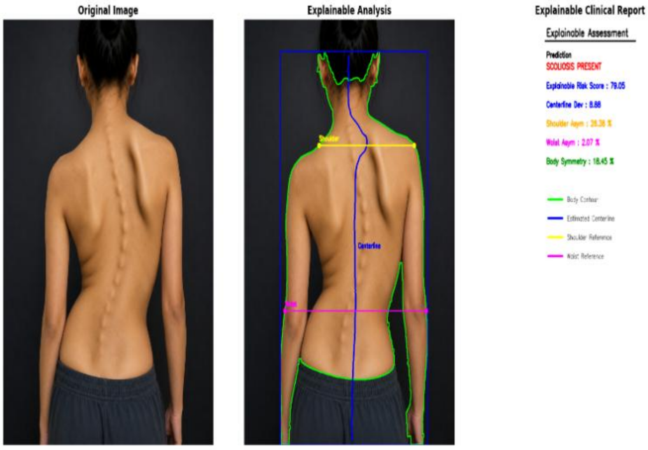

Table I. Experimental Environment

Parameter	Specification
Dataset Size	203 Images
Image Type	Posterior Spatial Body Images
Programming Language	Python
Development Environment	Google Colaboratory
Computer Vision Library	OpenCV
Numerical Library	NumPy
Data Processing	Pandas
Visualization	Matplotlib
Output	Explainable Scoliosis Risk Score (ESRS) and Three-Level Clinical Classification

B. Results and Discussion

Head The proposed framework was evaluated using representative posterior body images corresponding to three clinically meaningful categories: Scoliosis Not Present, Mild Scoliosis Risk, and Scoliosis Present. For each subject, the framework automatically generated an explainable clinical visualization consisting of the estimated body centerline, shoulder and waist landmarks, geometric measurements, Body Symmetry Index (BSI), Explainable Scoliosis Risk Score (ESRS), and the final screening result. The representative outputs are shown in Fig. 6.

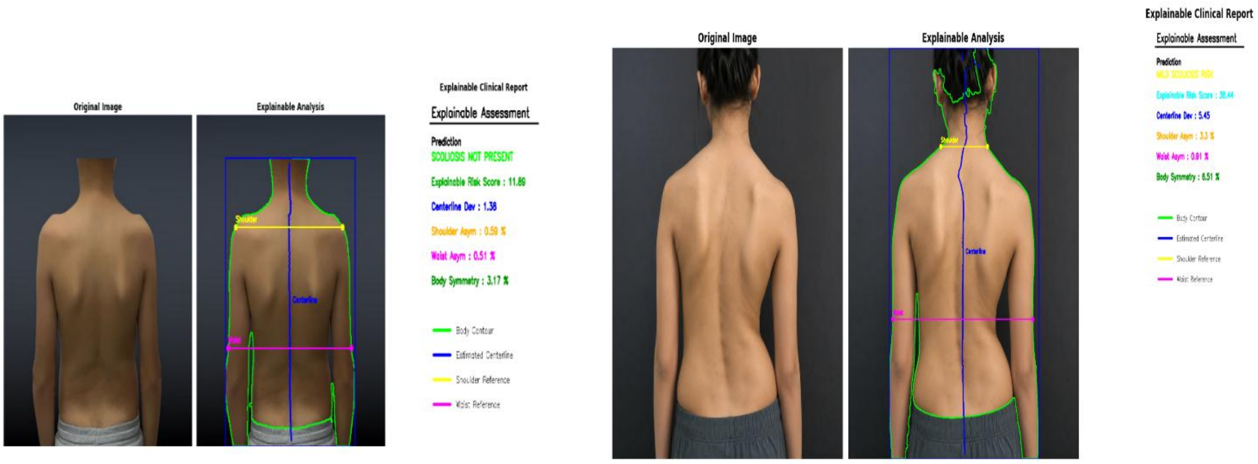

Fig. 6. Representative explainable clinical visualizations generated by the proposed framework for (a) Scoliosis Not Present, (b) Mild Scoliosis Risk

The first subject exhibits a nearly symmetrical body posture with minimal centerline deviation and low shoulder and waist asymmetry, resulting in a Body Symmetry Index of 3.17% and an ESRS of 11.89, leading to the classification Scoliosis Not Present. The second subject demonstrates moderate postural imbalance with increased centerline deviation and asymmetry measurements, producing an intermediate ESRS of 36.44 and the classification Mild Scoliosis Risk. In contrast, the third subject presents pronounced postural asymmetry, including substantial centerline deviation and shoulder imbalance, resulting in a Body Symmetry Index of 18.45% and an ESRS of 79.05, leading to the classification Scoliosis Present. These representative cases demonstrate the capability of the proposed framework to distinguish different levels of scoliosis severity through explainable geometric analysis.

The corresponding quantitative measurements are summarized in Table II. A consistent increase in centerline deviation, shoulder asymmetry, waist asymmetry, Body Symmetry Index, and ESRS is observed as postural asymmetry becomes more pronounced. This progressive relationship demonstrates that the proposed ESRS effectively integrates multiple geometric features into a transparent and interpretable scoliosis assessment.

Table II. Quantitative Analysis of Representative Experimental Cases

Parameter	**Scoliosis Not Present Case**	**Mild Scoliosis Case**	**Scoliosis Present Case**
Body Height	522	900	833
Body Width	413	583	504
Centerline Deviation	1.38	5.45	8.88
Shoulder Asymmetry (%)	0.59	3.30	26.38
Waist Asymmetry (%)	0.51	0.91	2.07
Body Symmetry Index (%)	3.17	6.51	18.45
Explainable Risk Score	11.89	36.44	79.05
Final Prediction	Scoliosis Not Present	Mild Scoliosis Risk	Scoliosis Present

Overall, the experimental results demonstrate that the proposed framework provides an efficient and explainable approach for non-invasive scoliosis screening. By combining geometric feature extraction with transparent risk estimation, the framework produces clinically interpretable screening outcomes without requiring radiographic imaging, specialized equipment, or computationally intensive deep learning models. These characteristics make the proposed methodology suitable for community-based screening, school health programs, and primary healthcare applications [2], [6], [13].

V. CONCLUSION

This paper presented an explainable framework for non-invasive scoliosis screening using conventional posterior body images. The proposed methodology combines image preprocessing, geometric feature extraction, and the Explainable Scoliosis Risk Score (ESRS) to perform automated scoliosis screening without requiring radiographic imaging or computationally intensive deep learning models. By utilizing measurable geometric features, including estimated body centerline deviation, shoulder asymmetry, waist asymmetry, and the Body Symmetry Index (BSI), the framework provides transparent and clinically interpretable screening outcomes.

The experimental results demonstrate that the proposed framework effectively distinguishes between Scoliosis Not Present, Mild Scoliosis Risk, and Scoliosis Present through explainable geometric analysis. The generated clinical visualization further enhances result interpretability by enabling direct association between the extracted anatomical features and the corresponding screening outcome. Owing to its computational efficiency, transparency, and non-invasive nature, the proposed framework offers a practical solution for preliminary scoliosis screening in school-based programs and primary healthcare settings.

Although the proposed framework demonstrates promising performance, its effectiveness may be influenced by variations in body posture, illumination, clothing, and image acquisition conditions. Future work will focus on validating the framework using larger and more diverse clinical datasets and investigating the integration of machine learning techniques to further improve screening performance while preserving interpretability.

References

[1] Li D, Wang P, Zhang M, Zhang X, Yao H, Liu X. *Advances in examination methods for adolescent idiopathic scoliosis*. *Pediatr Discov*. 2025; 3(1):e2518. doi: https://doi.org/10.1002/pdi3.2518

[2] M. Bertsch, J. Reinhardt, and M. Scherer, "Non-ionizing methods for scoliosis assessment: A systematic review and meta-analysis," *BMC Musculoskeletal Disorders*, vol. 26, Art. no. 145, Dec. 2025, doi: 10.1186/s12891-025-09034-8.

[3] Z. Zhou, Z. Peng, D. Jin, C. Fan, F. An, and S. Yu, "Pose as clinical prior: Learning dual representations for scoliosis screening," in *Medical Image Computing and Computer-Assisted Intervention – MICCAI 2025* (Lecture Notes in Computer Science), Cham, Switzerland: Springer Nature, 2025, pp. 464–474, doi: 10.1007/978-3-031-72381-8_45.

[4] X. Zhu, R. Chen, X. Guo, Z. Shao, Y. Dai, M. Zhang, and C. Lang, "Symmetric perception and ordinal regression for detecting scoliosis natural image," Appl. Intell., vol. 55, no. 5, 2025.

[5] N. Meng, J. P. Y. Cheung, T. Huang, M. Zhao, Y. Zhang, C. Yu, C. Shi, and T. Zhang, "EUFormer: Learning driven 3D spine deformity assessment with orthogonal optical images," in Proc. 46th Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. (EMBC), Orlando, FL, USA, Jul. 2024.

[6] B. Mehta and N. Chockalingam, "Non-invasive assessment of back surface topography: Technologies, techniques and clinical utility," *Sensors*, vol. 23, no. 20, Art. no. 8485, Oct. 2023, doi: 10.3390/s23208485.

[7] A. Tabard-Fougère *et al.*, "Three-dimensional spinal evaluation using rasterstereography in patients with adolescent idiopathic scoliosis," *Diagnostics*, vol. 13, no. 14, Art. no. 2431, Jul. 2023, doi: 10.3390/diagnostics13142431.

[8] M. Imran *et al.*, "Vision-based human posture analysis for musculoskeletal screening," *Healthcare Technology Letters*, vol. 10, no. 5-6, pp. 112–119, Dec. 2023, doi: 10.1049/htl2.12051.

[9] S. H. Lee *et al.*, "Development of smartphone-based scoliosis screening using image analysis," *Sensors*, vol. 22, no. 19, Art. no. 7306, Sep. 2022, doi: 10.3390/s22197306.

[10] J. P. Y. Cheung *et al.*, "Clinical evaluation of external trunk asymmetry in adolescent idiopathic scoliosis," *Spine*, vol. 46, no. 14, pp. E775–E783, Jul. 2021, doi: 10.1097/BRS.0000000000003928.

[11] W. Samek, G. Montavon, S. Lapuschkin, C. Anders, and K. Müller, *Explainable AI: Interpreting, Explaining and Visualizing Deep Learning*. Cham, Switzerland: Springer, 2019, doi: 10.1007/978-3-030-28954-6.

[12] D. Gunning and D. Aha, "DARPA's explainable artificial intelligence program," *AI Magazine*, vol. 40, no. 2, pp. 44–58, Jun. 2019, doi: 10.1609/aimag.v40i2.2850.

[13] S. Negrini, S. Donzelli, A. G. Aulisa *et al.*, "2016 SOSORT guidelines: Orthopaedic and rehabilitation treatment of idiopathic scoliosis during growth," *Scoliosis and Spinal Disorders*, vol. 13, Art. no. 3, Jan. 2018, doi: 10.1186/s13013-017-0145-8.

[14] R. C. Gonzalez and R. E. Woods, *Digital Image Processing*, 4th ed. Upper Saddle River, NJ, USA: Pearson, 2018.

[15] P. Knott *et al.*, "Multicenter comparison of surface topography and radiography for spinal deformity assessment," *Spine Deformity*, vol. 4, no. 2, pp. 118–122, Mar. 2016, doi: 10.1016/j.jspd.2015.08.009.

[16] M. T. Hresko, "Clinical practice: Idiopathic scoliosis in adolescents," *The New England Journal of Medicine*, vol. 368, no. 9, pp. 834–841, Feb. 2013, doi: 10.1056/NEJMcp1209063.

[17] J. R. Cobb, "Outline for the study of scoliosis," *Instructional Course Lectures, American Academy of Orthopaedic Surgeons*, vol. 5, pp. 261–275, 1948.