DopUS-Net: Quality-Aware Robotic Ultrasound Imaging Based on Doppler Signal

Zhongliang Jiang*, Felix Duelmer*, and Nassir Navab, *Fellow, IEEE*
Affiliation: Computer Aided Medical Procedures, Technical University of Munich, Munich, Germany
*Contributed equally

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Introduction

Motivation

Peripheral Artery Disease (PAD) is associated with:

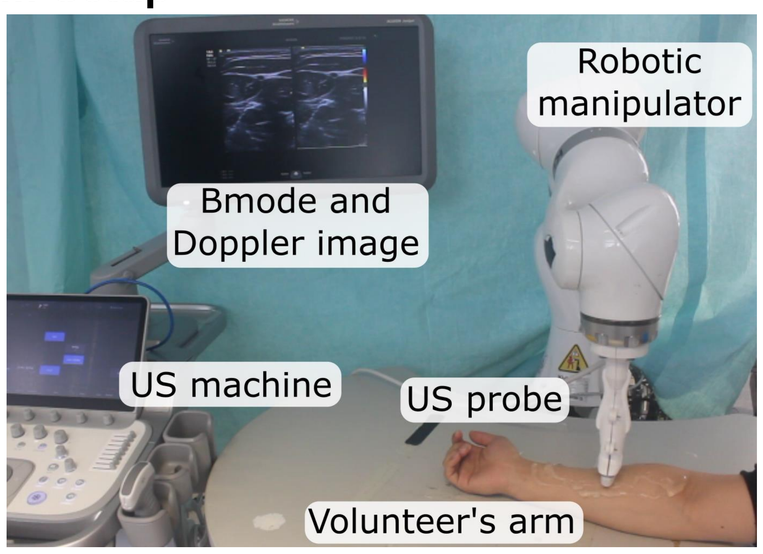
- Increased risk of cardiovascular morbidity and mortality
- Reduced functional capacity

It is estimated that >200 million people have PAD worldwide [1]

Regular screening procedures are recommended, but a lack of clinical experts and expensive equipment limit their application.

→ We propose a robust quality-aware robotic Ultrasound screening using Doppler information for autonomous peripheral artery segmentation and 3D reconstruction.

System Setup



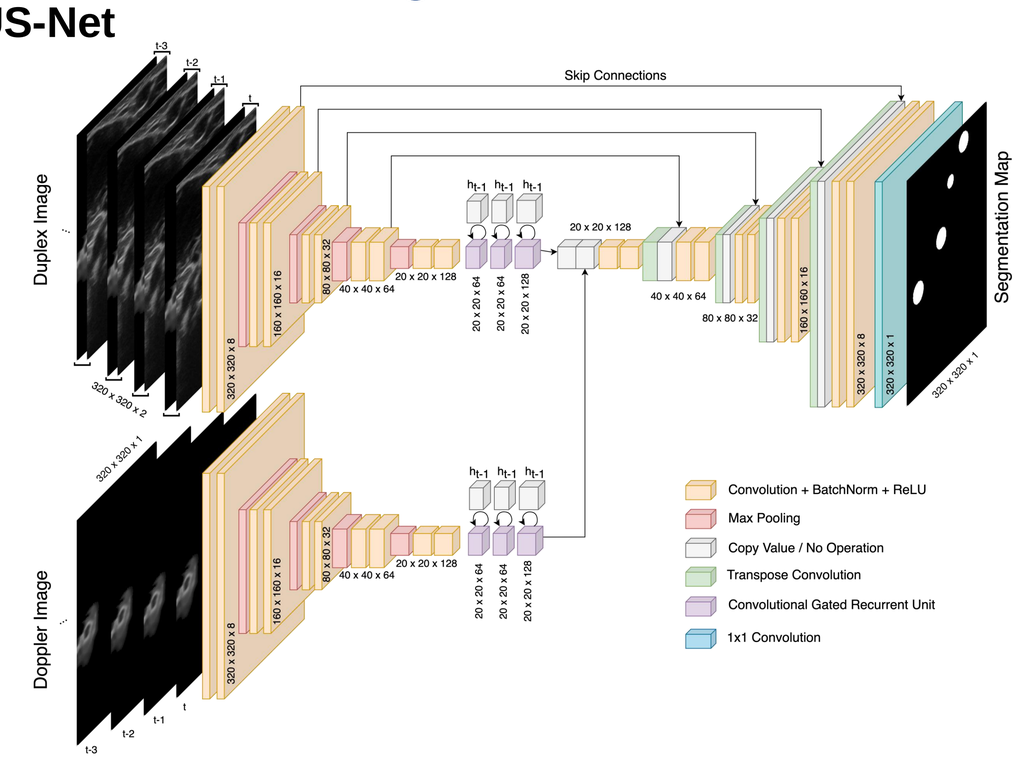
Video

Code

Paper

Segmentation

DopUS-Net



Two Encoders: enable the optimal use of the Doppler effect:

- Top encoder uses a 2-channel input of B-Mode and Doppler grey-scale image for enhanced structural accuracy
- Bottom encoder uses only Doppler images to act as a region proposal module

Temporal Continuity: exploits the anatomical continuity of vessels

- A convolutional gated recurrent unit (ConvGRU) uses a hidden state to keep information from previous frames in memory

Quantitative Evaluation

TABLE II
COMPARISON OF THE RESULTS

Network	Top Encoder	Bottom Encoder	# Parameters	Patient 0	1	2	3	4	5	6	Dice Score Mean (SD)
U-Net	B	-	0.6 M	0.61	0.51	0.45	0.40	0.45	0.29	0.38	0.44 (0.09)
U-Net	BD	-	0.6 M	0.83	0.59	0.54	0.52	0.49	0.39	0.45	0.55 (0.13)
DopUS-Net$^{(0)}$	BD	D	1.3 M	0.83	0.61	0.58	0.60	0.54	0.43	0.47	0.58 (0.12)
VesNet	BD-RNN	-	2.6 M	0.80	0.62	0.60	0.43	0.33	0.42	0.43	0.52 (0.15)
VesNet+	BD-RNN	-	6.3 M	0.80	0.62	0.68	0.58	0.58	0.47	0.53	0.61 (0.10)
U-Net	BD-RNN	-	3.0 M	0.86	0.61	0.71	0.66	0.68	0.60	0.50	0.66 (0.10)
U-Net+	BD-RNN	-	6.5 M	0.78	0.58	0.37	0.40	0.36	0.32	0.41	0.46 (0.15)
DopUS-Net$^{(1)}$	B-RNN	D-RNN♣	6.2 M	0.78	0.54	0.45	0.56	0.55	0.27	0.18	0.48 (0.19)
DopUS-Net$^{(2)}$	BD	D-RNN	3.7 M	0.87	0.69	0.76	0.76	0.72	0.56	0.61	0.71 (0.10)
DopUS-Net$^{(3)}$	B-RNN	D-RNN	6.1 M	0.88	**0.71**	0.79	0.76	0.75	0.57	**0.61**	0.72 (0.10)
DopUS-Net$^{(4)}$	BD-RNN	D-RNN	6.1 M	**0.88**	0.69	**0.79**	**0.78**	**0.76**	**0.62**	0.60	**0.73 (0.09)**

**Nomenclature:* B:B-Mode, D: Doppler, RNN: convGRU module, +: increased parameters, DopUS-Net$^{(x)}$: specific DopUS-Net version, ♣: additional skip connections from the bottom encoder to the decoder.

Performance: Compared with U-Net [2] and VesNet [3], DopUS-Net outperforms the other networks in terms of Dice score.

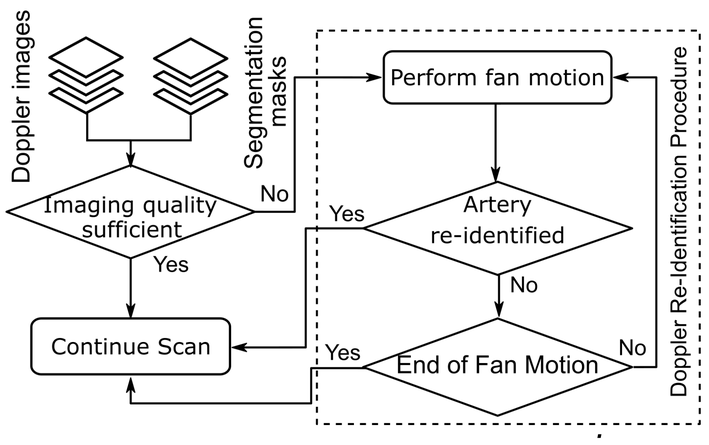
Ablations & Observations:

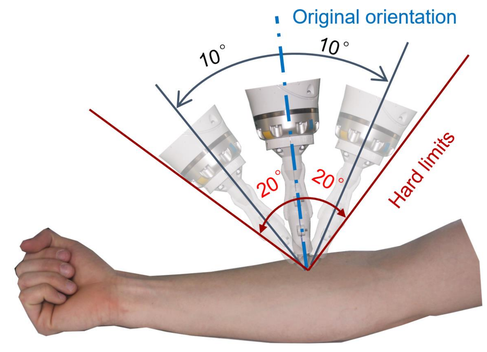
- Leveraging an RNN module enhances the performance. Pulsation of blood flow leads to unstable Doppler signal, which can be alleviated through temporal information.
- Using a separate encoder for the Doppler signal enhances the performance

Doppler Re-Identification

Re-Identification

Doppler effect in the forearm is most prominent in the vessels.





Quality-Awareness: This module constantly checks if the predicted segmentation mask aligns with the Doppler signal. In case of an insufficient overlap a re-identification procedure is triggered.

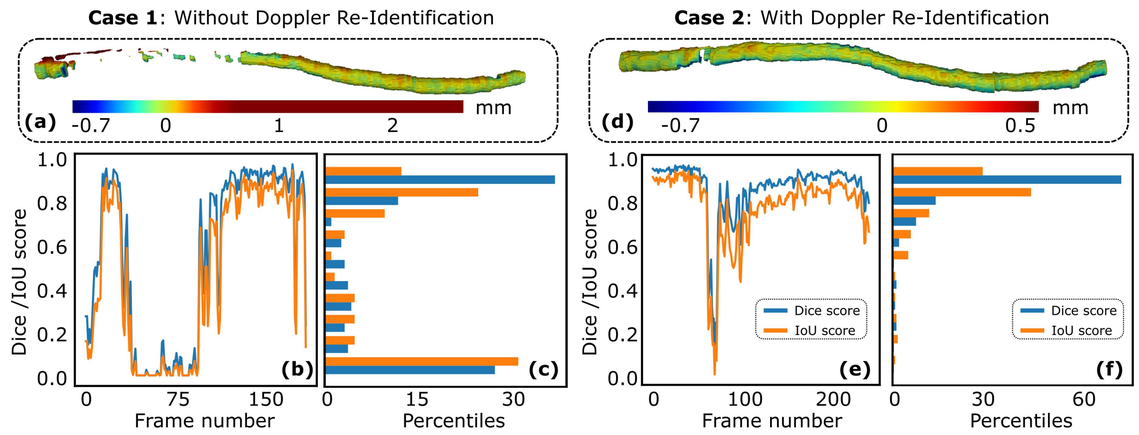
Re-identification procedure:

Goal: Re-align segmentation mask with Doppler signal

Procedure:

- Rotate in 5° steps in the out-of-plane direction: [-10°, -5°, 0°, 5°, 10°]
- After every fan motion (rotation) check for re-alignment and artery re-identification
- If no step leads to a re-identification continue scan

Qualitative Evaluation



Quantitative Evaluation

Performance: Re-identification procedure enhances overall Dice score and IoU due to the quality-awareness module.

TABLE III
SEGMENTATION RESULTS OVER VOLUME [MEAN (SD)]

Re-Identification	Dice Score	IoU
Enabled	0.86 (0.14)	0.78 (0.16)
Disabled	0.54 (0.39)	0.47 (0.37)

Conclusion

We introduced a quality-aware robotic Ultrasound screening using Doppler information for autonomous peripheral artery segmentation and 3D reconstruction:

- DopUS-Net: novel segmentation network leveraging Doppler and continuity information for superior segmentation performance
- Quality-aware scanning: Doppler re-identification procedure for robust reconstruction performance using a closed-loop control scheme

References

[1] Shu, J., & Santulli, G. (2018). Update on peripheral artery disease: Epidemiology and evidence-based facts. Atherosclerosis, 275, 379-381.

[2] Ronneberger, O., Fischer, P., & Brox, T. (2015). U-net: Convolutional networks for biomedical image segmentation. In Medical image computing and computer-assisted intervention–MICCAI 2015: 18th international conference, Munich, Germany, October 5-9, 2015, proceedings, part III 18 (pp. 234-241). Springer International Publishing.

[3] Jiang, B., Chen, A., Bharat, S., & Zheng, M. (2021). Automatic ultrasound vessel segmentation with deep spatiotemporal context learning. In Simplifying Medical Ultrasound: Second International Workshop, ASMUS 2021, Held in Conjunction with MICCAI 2021, Strasbourg, France, September 27, 2021, Proceedings 2 (pp. 3-13). Springer International Publishing.