Using Attention-based Convolutional Auto-Encoders for Catheter Path Reconstruction in Ultrasound Images

MATHÉMATIQUES VISION APPRENTISSAGE

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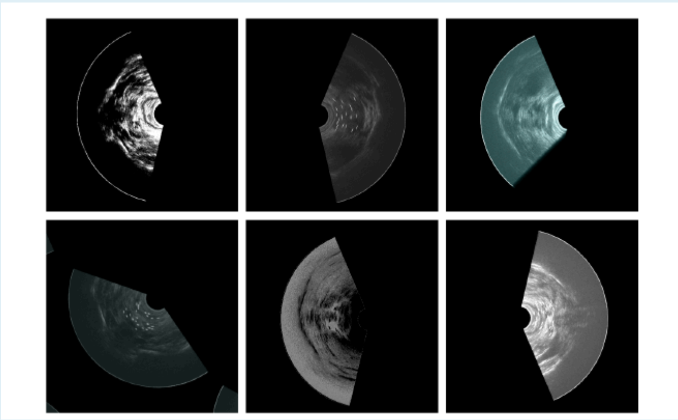
Introduction

Prostate cancer is the second most common cancer in men and the fifth leading cause of death worldwide. High-dose-rate (HDR) brachytherapy, involving the insertion of catheters under image guidance, is a treatment option. However, manually identifying catheters in low signal-to-noise 3D TRUS images is challenging and time-consuming. This article presents an innovative deep-learning method to automate catheter path reconstruction.

Proposed method & model

Data Generation

- **Dataset:** TRUS 3D images on which catheters were synthetically inserted
- **Data Augmentation :** Faster AutoAugment



Model architecture

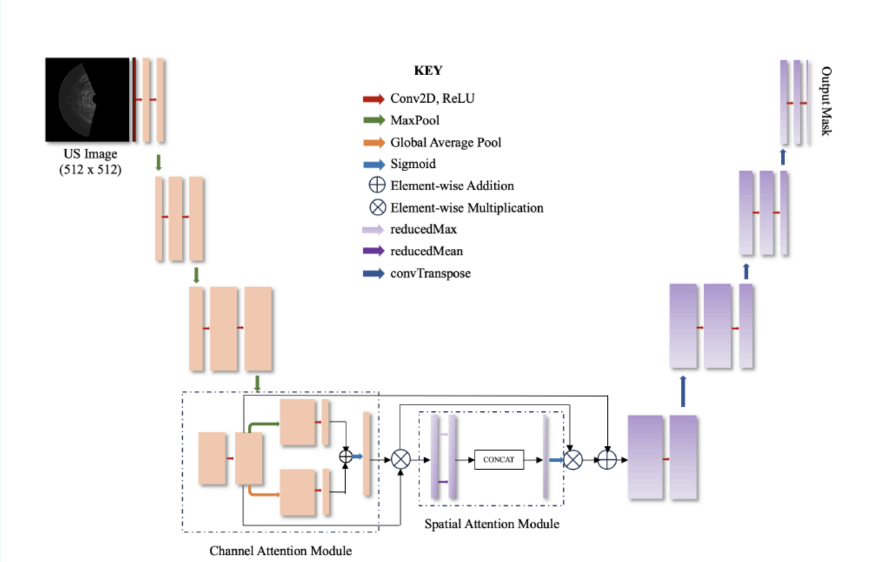


Figure 2: A schematic diagram of the model architecture implemented

Pipeline

- **Input:** 3D ultrasound images
- **Processing:** Attention-based autoencoder generates 2D binary segmentation masks of catheter locations
- **Refinement:** Contour detection and centroid calculation to form a 3D point cloud
- **Reconstruction:** Modified RANSAC algorithm reconstructs 3D catheter paths

Training & Evaluation

- **GPU:** Single NVIDIA A100
- **Epochs:** 100
- **Initialization:** Kaiming
- **Optimizer:** Adam with weight decay
- **Loss Function:** Focal Tversky with optimized parameters

- **Compared against a U-Net model**
- **Usual Metrics :** precision, recall, Dice score, IoU, and MCC
- **Special ones :** Catheter shaft and tip localization error, detection accuracy.

Results

Proposed model vs. U-Net

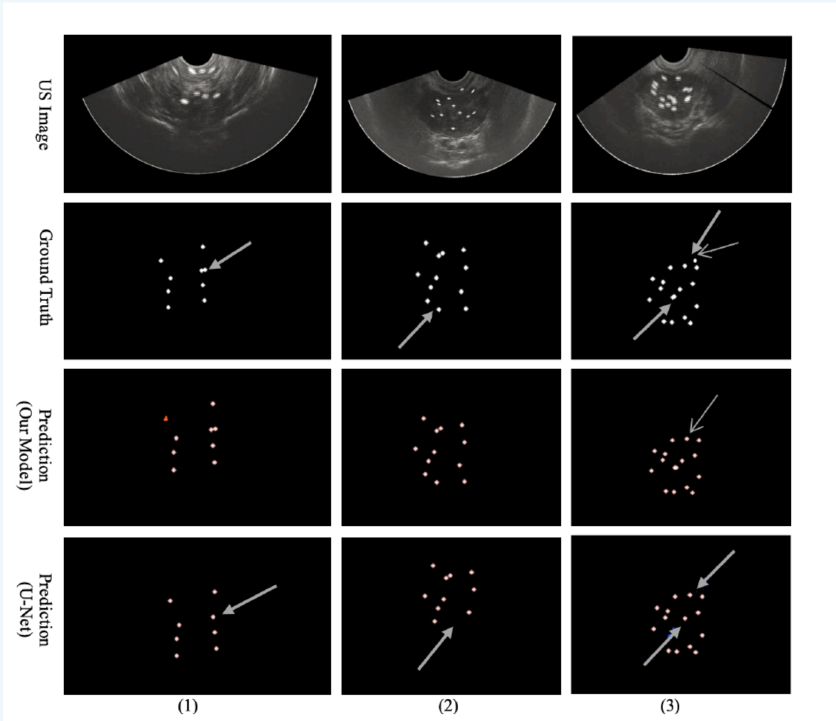
- **Globally better results** on both types of metrics
- U-Net still better on Recall
- **Better inference** (0.0029 seconds vs 0.0057 seconds)

Table 3: A comparison of the evaluation metrics for different methods.

	Dice Score	Precision	Recall	IoU	MCC
U-Net	0.524	0.363	**0.983**	0.361	0.593
Proposed Model	**0.685**	**0.531**	0.982	**0.525**	**0.719**

Table 4: Detection accuracy, tip error and shaft error for different methods.

	Detection Accuracy	Mean Tip Error	Mean Shaft Error
U-Net	93.143	0.283	0.445
Proposed Model	**97.954**	**0.178**	**0.384**



Limitations & Future Work

- **No Ablation Studies**
- **No explanation how the hyperparameters values where obtained**
- **Lack comparaison with SOTA studies**
- **Limited Testing Environment**: Needs to evaluate performance on standard clinical hardware beyond NVIDIA A100
- **Synthetic Dataset Limitation**s: Needs to collect real clinical data with actual implanted catheters from two medical centers

Conclusion

This solution achieved a 98% catheter path detection rate with mean tip and shaft errors of 0.18 mm and 0.39 mm, outperforming the U-Net architecture in accuracy, localization errors, and inference time. To strengthen this work, ablation studies, validation with real patient data, comprehensive comparisons with state-of-the-art methods, and thorough analysis of failure cases are recommended.

Reference

Using attention-based convolutional auto-encoders for catheter path reconstruction in ultrasound images, Shreyasi Mandal, Srinjoy Bhuiya, and Elodie Lugez