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Advancements in Adolescent Idiopathic Scoliosis Diagnosis: A Focus on Non-Invasive Techniques

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Abstract: Adolescent idiopathic scoliosis (AIS) poses a significant health concern, affecting the spinal curvature of adolescents during their growth period. Early diagnosis of AIS is critical for effective intervention and management. However, conventional diagnostic methods often involve repetitive exposure to X-rays, which can lead to radiation-related side effects. This research paper explores the significance of early diagnosis in AIS and emphasizes the utilization of non-invasive techniques, particularly video raster stereography (VRS), combined with deep ensemble neural networks (DNNs) to enhance diagnostic accuracy while minimizing the risks associated with radiation exposure. We delve into the potential of DNNs in analyzing VRS data and compare its efficacy with other machine learning alternatives.
Keywords: Adolescent Idiopathic Scoliosis, Early Diagnosis, Non-Invasive Techniques, Video Raster Stereography, Deep Ensemble Neural Networks.

I. INTRODUCTION

Scoliosis manifests as a spinal condition characterized by lateral curvature and vertebral rotation. Its origins span a spectrum of causes, including congenital, neuromuscular, syndrome-related, idiopathic, and secondary factors. Among these, idiopathic scoliosis is predominant in clinical settings, presenting a diverse natural history shaped by etiology and age at onset, thus guiding treatment strategies. Crucially, initial evaluation hinges on patient history, physical examination, and radiographic assessment, with particular emphasis on identifying non-idiopathic cases for targeted intervention. For instance, congenital scoliosis necessitates scrutiny for associated cardiac and renal anomalies. While school-based screening once held sway, its efficacy now faces scrutiny.

Treatment protocols for idiopathic scoliosis are multifaceted, contingent upon factors such as age, curve severity, and risk of progression. Options encompass observation, orthotic management, and surgical fusion. Notably, referral to a specialist is warranted if the curvature exceeds 10° in patients younger than 10 years, or surpasses 20° in older patients. Additional indications include atypical features, back pain, or neurological symptoms. This paper elucidates the dynamic realm of scoliosis diagnosis, highlighting innovations that enhance precision while mitigating inherent risks.

II. LITERATURE REVIEW

Caesarendra et al. (2022) develop a Convolutional Neural Network (CNN)-based system for automated Cobb angle measurement in Adolescent Idiopathic Scoliosis. Their study highlights the CNN's accuracy, offering a promising tool for efficient scoliosis diagnosis and monitoring.

Yahara et al. (2022) piloted a deep convolutional neural network to forecast curve progression in Adolescent Idiopathic Scoliosis, showing potential for early detection and treatment planning.

Yip et al. (2020) systematically analyze non-surgical treatments for Adolescent Idiopathic Scoliosis (AIS) through a comprehensive literature review and citation network analysis, aiming to provide insights into the efficacy of various non-invasive interventions.

Anthony et al.'s (2020) study identifies trends in detection and referral of Adolescent Idiopathic Scoliosis (AIS), highlighting challenges in effective treatment due to skeletal maturity and late presentations.

Sekiya et al. (2018) investigate leg length discrepancies in AIS patients, showing functional discrepancies correlated with pelvic obliquity and lumbar Cobb angle.

Dufvenberg et al. (2018) conduct a meta-analysis, indicating decreased postural stability in AIS patients compared to typically developed individuals, emphasizing the importance of studying postural stability in AIS.

Sitoula et al. (2015) validate the Sanders Skeletal Maturity Staging System for predicting curve progression in idiopathic scoliosis, highlighting its strong correlation with initial Cobb angle.

Schimmel et al. (2015) explore treatment options for Adolescent Idiopathic Scoliosis (AIS), including bracing and surgical techniques, while addressing debates around screening efficacy and intervention outcomes.

Komeili et al. (2015) utilize 3D marker-less surface topography for scoliosis monitoring, potentially reducing X-ray requirements through early detection of curve progression.

Schlösser et al. (2014) conduct a systematic review on associated abnormalities in AIS, revealing limited evidence and weak associations, highlighting the challenge in understanding its etiology.

Weinstein et al. (2013) respond to the efficacy of bracing in reducing high-risk curve progression in Adolescent Idiopathic Scoliosis (AIS), emphasizing the role of brace wear duration in achieving successful outcomes.

Paolucci et al.'s (2013) case-control study at Policlinico Umberto I Hospital found that scoliosis patients had higher instability than healthy controls, but wearing a Chêneau brace improved stability, especially in limb load symmetry, sway length, and velocity.

Sahlstrand et al. (2013) examine bone quality profiles in AIS patients, revealing unique changes in trabecular compartments associated with osteopenia.

Lao et al. (2008) explore the impact of somatosensory dysfunction on dynamic balance in AIS, suggesting a link between somatosensory issues and balance control.

Danielsson et al. (2007) present a long-term follow-up study on AIS patients treated primarily with bracing, demonstrating stable curves without surgeries compared to those in the observation group.

Lenke et al. (2001) propose a new classification system for AIS to determine the extent of spinal arthrodesis, highlighting the need for further studies to evaluate its applicability.

Pruijs et al. (1994) assess the reliability of Cobb angle measurement in scoliosis management, emphasizing the importance of standardizing radiograph production.

Morrissy et al. (1990) analyze Cobb angle measurements in scoliosis radiographs, revealing intraobserver and interobserver variability.

Herman et al. (1985) explore the link between impaired axial motor control and idiopathic scoliosis, indicating a high correlation with curve magnitude in vestibular processing variables.

Beekman & Hall (1979) highlight variability in scoliosis measurements, emphasizing the need to distinguish actual changes from measurement variability in exercise programs.

Sahlstrand et al. (1978) study postural control in AIS patients, showing poorer postural control compared to healthy children, with left convex patients exhibiting more pronounced instability.

III. METHODOLOGY

A. *Modules*

1) *Numpy:* NumPy is a fundamental library for numerical computing in Python. It provides support for multi-dimensional arrays and matrices, along with a wide range of mathematical functions to operate on these arrays efficiently.
2) *Pandas:* Panda is a powerful library for data manipulation and analysis. It offers high-level data structures like DataFrame and Series, which allow for easy indexing, selection, and filtering of data. Pandas is particularly useful for handling tabular data and time series data
3) *Scikit-learn:* It provides a wide range of algorithms for various machine learning tasks, including classification, regression, clustering, dimensionality reduction, and more. It also offers tools for data preprocessing, model evaluation, and model selection.

B. *Ensemble Learning Algorithms and Model Training Techniques*

1) *Ensemble Deep Learning:* Multiple neural network models are combined to classify scoliosis and healthy subjects based on Video-Raster-Stereography (VRS) data. Each model contributes to the final prediction, enhancing accuracy and robustness.
2) *Binary Crossentropy Loss Function:* It measures the disparity between predicted probabilities and actual binary labels during model training, aiding in learning optimal classification boundaries for scoliosis detection.
3) *Adam Optimizer:* This optimization algorithm adjusts the learning rate for each parameter individually, facilitating faster convergence and improved performance of the neural network models.
4) *Early Stopping:* Implemented as a regularization technique, early stopping monitors model performance on a validation set and halts training if no improvement is observed, preventing overfitting and enhancing generalization.
5) *Balanced Accuracy Score:* It evaluates the ensemble model's performance by considering class imbalances in the dataset, providing a reliable measure of classification accuracy for scoliosis severity prediction.

C. Steps of Implementation

1) *Data Collection and Preprocessing:* Acquired Video-Raster-Stereography (VRS) data from subjects diagnosed with Adolescent Idiopathic Scoliosis (AIS) and healthy individuals. Conducted thorough cleaning and exploratory data analysis (EDA) to ensure data reliability and understand its distribution.

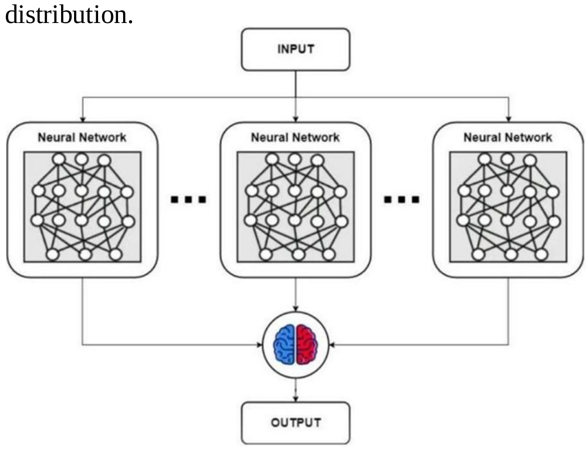

Fig 1. Role of Neural Network to operate ensemble

2) *Ensemble Deep Learning Model Construction:* Developed an Ensemble Neural Network using Keras, comprising multiple Multi-Layer Perceptron (MLP) neural networks with two hidden layers of 64 neurons each.
3) *Model Training and Evaluation:* Trained the Ensemble Neural Network on a balanced dataset containing both healthy and scoliotic subjects. Assessed model performance using metrics like balanced accuracy, considering sensitivity and specificity.
4) *Implementation, Testing, and Validation:* Implemented the model using Python and Keras, emphasizing usability, and conducted extensive testing on new data. Compared model performance with existing diagnostic methods and validated accuracy against established approaches
5) *Optimization and Documentation:* Explored techniques to enhance model efficiency, fine-tuned hyperparameters for optimal performance, and thoroughly documented the entire process for transparency and reproducibility.
6) *Results Analysis and Application:* Analyzed results to showcase the model's significance in improving diagnostic accuracy for scoliosis and explored potential real-world applications.

IV. CONCLUSION

This paper underscores the critical need for early diagnosis of adolescent idiopathic scoliosis (AIS) while mitigating the risks associated with radiation exposure. We advocate for the adoption of non-invasive techniques like video raster stereography (VRS) coupled with deep ensemble neural networks (DNNs) to achieve higher diagnostic precision. Through an extensive review of existing literature and a detailed methodology, we highlight the potential of machine learning algorithms in automating the classification of scoliosis and predicting its progression.

Our study not only explores the current landscape of AIS diagnosis but also offers practical insights into the development and application of advanced diagnostic tools. By leveraging ensemble learning and optimizing model training techniques, we demonstrate the feasibility of integrating these innovative approaches into clinical settings. Looking ahead, collaborative efforts and ongoing refinements in algorithmic methodologies will be pivotal in realizing the full potential of these non-invasive techniques, ultimately enhancing patient care and treatment outcomes in AIS management.

V. FUTURE SCOPE

In the future, the research endeavors to delve deeper into the integration of deep ensemble neural networks (DNNs) with non-invasive techniques such as video raster stereography (VRS) to achieve even higher levels of diagnostic accuracy in adolescent idiopathic scoliosis (AIS). Further advancements in artificial intelligence (AI) and computer vision algorithms will be explored to refine the analysis of VRS data, potentially uncovering subtle patterns and markers for early detection and precise classification of AIS.

Longitudinal studies will validate the effectiveness of these techniques in real-world settings. User-friendly software and mobile apps can enable remote monitoring and proactive patient care. Collaboration and innovation will lead to personalized and effective adolescent idiopathic scoliosis management.

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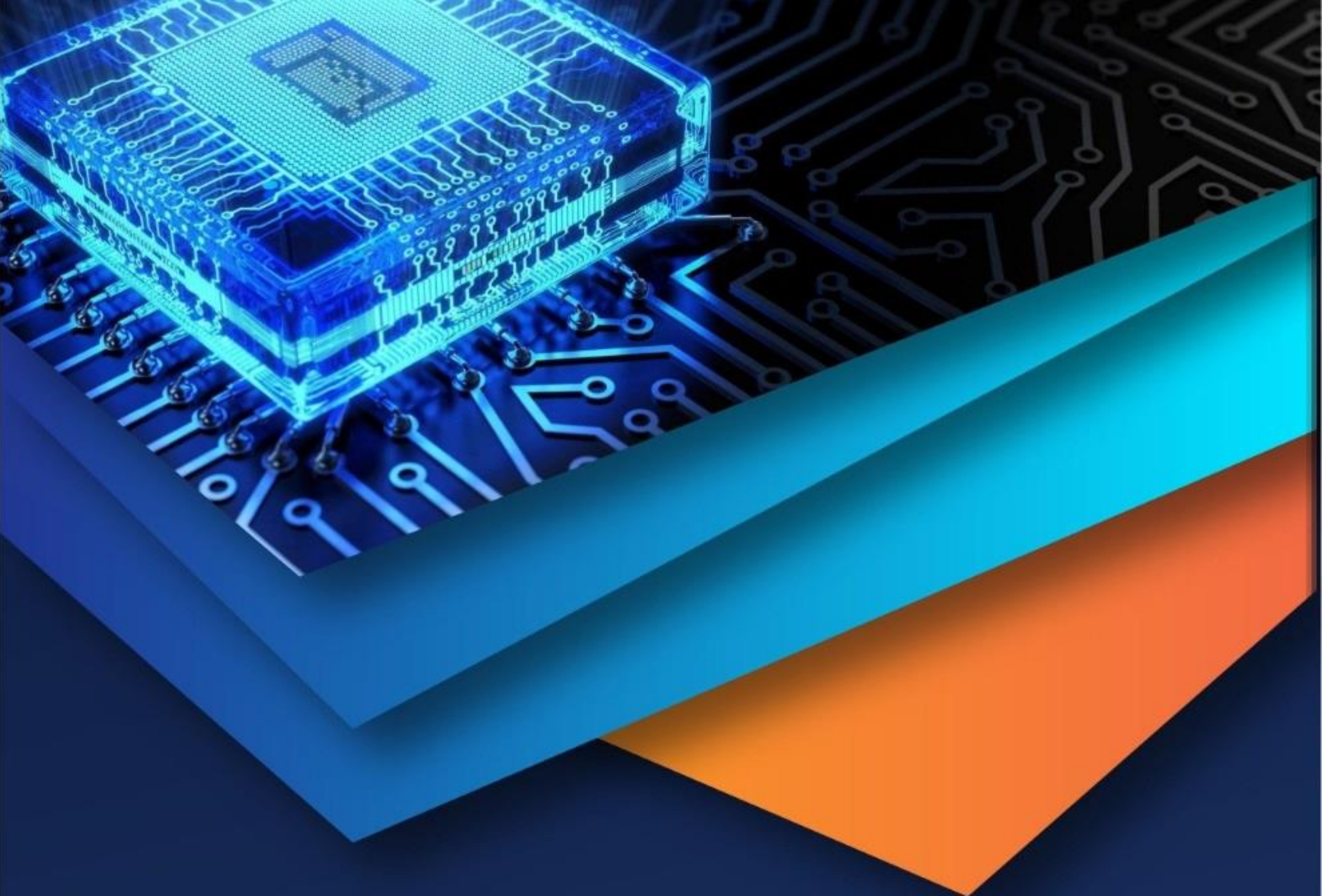

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