Uncertainty-Aware Meta-Learning for Robust Stent Segmentation via Selective Ensemble

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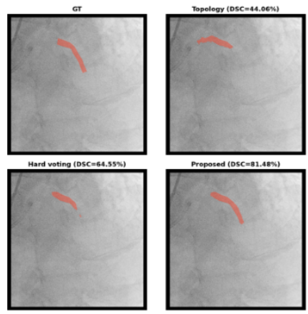
Coronary stent segmentation in fluoroscopic imaging is important for evaluating stent placement and expansion during PCI and for quantitative assessment of structural abnormalities associated with restenosis and thrombosis risk. However, automatic segmentation remains challenging because of low image contrast, motion artifacts, and substantial geometric variation across stent types and deployment settings.



Representative examples

We propose a selective ensemble framework for coronary stent segmentation with a meta learner. The meta learner takes as input the base-model probability maps and pixel-wise uncertainty estimates from five base models, together with the original image, integrates them through a CBAM-based attention mechanism. It is trained using random-fit and nearest-neighbor-fit procedures, and its output is used as pseudo ground truth.

All base models share the EfficientNet-B7/FPN backbone and are independently trained with distinct auxiliary loss functions, including clDice, Hausdorff distance, perimeter regularity, Wasserstein topological homology, and TopK loss, to capture complementary structural characteristics. The proposed framework was evaluated against a hard voting method.

Segmentation Performance in DSC

Division	Internal	External
ClDice	89.21%	80.48%
Hausdorff	89.32%	81.01%
Perimeter	89.24%	81.44%
TopK	89.35%	81.05%
Topology	88.79%	79.87%
Hard voting	90.22%	82.90%
Proposed	90.43%	83.55%

Five-fold validation was performed on 942 images from 826 patients, and external validation was conducted on 361 images from 212 patients. In the internal validation, the proposed method achieved a DSC of 90.43%, compared with 89.35% for the best individual model and 90.22% for the hard voting method. In the external validation, the proposed method achieved a DSC of 83.55%, representing up to a 3.68% improvement over other methods. Our framework improves segmentation accuracy and ensemble robustness, supporting automatic stent analysis in fluoroscopic imaging.