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Review Article

Optical Sensing: A Promising and Radiation-Free Approach for Spine Malalignment Assessment

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Background

Adolescent Idiopathic Scoliosis (AIS) is a multifaceted three-dimensional (3D) spinal deformity characterized by lateral curvature and often accompanied by a rotation of the vertebrae [1]. The prevalence of AIS varies between 0.47% and 5.2% globally, with regional differences, and is observed to be twice as common in females compared to males [2]. In Hong Kong, AIS affects approximately 3%–4% of the adolescents [3,4], while in mainland China, the prevalence is slightly higher at around 5% [5]. Given the immature skeletal systems of adolescents, there is a significant risk of disease progression [6,7]. A recent longitudinal study has shown that approximately 29.1% of untreated AIS cases progress over time [8].

Accurate and quantitative assessment of scoliosis severity is crucial for proper diagnosis, effective treatment planning, accurate prognosis, and continuous monitoring of disease progression and treatment outcomes [9]. Traditional physical examinations tend to be subjective and lack quantitative precision [10]. The Cobb method, which relies on X-ray imaging, is considered the gold standard for evaluating AIS severity [11]. Typically, AIS patients undergo X-ray assessments every four to six months until they reach skeletal maturity. However, frequent exposure to radiation increases the risk of breast cancer in girls with scoliosis [12,13] and has been linked to higher rates of leukemia and prostate cancer in children [14]. The necessity for frequent X-ray scans to manage and treat AIS is thus complicated by the harmful effects of radiation, requiring a delicate balance between radiation exposure and effective disease monitoring.

Related Work on Radiation Reduction for AIS

To address the issue of radiation dose accumulation from continuous radiographic monitoring, researchers have explored and tested various alternatives for many years. One direct approach has been the improvement of radiographic imaging systems. A significant development in this area is the EOS low-dose biplanar X-ray imaging system, which employs slot-scanning technology [16]. This system achieves an 8 to 10-fold reduction in the radiation dose required for obtaining 2D spinal images while maintaining high image quality and diagnostic accuracy [17]. Despite this substantial reduction, the remaining radiation risk necessitates the EOS system's installation in specially shielded X-ray rooms, thereby increasing implementation costs and limiting its widespread use.

With the development of various imaging technologies, multiple non-radiative medical imaging modalities have gradually been applied in the assessment and monitoring of scoliosis due to their safety, simplicity, and convenience compared to the EOS system [18]. Among these, optical and acoustic imaging methods are the most advanced, with relevant imaging equipment already developed. Moiré topography [19,20] and rasterstereography systems [21], based on structured light imaging principles, are the most valuable and widely used tools for investigating the 3D shape of the torso's back surface. Since abnormal torso shapes are often associated with scoliosis, these methods can indirectly assess the condition. Moiré topography projects structured light onto the back surface and analyses the reflected Moiré patterns to reconstruct the 3D body sur-

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face structure. Similarly, rasterstereography projects a grid of horizontal black lines onto the patient's back and analyses the distortion of the reflected grid lines to create a 3D surface map of the back, such as the DIERS Formetric 4D system (DIERS Medical Systems, Chicago, Illinois, USA) [22]. Many researchers have used structured light methods to evaluate back shape and spinal deformity with varying degrees of success [23,24]. The primary issue with structured light methods is their heavy reliance on fringe patterns obtained from body surface reflections. Fringe patterns are highly susceptible to changes in the patient's position, meaning that even a slight shift can cause significant changes in the fringe pattern. This sensitivity greatly limits the robustness and accuracy of structured light methods.

Ultrasonic imaging is a contact-based, non-radiative medical imaging method that uses the reflection of ultrasound waves from the bone cortex surface to provide clear images and anatomical information of the spine area [25]. Unlike structured light methods, ultrasonic imaging can penetrate the superficial layers of the back, revealing and recording partial anatomical and spatial morphological information of the spine. This technique primarily captures the shape of the spine near the back of the torso, while it is less effective in acquiring information from the front side of the torso.

One notable application of ultrasonic imaging for spine detection is the Scolioscan system [26]. Due to its radiation-free nature, the Scolioscan system can be installed in less restricted spaces, reducing operational costs compared to the EOS system. However, the ultrasound system and its data are susceptible to electromagnetic field distortion [18], leading to system offsets, counteractions, or transient jitters in spatial and orientation data. Therefore, strict experimental environmental controls are required. In addition, ultrasonic equipment faces challenges such as being large and expensive (e.g., Scolioscan), requiring highly skilled operators, and being time-consuming to capture full spinal information. In recent years, significant advancements have been made in the miniaturization and portability of ultrasonic imaging devices, such as the handheld Scolioscan Air [27]. These advancements have addressed issues of equipment bulkiness and mobility, reduced costs, and facilitated spine examinations in remote areas.

Advancement and Benefits of Optical Sensing Technique

Recently, an emerging active imaging technology known as optical sensing has gained traction in the fields of robotic vision and navigation [28]. This technique utilizes time-of-flight imaging principles, where lasers or modulated light are emitted into the environment, and the time taken for the light to reflect back to the receiver is recorded to determine the distance to various objects. Compared to traditional structured light technology, optical sensing offers greater robustness in object positioning and superior resistance to ambient light interference. Additionally, optical sensing effectively simulates the process by which experienced physicians visually examine the backs of AIS patients. This capability allows the technology to be seamlessly integrated into AIS clinical workflows, enhancing the accuracy of diagnoses and increasing clinical interpretability. As a result, this technology is being increasingly applied in clinical applications [11,29].

Compared to traditional structured light and ultrasound imaging, optical sensing technology offers unique advantages in clinical spinal applications. First, the simplicity of its imaging principle and the compact size of key imaging modules provide significant benefits in terms of device miniaturization and portability. Second, optical sensing technology is highly robust to external environmental factors, making it less susceptible to variations in light distribution, electromagnetic fields, and patient posture. This leads to theoretically more accurate and consistent detection results. Furthermore, optical sensing enables rapid, non-contact 3D imaging, which can enhance clinical efficiency and improve patient compliance. Several studies have already applied optical sensing technology to clinical spinal health assessments [30-32]. These applications typically involve using depth cameras to capture geometric information of the patient's back and analysing this data to assess spinal morphology. For example, Liang et al. [32]. utilized the iPhone LIDAR to gather back surface information, constructing a statistical shape model of the spine for morphological analysis. Similarly, Meng et al. [30] employed the Azure Kinect camera to capture high-precision RGBD images of the back. They used generative AI to synthesize radiographs from these RGBD images, which were then used to assess scoliosis.

Limitation of Optical Sensing Assessment Method

While optical sensing technology offers numerous advantages in spinal health monitoring and morphological assessment, it also faces several challenges. Primarily, due to its imaging principles, optical sensing can only detect information from the body surface, estimating the health of the spine based on surface morphology without directly capturing anatomical details of the spine. This necessitates further reconstruction of spinal morphology or anatomical information. Since reconstruction techniques are based on the assumption that back surface contours correlate with the spine's internal anatomy, the resulting internal spine alignment may not be entirely accurate. On the other hand, current methods typically utilize a single RGBD image of the back, capturing only the posterior geometry of the torso in the posteroanterior direction. This approach neglects the geometric information from the front and sides of the torso, further limiting the accuracy of the assessment.

Future Directions

To address the challenges faced by optical sensing technology in spinal health detection and assessment, future research should focus on enhancing the accuracy of spinal morphology and anatomical information reconstruction, as well as incorporating multi-view data. With the continuous advancements in artificial intelligence, deep learning methods have achieved unprecedented precision in computer vision and 3D geometric reconstruction, providing powerful tools for accurately reconstructing the spine's 3D alignment [33,34]. Additionally, optical sensing should collect data from multiple views to capture comprehensive information about the torso. This includes acquiring 360-degree data or light field information [35,36] around the torso to provide more precise geometric data for subsequent analysis. Future analytical techniques will also need to leverage multi-view vision and light field reconstruction [37-40] technologies to improve accuracy and effectiveness.

Conclusion

In summary, optical sensing technology offers unique advantages in spinal health detection and assessment. Compared to existing non-radiative evaluation techniques, it boasts high sensing accuracy, strong resistance to environmental interference, low cost, and portability. With the integration of LIDAR sensors in smartphones, this technology holds significant potential for widespread use in daily life, enabling individuals to monitor their spinal health with a simple smartphone. This is particularly impactful for adolescent spinal health. As optical sensing technology and analytical techniques continue to advance, we can anticipate that this technology will increasingly benefit society, providing accessible and accurate spinal health monitoring for all.

References

1. Brink RC, Colo D, Schlösser TP, Vincken KL, van Stralen M, Hui SCN, et al. Upright, prone, and supine spinal morphology and alignment in adolescent idiopathic scoliosis. Scoliosis and spinal disorders. 2017; 22: 6.

2. Konieczny MR, Senyurt H, Krauspe R. Epidemiology of adolescent idiopathic scoliosis. Journal of children's orthopaedics. 2013; 7: 3-9.

3. Fong DY, Cheung KM, Wong YW, Wan YY, Lee CF, Lam TP, et al. A population-based cohort study of 394,401 children followed for 10 years exhibits sustained effectiveness of scoliosis screening. The Spine Journal. 2015; 15: 825-33.

4. Fok Q, Liu P, Yip J, Cheung MC, Yick KL, Ng SP, et al. School scoliosis screening in Hong Kong: trunk asymmetry of girls with scoliosis. MOJ orthopedics & rheumatology. 2020; 12: 7-10.

5. Cheng JC, Castelein RM, Chu WC, Danielsson AJ, Dobbs MB, Grivas TB, et al. Adolescent idiopathic scoliosis. Nature reviews disease primers. 2015; 1: 15030.

6. Reamy BV, Slakey JB. Adolescent idiopathic scoliosis: review and current concepts. American family physician. 2001; 64: 111-6.

7. Lonstein JE, Carlson J. The prediction of curve progression in untreated idiopathic scoliosis during growth. JBJS. 1984; 66: 1061-71.

8. Lara T, Astur N, Jones TL, Perake V, Moisan A, Warner WC, et al. The risk of curve progression and surgery in African Americans with adolescent idiopathic scoliosis. Spine deformity. 2017; 5: 250-4.

9. Meng N, Cheung JP, Wong K-YK, Dokos S, Li S, Choy RW, et al. An artificial intelligence powered platform for auto-analyses of spine alignment irrespective of image quality with prospective validation. E Clinical Medicine. 2022; 43: 101252.

10. Zhang T, Zhu C, Zhao Y, Zhao M, Wang Z, Song R, et al. Deep Learning Model to Classify and Monitor Idiopathic Scoliosis in Adolescents Using a Single Smartphone Photograph. JAMA Network Open. 2023; 6: e2330617-e.

11. Meng N, Cheung JP, Huang T, Zhao M, Zhang Y, Yu C, et al. EUFormer: Learning Driven 3D Spine Deformity Assessment with Orthogonal Optical Images. arXiv preprint arXiv:240716942. 2024.

12. Hoffman DA, Lonstein JE, Morin MM, Visscher W, Harris III BS, Boice Jr JD. Breast cancer in women with scoliosis exposed to multiple diagnostic x rays. JNCI: Journal of the National Cancer Institute. 1989; 81: 1307-12.

13. Doody MM, Lonstein JE, Stovall M, Hacker DG, Luckyanov N, Land CE. Breast cancer mortality after diagnostic radiography: findings from the US Scoliosis Cohort Study. Spine. 2000; 25: 2052-63.

14. Schmitz-Feuerhake I, Pflugbeil S. 'Lifestyle' and cancer rates in former East and West Germany: the possible contribution of diagnostic radiation exposures. Radiation protection dosimetry. 2011; 147: 310-3.

15. Geijer Hk, Beckman K-W, Jonsson B, Andersson Tr, Persliden J. Digital radiography of scoliosis with a scanning method: initial evaluation. Radiology. 2001; 218: 402-10.

16. McKenna C, Wade R, Faria R, Yang H, Stirk L, Gummerson N, et al. EOS 2D/3D X-ray imaging system: a systematic review and economic evaluation. Health technology assessment (Winchester, England). 2012; 16: 1-188.

17. Rehm J, Germann T, Akbar M, Pepke W, Kauczor HU, Weber MA, et al. 3D-modeling of the spine using EOS imaging system: Inter-reader reproducibility and reliability. PLoS One. 2017; 12: e0171258.

18. Kandasamy G, Bettany-Saltikov J, Van Schaik P. Posture and back shape measurement tools: A narrative. Spinal Deform Adolesc Adults Older Adults 2021; 21.

19. Takasaki H. Moiré topography. Applied optics. 1970; 9: 1467-72.

20. Labecka MK, Plandowska M. Moiré topography as a screening and diagnostic tool—A systematic review. PloS one. 2021; 16: e0260858.

21. Berryman F, Pynsent P, Fairbank J, Disney S. A new system for measuring three-dimensional back shape in scoliosis. European Spine Journal. 2008; 17: 663-72.

22. Betsch M, Wild M, Rath B, Tingart M, Schulze A, Quack V. Radiation-free diagnosis of scoliosis: An overview of the surface and spine topography. Der Orthopäde. 2015; 44: 845-51.

23. Ng S-Y, Bettany-Saltikov J. Suppl-9, M5: Imaging in the diagnosis and monitoring of children with idiopathic scoliosis. The open orthopaedics journal 2017; 11: 1500-1520.

24. Adankon MM, Chihab N, Dansereau J, Labelle H, Cheriet F. Scoliosis follow-up using noninvasive trunk surface acquisition. IEEE Transactions on Biomedical Engineering. 2013; 60: 2262-70.

25. Suzuki S, Yamamuro T, Shikata J, Shimizu K, Iida H. Ultrasound measurement of vertebral rotation in idiopathic scoliosis. The Journal of Bone & Joint Surgery British. 1989; 71: 252-5.

26. Zheng Y-P, Lee TT-Y, Lai KK-L, Yip BH-K, Zhou G-Q, Jiang W-W, et al. A reliability and validity study for Scolioscan: a radiation-free scoliosis assessment system using 3D ultrasound imaging. Scoliosis and spinal disorders. 2016; 11: 1-15.

27. Lai KK-L, Lee TT-Y, Lee MK-S, Hui JC-H, Zheng Y-P. Validation of scolioscan air-portable radiation-free three-dimensional ultrasound imaging assessment system for scoliosis. Sensors. 2021; 21: 2858.

28. Shan J, Toth CK. Topographic laser ranging and scanning: principles and processing. CRC press. 2018.

29. Nguyen CV, Izadi S, Lovell D. Modeling kinect sensor noise for improved 3d reconstruction and tracking. 2012 second international conference on 3D imaging, modeling, processing, visualization & transmission. 2012: 524-30.

30. Meng N, Wong K-YK, Zhao M, Cheung JP, Zhang T. Radiograph-comparable image synthesis for spine alignment analysis using deep learning with prospective clinical validation. E Clinical Medicine. 2023; 61: 102050.

31. Hai JJ, Meng N, Zhao M, Cheung JP-Y, Zhang T. AI Powered Mobile Analysis of Scoliosis among Children in Qinghai-Tibetan Plateau of China. 2024 IEEE Integrated STEM Education Conference (ISEC). 14th IEEE Integrated STEM Education Conference (09/03/2024-09/03/2024, Princeton University, NJ); 2024; 2024.

32. Liang Y, Wang C, Yu Y, Zhou Y, Zheng Y, Luo Y, et al. 3d spine model reconstruction based on rgbd images of unclothed back surface. IEEE Transactions on Biomedical Engineering. 2023: 71.

33. Zhao M, Meng N, Cheung JPY, Zhang T. PCT-GAN: A Real CT Image Super-Resolution Model for Trabecular Bone Restoration. 2023 IEEE 20th International Symposium on Biomedical Imaging (ISBI). 2023: 1-5.

34. Zhao M, Meng N, Cheung JPY, Yu C, Lu P, Zhang T. Spine HR former: A Transformer-Based Deep Learning Model for Automatic Spine Deformity Assessment with Prospective Validation. Bioengineering. 2023; 10: 1333.

35. Sun X, Meng N, Xu Z, Lam EY, So HK-H. Sparse hierarchical nonparametric Bayesian learning for light field representation and denoising. 2016 International Joint Conference on Neural Networks (IJCNN); 2016: IEEE. 2016; 3272-9.

36. Meng N, Zeng T, Lam EY. Spatial and angular reconstruction of light field based on deep generative networks. 2019 IEEE International Conference on Image Processing (ICIP); 2019: IEEE. 2019: 4659-63.

37. Meng N. Geometric representation learning for light field restoration. HKU Theses Online (HKUTO). 2020.

38. Meng N, Li K, Liu J, Lam EY. Light field view synthesis via aperture disparity and warping confidence map. IEEE Transactions on Image Processing 2021; 30: 3908-21.

39. Meng N, So HK-H, Sun X, Lam EY. High-dimensional dense residual convolutional neural network for light field reconstruction. IEEE transactions on pattern analysis and machine intelligence. 2019; 43: 873-86.

40. Meng N, Ge Z, Zeng T, Lam EY. LightGAN: A deep generative model for light field reconstruction. Ieee Access. 2020; 8: 116052-63.