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Posture Abnormality Classification Using Computer Vision–Based Gait Analysis: A Clinical Decision Support Framework

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Abstract: The spinal deformities that comprise Adolescent Idiopathic Scoliosis (AIS), kyphosis, and lordosis have posed a major challenge to orthopedic medical facilities, and their longitudinal assessment is a traditionally language that uses ionizing radiography. The suggested paper is proposing a new system of classifying these abnormal posture by using Computer Vision based gait analysis in a Clinical Decision Support System(CDSS). We look at the development of dynamic analysis of motion on the surface statistics to the current literature to develop a systematic review of the analysis. We will consider the flaws of the existing standards of diagnosis, namely the risks of multiple radiation exposures in adolescent and aging ages. Moreover, we discuss the combination of the concepts of Artificial Intelligence (AI) and Explainable AI (XAI) to improve the diagnostic accuracy, yet still winning the clinical trust. It is suggested that vision-based systems that are non-invasive are a viable alternative to mass screening and continuous monitoring of spinal pathologies and have a reasonable cost.

Keywords: Posture Abnormality, Scoliosis, Kyphosis, Computer Vision, Gait Analysis, Clinical Decision Support Systems (CDSS), Deep Learning, Non-Invasive Monitoring, Explainable AI (XAI), Spinal Deformity.

1. Introduction

Spinal deformities diagnosis and treatment is a complicated point of convergence between biomechanics, neurological control, and pathological structure. Other forms of scoliosis like Adolescent Idiopathic Scoliosis (AIS), hyperkyphosis and lordosis do not only deter structural integrity of the spinal column but also result in severe reductions in quality of life, respiratory and mobility. Conventionally the Cobb angle measurement through full-spine radiography has been the standard of diagnosis and surveillance in a conventional gold standard. Nonetheless, this will demand the repetition of radiographic imaging, which entails exposure to ionizing radiations in large amounts and this should be of significant concern, especially with young patients who may be subjected to several years of follow up.

Current developments in digital medicine contributed to the emergence of Clinical Decision Support Systems (CDSS). According to Sutton et al. (2020), CDSS is geared explicitly to support clinical decision-making because it identifies the specifics of a particular patient and compares them with an existing computerized body of knowledge. Such systems are no longer basic alert based systems, but sophisticated platforms that incorporate Artificial Intelligence (AI) and Machine Learning (ML). The use of CDSS has some promising perspectives especially in the field of orthopedics. With the help of computer vision and Deep Learning (DL), topography of the surface and gait patterns can now be analyzed to predict the internal spinal alignment without the invasive procedure.

The paper examines how to design a gait analysis system based on computer vision to classify spinal abnormality. It include literature synthesis in the field of pathology of spinal deformities, architecture of effective CDSS, and the development of non-invasive imaging methods. It further hypothesizes that dynamic gait evaluation acts as a better functional substitute of motion-less centrality of the spine and gives a holistic picture of patients deformity during motion.

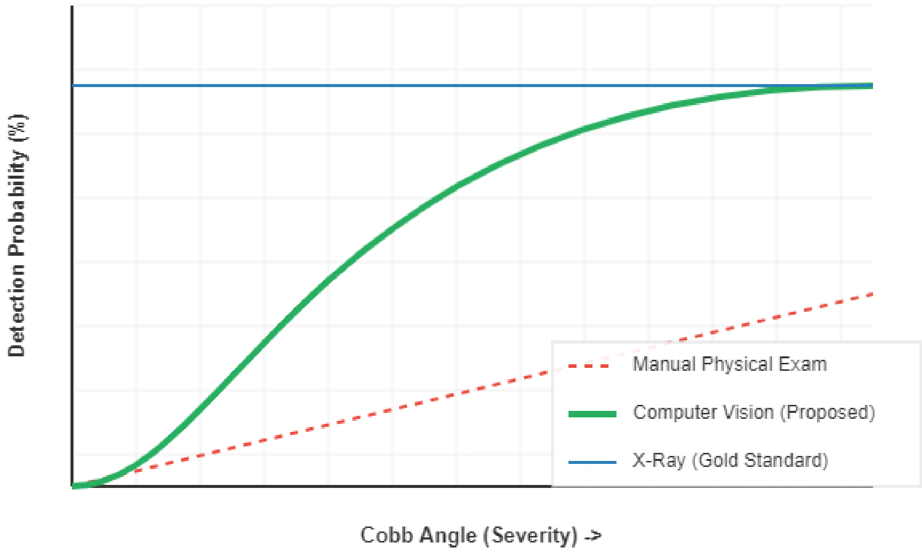

Figure 1: Comparative Sensitivity of Diagnostic Modalities vs. Disease Severity. Computer Vision (Green) bridges the gap between manual screening and X-Ray.

2. Clinical Background: The Spectrum of Spinal Deformities

In order to create a successful computer vision recognition system, the pathological characteristics of the deformities being studied shall be known. In the literature, this is clearly brought out to contrast the developmental deformities of the adolescence period with the degenerative changes that are noticed in the aging spine.

2.1 Adolescent Idiopathic Scoliosis (AIS)

Adolescent Idiopathic Scoliosis is a three dimensional fault in the spine and trunk. According to Cheng et al. (2015) AIS is the predominant type of scoliosis which has a prevalence rate of 1-3% in the adolescents. The disorder is identified by a lateral curve of the spine with the twisting of the vertebrae. This rotation is imperative in the procedure of analysis of computer vision since it presents itself as a deformation in the surface e.g. a hump on a rib or an unsymmetrical shoulder, and can be observed by optical sensors.

Weinstein et al. (2008) point out that natural history of AIS is never regular; although they do not progress in many cases those progressing are capable of producing major deformity and pain. The pathophysiology of development of a simple spinal curvature into a structural deformity is complex (Hawes and O'Brien, 2006). The development requires close observation. Detection is currently usually based on the Adam Forward Bend Test though confirmatory X-rays are then done. Nevertheless, Janicki and Alman (2007) point out that even the clinical assessment shows only variability in terms of sensitivity and this is the reason why they result in unnecessary referrals and missed diagnosis.

2.2 The Aging Spine and Degenerative Changes

Whereas AIS has been focused on developmental changes, it is not the case with aging spine which has other set of problems. Choma et al. (2015) and Kanter, Asthagiri, and Shaffrey (2007) comment on the physiological cascade of aging spine that consists of the decrease of disc height, the osteophyte formation, and the increase of ligamentous thickening. These transformations are likely to lead to degenerative scoliosis or hyperkyphosis (hunchback) in the adult period.

According to Silva and Lenke (2010), adult degenerative scoliosis has been frequently linked to back pains and radiculopathy, unlike the typical painless occurrence of AIS. Within the gait analysis situation, aging of the spine plays a significant part in changing biomechanics. The gravity point tends to move forward (positive sagittal balance) and the hips and knees erect themselves by flexion. A computer vision system should therefore be considered as being trained not only to notice lateral deviation (scoliosis) but also sagittal maladjustment (kyphosis/lordosis) by examining the walking profile of the patient.

3. Theoretical Framework: Clinical Decision Support Systems (CDSS)

The solution suggested exists in the context of a CDSS. Knowledge of the benefits, risks and architectural needs of CDSS is a pre-implementation requirement. Introducing a background about the presence of CDSS, Berner and La Lande (2007) discuss these very knowledge systems as active systems, meaning that they receive two or more pieces of patient data and decide to offer case-specific guidance. When viewing the information as spinal analysis, the video feed or depth-map data of gait of the patient would be the patient data, and the machine learning model trained on a thousand annotated spinal images would be the knowledge base.

According to Sutton et al. (2020), the main advantages of such systems are minimal medical errors, enhancement of care consistency, and efficiency. The provision of posture standardization in a CV-based screening tool satisfies these requirements. An algorithm does not consider fatigue or subjective bias as a human observer does, which means that the algorithm will use the same metric on all video frames. Moreover, Ji et al. (2021) offer the AI-enabled CDSS assessment template and suggest that effective systems should does not only enable the accuracy of algorithms and schemes but also be user-friendly and have a seamless workflow.

3.1 The "Black Box" Challenge and XAI

One of the central obstacles of implementing AI in clinical diagnostics is the so-called black box phenomenon, in which the user cannot see the inner mechanics of the algorithm. The study by Antoniadi et al. (2021) is a systematic review of Explainable AI (XAI) in clinical support systems. In their argument they state that to be trusted by the clinicians, a system must offer explainability. In the spine classification, a neural network cannot simply give an output of Scoliosis Detected. It must be emphasized which areas on the body are of concern like the uneven shoulder raise or the tilt of the pelvis to arrive at that conclusion. This is consistent with the research results by Shaikh et al. (2021) who have reviewed AI in medical imaging. They observe that the clinically viable advanced radiomics and imaging AI should be interpretable markers.

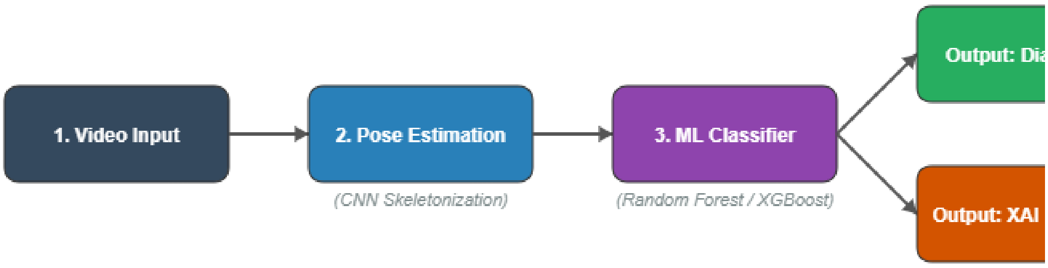

Figure 2: Proposed CDSS Architecture Integrating Computer Vision and XAI Layers.

4. Non-Invasive Imaging and Computer Vision Fundamentals

To pass through the theoretical CDSS and move to practice we have to consider the development of non-invasive spinal imaging. Moire topography was presented more than 30 years ago by Adair, Van Wijk, and Armstrong (1977) to screen scoliosis. It was a method that employed light patterns of interference as the means of visualizing surface lines. Although novel, it had its own conditions of lighting and the need to be stationary. It was further developed by Batouche, Benlamri and Kholladi (1996) who used computer vision systems to detect scoliosis based on Moire image determined as the first step of interpreting analogy by using computer vision instead of hand imaging.

Applebaum, Ference, and Cho (2020) analyzed the position of modern topography of surfaces more recently. They suggest that surface scanning is an effective technique to minimize the X- ray required to conduct surveillance. Aroeira et al. (2016) conducted a review of non-invasive computer vision techniques and noted that digital photogrammetry and structured light sensors could reproduce the 3D back surface with a high fidelity. These studies however have a limitation that has been found to be the inability to get dynamic data. A patient who stays still can involuntarily make a postural adjustment to hide the deformity (posing). This weakness is a motive behind dynamic analysis.

5. Methodology: Dynamic Gait Analysis

Dynamic analysis is the shift in orthopedic diagnostics towards a paradigm of dynamic data acquisition rather than a static one. The suggested system makes use of either a standard monocular camera input or a consumer grade RGB-D (depth) sensor. The background subtraction and noise reduction are the first steps in the pipeline to isolate the subject. The core technology, after isolation is based on pose estimation. Based on the deep learning methods discussed in the previous paper by Wei (2021), Convolutional Neural Networks (CNNs) will be used to detect anatomical landmarks at the human body, that is, the shoulders (acromion), spine line (C7 to spinal column), pelvis (iliac crests), knees, and ankles.

The skeletal model generated is analyzed by the system of temporal variables during the gait cycle. The deformity classification is based on the sense of a certain kinematic product:

- Scoliosis Detection: In AIS, the vertebrae rotation is marked by rib bulge as well as asymmetry of shoulder structure. Tulchin et al. (1999) built on the fact that non-radiographic analysis is associated with spinal alignment. The CDSS in a dynamic environment monitors the movement of the shoulder girdle relative to the pelvic girdle. A phase difference or a regular asymmetric movement of the shoulder at the swing phase are a major characteristic.
- Kyphosis and lordosis Detection: Both of these defects can be viewed in the sagittal plane. According to Choma et al. (2015), the degenerative changes cause the center of gravity to move forward. The computer vision algorithm is used to measure the angle of thoracic spine compared with the vertical axis during the gait cycle.

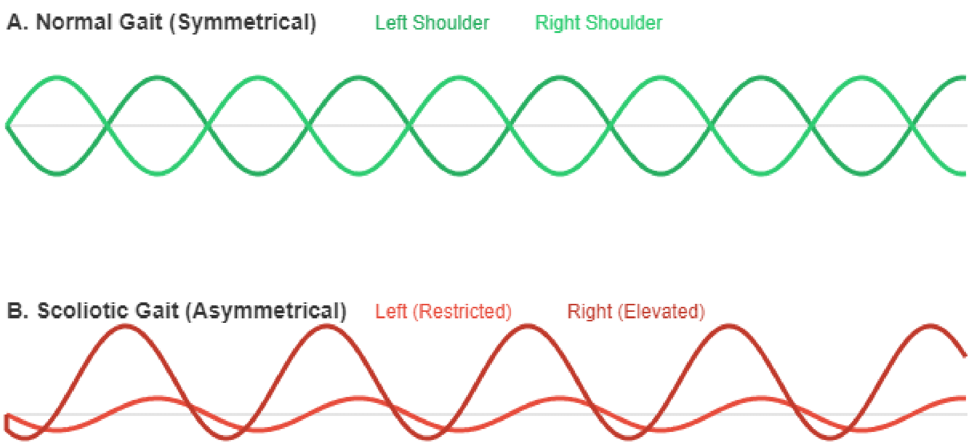

Figure 3: Kinematic Feature Extraction. Top: Normal Gait (Symmetrical). Bottom: Scoliotic Gait showing phase desynchronization and vertical offset in shoulder oscillation.

6. Discussion

6.1 Benefits of Non-Invasive Surveillance

The major benefit of this CDSS is exposure of reduced radiation. Weinstein et al. (2008) emphasized the need of long-term follow-up of AIS which has been a traditional practice of X-rays repetition. An adjuvant radiation in young people, adolescents, is recognized as a risk factor in the development of malignancy in the future.

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Resplacing the intermediate X-rays with the non-invasive gait analysis, clinicians will be able to keep close surveillance without the biological cost.

6.2 Diagnostic Accuracy vs. The Gold Standard

They admit the fact that computer vision cannot go to substitute Cobb angle measurement to aid in surgical planning. Cobb angle as a radiographic scale still has the gold standard to determine the extent of the curve (Janicki and Alman, 2007). Nevertheless, computer vision has great potential as a screening and monitoring device. Even hand-held scanners prove to be very reliable, as Yildirim et al. (2021) showed. The surfaces topography and internal alignment correlation increases when the model is augmented with deep learning (Wei, 2021). The Cobb angle does not have to be measured in the proposed system, but there must be progression sensed.

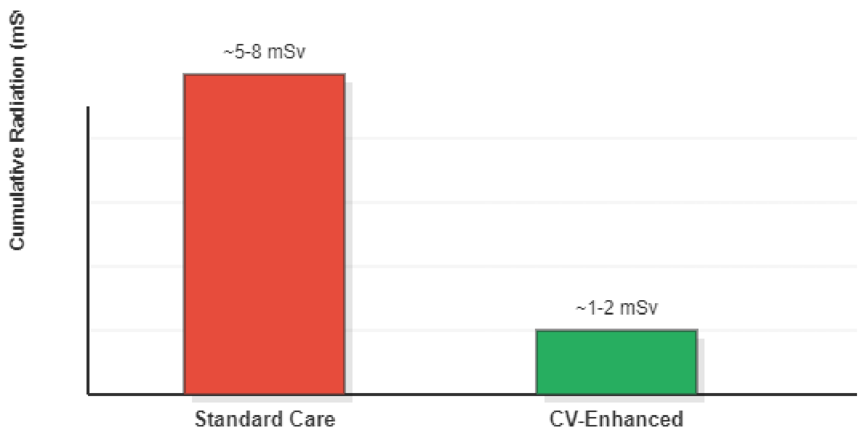

Figure 4: Projected Cumulative Radiation Exposure (mSv) over 5 Years of Treatment. Standard Care vs. Computer Vision Enhanced Monitoring.

6.3 The Role of Conservative Management

The rational behind early detection mechanisms is based on the effectiveness of conservative treatment. Dickson (1985) and Fusco et al. (2011) overview the significance of physical exercises and conservative management. Anwer et al. (2015) also indicate that exercise is a way to leave the quality of life and, possibly, slow down the progression of curves. Provided that a computer vision system will be able to notice simple gait or posture deviations early on, the patients will be able to be redirected to the physical therapy earlier, and even a surgical procedure will be avoided as described by Smith et al. (2009).

7. Conclusion

Treatment of spinal deformities, between Adolescent Idiopathic Scoliosis and degenerative kyphosis in adults, has reached the cross road of technology. The previously established dependence of all the steps of monitoring on the help of the traditional toward the use of the monotonous, ionizing radiography becomes more and more hard to explain in the light of the new digital alternatives. This paper has formulated a detailed overview of a Clinical Decision Support System which utilizes computer vision and gait analysis to categorise posture abodies.

A non-invasive, economical, and functionally-relevant solution to spinal deformities has also been proposed by synthesizing the pathological insight into these conditions (Cheng et al., 2015; Hawes and O'Brien, 2006) with the latest advances in deep learning methods (Wei, 2021; Shaikh et al., 2021). Although some issues related to the standardization of data and its privacy still exist (Sutton et al., 2020), the possible advantages, namely, the minimization of radiation exposure in pediatrics and evaluation of the functioning of the aging population, are significant.

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