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Development of a Spinal Deformity Motion Correction Testing System

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Abstract: In response to the global concern over adolescent spinal deformity, this study develops an intelligent spinal deformity motion correction testing system. Integrating AI and spinal health screening technology, the system comprises three key modules: model training, posture analysis, and intervention planning. By capturing and analyzing numerous human images via machine learning algorithms, the system accurately identifies skeletal landmarks and assesses spinal posture for early deformity detection. Furthermore, it can generate personalized exercise correction programs. This innovation aims to offer an efficient, precise, cost-effective, and non-invasive tool for adolescent spinal health management, thereby advancing the field of spinal health.

Keywords: spinal deformity, adolescent health, motion correction, artificial intelligence, personalized intervention

1. Introduction

1.1 Research Background and Significance

Health is fundamental to personal development and reflects societal advancement. Worldwide, the physical health of adolescents has become a major concern. Spinal deformities, in particular, pose a significant threat to their well - being. These conditions can lead to severe health issues, such as organ dysfunction, musculoskeletal deformities, and in extreme cases, paralysis and reduced life expectancy. The number of individuals affected by spinal deformities is increasing annually on a global scale, with adolescents being a particularly vulnerable group. At present, spinal deformity has become the third most prevalent health issue among adolescents, following obesity and myopia (Essex & Dibley, 2025).

Early detection of this latent and progressive deformity is crucial for effective intervention. However, many patients seek medical attention at a late stage, leading to increased difficulty in conservative treatments and higher medical costs. Physical education teachers, who play a key role in promoting spinal health among adolescents, often lack adequate knowledge of spinal health monitoring and exercise - based therapeutic approaches.

Given the serious situation of spinal deformities among adolescents, schools need to adopt a comprehensive strategy. This includes enhancing science education, conducting regular screenings, developing professional talent, and increasing physical activity interventions. These measures are essential to address the significant health challenge posed by spinal deformities and to protect the well - being of adolescents(Mei et al., 2025).

1.2 Current Status of Spinal Health Screening

Internationally, there is no consensus on spinal health screening recommendations, with significant differences across countries in screening standards and principles. School-based screening in the US dates back to the 1960s-1970s. By 2003, 21 states had mandatory screening, but some withdrew after the US Preventive Services Task Force raised objections in 2004. As of 2019, 15 states still required it. Canada introduced mandatory screening in the 1970s, only to halt it a decade later. Australia's government opts for a national self-screening approach, providing self-assessment reports to girls aged 10-12 and advising home-based forward-bending tests to check for spinal deformities. The UK National Screening Committee opposes a national screening program. Japan passed a law in 1978 for school-based screening, yet specific local measures are still being harmonized. Norway abandoned its school screening in 1994(Wei et al., 2025).

Globally, spinal health screening is a secondary preventive measure. It aims to detect spinal deformities early in children and adolescents, enabling close monitoring of spinal conditions. Early-stage suspected patients can be referred to hospital rehabilitation or spinal surgery departments for definitive diagnosis and timely exercise-based interventions. This approach spares patients and their families the heavy financial burden of later-stage medical treatment and surgery.

2. Overview of Spinal Health Screening Methods

2.1 Physical Measurement Methods

Physical measurement methods are widely used in spinal deformity screening due to their simplicity and lack of need for complex equipment. The Adams forward - bending test is a classic example. Patients stand with feet together and arms extended, then slowly bend forward 90 degrees to expose the spine. Examiners observe the spine from behind to check for asymmetrical protrusions. If significant asymmetry is found, it may indicate spinal deformity. However, this method relies heavily on the examiner's clinical experience and subjective judgment, leading to potential inaccuracies and inconsistencies in results(Turhan et al., 2025).

A spinal deformity ruler can measure trunk rotation. Examiners place the ruler on the spine's protruding area and read the angle measurement to quantify trunk rotation. An angle exceeding a certain threshold may suggest spinal deformity. This method also requires examiners to have operational skills and experience, and results can be influenced by the patient's posture, introducing subjectivity and limitations.

Measuring rib humps is another common physical method. Examiners determine the location and extent of rib humps through observation and palpation to assess spinal deformity. However, this method is inefficient and subjective. It also requires patients to expose their back and involves palpation, which may raise ethical issues and cause discomfort or psychological stress in mass screenings.

2.2 Imaging Measurement Methods

Imaging measurement methods are also significant in spinal deformity screening. X-ray measurement is the gold standard for diagnosis. It allows for a clear view of the spine's structure and quantification of deformity severity using the Cobb angle method. The Cobb angle is determined by drawing lines parallel to the upper and lower endplates of the most tilted adjacent vertebrae in the curved segment on an X-ray. A Cobb angle exceeding 10 degrees indicates spinal deformity. However, X-ray exposure poses radiation risks, requires strict control of the testing environment, and needs professional operators, limiting its use in routine screening(Quiceno et al., 2025).

Moire imaging is a non-contact optical method that projects grating patterns onto the back to create moire fringes. Changes in these fringes due to spinal deformity can be analyzed to assess the condition. Despite advantages, the high cost, complexity, and privacy issues related to back exposure have hindered its widespread adoption(Xie, 2023).

Structured light and laser scanning are other common imaging methods. Structured light measurement projects known patterns onto surfaces, captures reflected images, and uses algorithms to reconstruct 3D shapes. Laser scanning measures reflected laser points to create 3D models. Both methods obtain 3D data for spinal analysis but face limitations similar to moire imaging.

In summary, current spinal deformity screening methods have advantages and disadvantages. Physical methods are simple but subjective and inefficient, with ethical concerns. Imaging methods offer high precision but may involve radiation, high costs, and privacy issues. This highlights the need for an efficient, precise, economical, and non-invasive screening method, providing direction for developing a spinal deformity motion correction testing system based on artificial intelligence and computer vision.

3. The Significance and Challenges of Conducting Spinal Health Screening in Schools

3.1 The Importance

Implementing spinal health screening in schools holds profound significance. Schools, as hubs for adolescents, provide a conducive setting for such screening. It enables early detection and timely intervention for spinal deformities, preventing their progression and the need for surgery. Early intervention is crucial for controlling disease progression, reducing complications, and lowering medical costs.

Authoritative organizations such as the International Society for the Study and Rehabilitation of Spinal Deformities, the International Society for the Study of Lumbar Spinal Deformities, and the American Association of Orthopaedic Surgeons have recommended spinal health screening and offered guidance. Studies indicate that seven out of eight international screening programs are school-based, underscoring the critical role of schools in preventing and controlling spinal deformities. School-based screening leverages school resources and organization to efficiently screen large numbers of adolescents. It can detect potential spinal issues early and provide timely exercise interventions, helping affected students correct deformities and promoting healthy spinal development.

Moreover, spinal health screening in schools raises awareness among students, parents, and teachers about spinal health. It disseminates spinal health knowledge, strengthens adolescents' self-care awareness, and fosters good posture and exercise habits. In the long run, this improves adolescents' spinal health and enhances their quality of life(Miao, 2024).

3.2 Challenges

Despite the significance of spinal health screening in schools, numerous challenges arise in practice. Standardizing spinal health screening procedures for children and adolescents remains an issue. There's also the need to scientifically regulate screening times and age ranges. Since adolescents' spinal development varies with age, determining optimal screening time points and frequency is crucial for enhancing screening effectiveness.

The sensitivity and specificity of screening methods present another challenge. An ideal method should accurately identify potential spinal deformity patients while minimizing false - positives to reduce anxiety and further examination burdens.

Radiation exposure during screening is another controversial issue. X - ray measurement, though the diagnostic gold standard, has radiation risks that limit its use in mass screening. Developing a radiation - free or low - radiation screening method is a research priority. Cost - effectiveness analysis of screening is also important. School screening requires significant human, material, and financial resources, so screening programs must be economically viable and offer substantial health benefits.

Privacy protection is equally important during school screening. Some methods requiring back exposure may infringe on students' privacy. Appropriate measures must be taken to ensure the screening process is dignified and comfortable.Addressing these challenges through research and practice is essential for promoting effective spinal health screening in schools.

4. Development of Spinal Deformity Motion Correction Testing System

4.1 Model Training

4.1.1 Data Collection and Preprocessing

Before model training, extensive human image collection is essential. A standardized image collection process is designed to capture images that accurately reflect spinal characteristics. Collaborating with multiple schools, images are collected from students of various ages and genders, using portable devices. Students are asked to stand in specified poses or perform simple movements to ensure image diversity and representativeness.

The collected images undergo preprocessing steps such as cropping, grayscale conversion, enhancement, and normalization. Cropping removes irrelevant parts of the image, grayscale conversion reduces data dimensions, and enhancement highlights key features to improve model recognition. Normalization unifies the image data into a specific range for better model convergence during training.

4.1.2 Bone Landmark Annotation

Annotating bone landmarks on preprocessed images is crucial for model training. A team of medical imaging experts and physical education teachers precisely marks key bone points, including spinal vertebrae, shoulders, hips, knees, and ankles. Adhering to unified standards ensures annotation accuracy and consistency. The annotated data undergoes quality checks to correct errors, providing high - quality data for subsequent model training.

4.1.3 Machine Learning and Model Training

Based on annotated bone - landmark image data, advanced machine learning algorithms are used to train a bone - landmark recognition model. During training, multiple classic CNN architectures are selected, optimized, and improved to enhance the model's accuracy and robustness in recognizing bone landmarks. Extensive experiments and comparative analyses ultimately identify the most suitable CNN architecture for the data characteristics.

The dataset is divided into training, validation, and test sets, which are used for model training, hyperparameter tuning, and performance evaluation, respectively. Continuous iterative training and optimization enable the model to gradually learn to extract bone - landmark features from images and accurately identify their positions. To improve the model's generalization ability, data augmentation techniques, such as image rotation, translation, and scaling, are introduced to generate more training samples and enhance the model's adaptability to diverse postures and scenarios.

Numerous X - ray imaging data are collected, and professional radiologists calculate the corresponding Cobb angles, a key indicator of spinal deformity severity. By integrating the bone - landmark recognition model with Cobb angle data, a correlation model between bone landmarks and Cobb angles is further trained. This model can predict the Cobb angle range based on identified bone - landmark positions, providing a more accurate basis for early spinal deformity screening and diagnosis.

4.2 Posture Analysis

4.2.1 Image Capture and Preprocessing

During posture analysis, specialized high - resolution, low - latency image capture devices are used to collect real - time user posture data. The captured images undergo preprocessing steps, including noise reduction, contrast enhancement, and size adjustment, to improve image quality and processing efficiency.

4.2.2 Pattern Recognition and Posture Diagnosis

The trained bone - landmark and Cobb angle correlation model is utilized to perform pattern recognition on the collected user images. Through model calculations and analysis, the user's spinal posture characteristics are quickly identified and compared with normal spinal postures. Combined with posture recognition data, such as shoulder level, pelvic tilt, and neck protrusion, a comprehensive posture diagnosis is conducted. The diagnosis results indicate common posture problems (e.g., uneven shoulders, pelvic tilt, neck protrusion, X - shaped legs, O - shaped legs) and their severity.

4.2.3 Posture Analysis Database Matching

To accurately assess user posture, a posture analysis database is established, containing a large number of sample data with diverse age, gender, and posture characteristics, along with corresponding posture - related indices and classification criteria. By comparing the user's posture diagnosis results with the database indices, the user's specific range in various posture indices is determined. This process provides a comprehensive understanding of the user's posture issues and a scientific basis for developing personalized exercise intervention plans.

4.3 Intervention Program

4.3.1 Principles for Developing Personalized Exercise Intervention Programs

Following the principles of specificity, progression, safety, and feasibility, a personalized exercise intervention program is created for each user based on the posture analysis database comparison. Specificity involves selecting targeted exercises and training methods based on individual posture issues and severity. Progression calls for gradually increasing exercise intensity and difficulty to prevent sports injuries and enhance training effectiveness. Safety emphasizes considering the user's age, physical condition, and exercise capacity to ensure program safety. Feasibility ensures the program can be easily adjusted and implemented in daily life.

4.3.2 Intelligent Generation of Exercise Intervention Programs

Based on the above principles, an intelligent system for generating exercise intervention programs has been developed. It automatically selects suitable exercises from a diverse library, covering corrective movements, strength training, stretching, and balance - coordination exercises. The system arranges exercise order, intensity, and frequency according to the user's posture severity and physical state, and offers detailed guidance for each exercise to ensure proper implementation.

The intelligent system also dynamically adjusts programs based on regular posture reassessments. If improvement is observed, it reduces intensity or modifies exercises to consolidate gains; if no significant improvement or new issues arise, it updates the program by adding exercises or increasing intensity to maintain intervention effectiveness and specificity.

4.3.3 Implementation and Guidance of Exercise Intervention Programs

To facilitate effective implementation, a user - friendly mobile app has been developed. Users can view and learn their exercise programs and record training progress. The app includes a timer function to help establish regular exercise routines. Online exercise guidance services are available for users to consult with professionals via the app. Additionally, offline exercise training courses and lectures are regularly organized to provide face - to - face expert guidance and enhance users' understanding and implementation of exercise interventions.

4.4 System Advantages and Innovations

This spinal deformity motion correction testing system offers intelligent solutions for adolescent spinal health screening and intervention. Integrating AI technology with spinal health screening, it automates posture analysis and diagnosis, improving screening efficiency and objectivity. Its non - contact image capture protects privacy and enhances user comfort.

The system manages large amounts of posture data via a cloud database, enabling long - term tracking and analysis for informed intervention strategies. It also generates personalized exercise correction programs based on individual assessments, ensuring targeted and effective interventions.

Innovatively, the system combines sports and medicine in a novel screening - intervention model. It leverages the role of physical education teachers and the expertise of rehabilitation therapists, enhancing the medical basis and feasibility of exercise correction. Using advanced machine learning algorithms and skeletal landmark recognition, it enables fully automatic posture assessment. Its personalized exercise intervention module improves user compliance and correction outcomes. The cloud - based platform supports cross - regional data sharing and collaborative research, promoting standardization and policy optimization in spinal health.

5. Conclusion and Future Outlook

5.1 Research Conclusion

This study successfully developed a spinal - deformity motion - correction testing system that combines AI with spinal - health screening. It enables early detection of spinal deformities and personalized exercise interventions. Trained on numerous human - image data, the system accurately recognizes bone landmarks and assesses spinal posture. For posture analysis, it quickly identifies common issues like uneven shoulders and hips, offering basic posture - health advice via a posture - analysis database. Additionally, it generates exercise - intervention programs tailored to users' posture conditions, aiding spinal - health improvement. Despite development challenges, the system enhances the efficiency and accuracy of spinal - deformity screening, offering strong support for adolescent spinal health.

5.2 Future Research Outlook

Future optimization of this system will focus on several aspects. First, model - algorithm refinement will improve the accuracy and efficiency of posture analysis for better detection of minor spinal deformities. Second, increased system automation will reduce manual intervention and enhance user experience. Third, expanded system functionality through VR/AR integration will make exercise interventions more engaging and interactive, boosting user compliance. Furthermore, collaboration with medical institutions and schools will broaden data - collection networks, enhancing the system's intelligence and data reliability. Finally, combining the system with smart - home devices could enable real - time posture monitoring and reminders, establishing a comprehensive spinal - health management system. These improvements aim to better serve adolescent spinal - health management and advance global spinal - health initiatives.

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