

Title	医療画像分割の向上:モデルの精度、プライバシー、および効率に関する研究
Author(s)	孫, 冠群
Citation	
Issue Date	2024-09
Type	Thesis or Dissertation
Text version	ETD
URL	http://hdl.handle.net/10119/19388
Rights	
Description	Supervisor: NGUYEN, Minh Le, 先端科学技術研究科, 博士

氏名	孫冠群		
学位の種類	博士 (情報科学)		
学位記番号	博情第 530 号		
学位授与年月日	令和 6 年 9 月 24 日		
論文題目	ENHANCING MEDICAL IMAGE SEGMENTATION: STUDIES IN MODEL ACCURACY, PRIVACY, AND EFFICIENCY		
論文審査委員	Nguyen Le Minh	JAIST	Professor
	Jianhua Ma	Hosei University	Professor
	Shinobu Hasegawa	JAIST	Professor
	Naoya Inoue	JAIST	Assoc. Prof.
	Kiyooki Shirai	JAIST	Assoc. Prof.
	Shogo Okada	JAIST	Assoc. Prof.

論文の内容の要旨

Medical image segmentation plays a crucial role in quantifying diseases, assessing prognosis, and evaluating treatment results. However, manual segmentation is time-consuming, prone to interobserver variability, and limited by the availability of skilled experts. Despite advances in deep learning-based approaches for automatic segmentation, challenges such as precise boundary delineation, limited annotated data, and the trade-off between model complexity and performance persist. In addition, data privacy concerns hinder the sharing of medical images between institutions, preventing collaborative research and model development.

This dissertation focuses on improving medical image segmentation by addressing three key aspects: model accuracy, data privacy, and computational efficiency. This dissertation proposes novel deep learning architectures and techniques that leverage the power of attention mechanisms, transformer models, federated learning, and knowledge distillation to tackle these challenges.

Firstly, this dissertation introduces DA-TransUNet, a dual attention transformer U-Net architecture that integrates spatial and channel attention mechanisms with transformer models. DA-TransUNet effectively captures fine-grained details and long-range dependencies in medical images, leading to improved segmentation accuracy compared to state-of-the-art methods.

Secondly, this dissertation proposes MIPC-Net, a mutual inclusion mechanism for precise boundary segmentation. MIPC-Net uses complementary information from position and channel features to enhance the delineation of complex anatomical structures and small lesions, resulting in a more accurate boundary segmentation.

Thirdly, this thesis introduces FKD-Med, a framework for medical image segmentation that prioritizes privacy and optimizes communication. FKD-Med integrates federated learning and knowledge distillation techniques to enable collaborative model training between multiple institutions while preserving data privacy. It also improves model efficiency by distilling knowledge from complex models to lighter ones, reducing computational requirements without compromising segmentation performance.

Extensive experiments on multiple benchmark datasets demonstrate the superior performance of the proposed methods and frameworks in terms of segmentation accuracy, boundary precision, and computational efficiency. The contributions of this dissertation advance the field of medical image segmentation by proposing novel architectures, mechanisms, and frameworks that address key challenges related to model accuracy, data privacy, and computational efficiency.

Future research directions include exploring additional attention mechanisms and transformer variants, extending the proposed methods to 3D and volumetric segmentation tasks, integrating differential privacy techniques for enhanced data protection, developing advanced model compression and acceleration techniques, investigating the generalizability and transferability of the proposed approaches to different medical imaging modalities and anatomical regions, and improving the interpretability and explainability of the segmentation models.

By advancing the state-of-the-art in medical image segmentation, this dissertation contributes to the development of accurate, privacy-preserving, and efficient segmentation models that can be seamlessly integrated into clinical workflows, ultimately improving patient care through more precise diagnosis, treatment planning, and monitoring of various diseases and conditions.

Keywords: Medical Image Segmentation, Dual Attention, Mutual Inclusion, Federated Learning, Knowledge Distillation.

論文審査の結果の要旨

This thesis introduces three novel methods for medical image segmentation which includes three major works as follows. The first one proposed the DA-TransUNet which is an ensemble model combining TransUNet and Dual-Attention mechanisms. The second is MIPC-Net, designed to improve boundary detection performance. The third one is FKD-Med, which integrates Federated Learning and Knowledge Distillation to train an accurate model while addressing the privacy concerns of medical data. DA-TransUNet effectively captures fine-grained details and long-range dependencies in medical images, resulting in improved segmentation accuracy. MIPC-Net enhances boundary detection by employing a mutual inclusion mechanism that leverages complementary information from position and channel features, leading to more precise delineation of complex anatomical structures and small lesions. FKD-Med enables collaborative model training across multiple institutions by combining Federated Learning and Knowledge Distillation, optimizing both communication and computational efficiency while preserving data privacy. Extensive testing on benchmark datasets demonstrated that these methods outperform state-of-the-art approaches in segmentation accuracy, boundary precision, and computational efficiency. In general, this dissertation significantly advances the field of medical image segmentation by introducing innovative architectures, mechanisms, and frameworks that tackle critical challenges related to model accuracy, data privacy, and computational efficiency. These contributions have the potential to enhance patient care by enabling more precise and efficient disease quantification, prognosis assessment, and treatment evaluation. The candidate's work, published in international conferences and journals with outstanding results on standard datasets, clearly justifies the award of a Ph.D. degree. This is an excellent dissertation and we approve awarding a doctoral degree to SUN, Guanqun.