HOKKAIDO UNIVERSITY

Title	From Image Preprocessing to 3D Modeling : Deep Learning Approaches for Coronary Artery Analysis [an abstract of dissertation and a summary of dissertation review]
Author(s)	李, 彦君
Degree Grantor	北海道大学
Degree Name	博士(保健科学)
Dissertation Number	甲第16334号
Issue Date	2025-03-25
Doc URL	https://hdl.handle.net/2115/94965
Rights(URL)	https://creativecommons.org/licenses/by/4.0/
Type	doctoral thesis
File Information	Yanjun_Li_abstract.pdf, 論文内容の要旨

Hokkaido University Collection of Scholarly and Academic Papers : HUSCAP

様式　８

学位論文内容の要旨

博士の専攻分野の名称：博士（保健科学）　　　　氏名：LI YANJUN

学位論文題名

From Image Preprocessing to 3D Modeling: Deep Learning Approaches for Coronary Artery Analysis

（深層学習手法を用いた冠動脈解析のための画像前処理から 3D モデリングに関する研究）

Coronary artery disease (CAD) is one of the leading global health concerns, significantly contributing to mortality, morbidity, and the economic burden on healthcare systems. CAD is primarily diagnosed using invasive coronary angiography (ICA). However, this method heavily relies on the subjective interpretation of radiologists, resulting in variability in diagnostic accuracy. Factors such as suboptimal imaging angles, uneven contrast distribution, and anatomical complexity further complicate accurate assessment of stenosis. As the demand for precision and efficiency in medical diagnostics grows, advancements in deep learning have demonstrated great potential in overcoming these limitations.

Chapter 1 introduces a Hessian-based image preprocessing method, combined with image fusion techniques, to enhance the visibility of coronary vasculature in angiographic images. The Hessian-based Frangi vesselness (HFV) filter improves visualization of vascular structures by leveraging eigenvalue analysis, while image fusion preserves critical features of the original data. The preprocessing pipeline addresses issues like low contrast and image noise, enabling deep learning models to detect stenotic features with greater accuracy. Experimental results using advanced models, including YOLOv10-X and RT-DETR R101, show a significant improvement in AP50(%) metrics by approximately 5%. Furthermore, the effect of imaging angles was systematically analyzed, revealing the optimal performance at the left coronary artery (LCA) zero-degree angle with an AP50(%) of 90.5. Although this approach enhances diagnostic accuracy, it introduces additional latency, highlighting a trade-off between real-time feasibility and precision.

Chapter 2 explores a novel attention-enhanced YOLO network tailored for coronary artery stenosis localization. This method integrates GhostNet and Transformer components to combine lightweight efficiency with the global feature modeling capabilities of attention mechanisms. The proposed approach is particularly effective in detecting stenosis in smaller or overlapping branches, which are often neglected in traditional methods due to challenges in feature representation. Results indicate that incorporating attention mechanisms not only improves detection accuracy but also reduces computational overhead, making the method suitable for real-time diagnostic applications.

In Chapter 3, the focus shifts to the automated extraction and 3D reconstruction of the right coronary artery (RCA) from CT images. The approach embeds GhostNet into neural network for efficient segmentation and Transformers to capture global contextual dependencies. By extracting vascular cross-sections from segmented images and integrating them into a volumetric mesh grid, the technique produces high-fidelity 3D representations of the RCA. Comparative evaluations of interpolation methods, such as Laplacian pyramid and Gaussian smoothing, reveal substantial improvements in structural integrity and rendering accuracy. The resulting 3D models offer detailed visualizations, supporting clinicians in diagnosing complex conditions and planning interventions with greater confidence.

The cumulative contributions of this research address several critical challenges in CAD diagnostics. First, the preprocessing methodology enhances image quality, particularly for datasets with noise or low contrast, ensuring that deep learning models achieve higher detection accuracy. Second, the YOLO-based attention-enhanced network improves the detection of stenosis in smaller vessels and complex regions, making it highly applicable in clinical settings. Finally, the automated 3D reconstruction framework bridges the gap between 2D image analysis and comprehensive 3D visualization, providing clinicians with actionable insights into coronary artery conditions.

Despite its contributions, this study acknowledges certain limitations. The preprocessing pipeline, while effective in improving accuracy, introduces latency due to the computational complexity of the HFV filter and image fusion steps. Additionally, while the YOLO-based network performs well in detecting branch stenosis, further optimization is needed to handle more diverse datasets with varying patient demographics. The 3D reconstruction framework, though promising, would benefit from expanded validation on larger datasets to confirm its generalizability across different clinical conditions.

Future work will focus on integrating these methods into a unified system that supports end-to-end CAD diagnosis. By expanding the dataset to include a broader and more diverse patient population and optimizing the model to further reduce latency, this research aims to enable seamless real-time implementation within clinical workflows. Additionally, exploring hybrid architectures that combine attention mechanisms with lightweight networks holds potential to advance the field of medical imaging analysis. It is anticipated that, by bridging the gap between computational advancements and clinical needs, this work will contribute to the continuous improvement of patient outcomes and the advancement of medical image analysis.