TUHH Hamburg University of Technology
European Union European Regional Development Fund
MTEC Medical Technology | Intelligent Systems
MIDL Lübeck 2021

Attention via Scattering Transforms for Segmentation of Small Intravascular Ultrasound Data Sets

Lennart Bargsten[1], Katharina A. Riedl[2], Tobias Wissel[3], Fabian J. Brunner[2], Klaus Schaefers[4], Michael Grass[3], Stefan Blankenberg[2], Moritz Seiffert[2], Alexander Schlaefer[1]

Motivation

- Limited data for CNN training leads to inefficient filters unable to extract meaningful features.
- The scattering transformation, basically a special form of CNN with pre-defined filters, is able to produce meaningful features without learning weights.
- Combining CNNs with scattering transformations could improve segmentation performance when dealing with small amounts of data.
- We investigate this hypothesis using segmentation of intravascular ultrasound images.

Methods

- An ordinary wavelet transformation can be calculated by applying a filter cascade with low-pass filters ϕ and band-pass filters ψ (Fig. 1).
- Scattering transformations also rely on a wavelet basis, but band-pass filters are applied to all intermediate feature maps (Fig. 2).
- Problem: exponential growth of output feature maps with increasing order of transformation.
- Solution: use scattering transformation in a squeeze and excitation block (SEST) (Fig. 3).

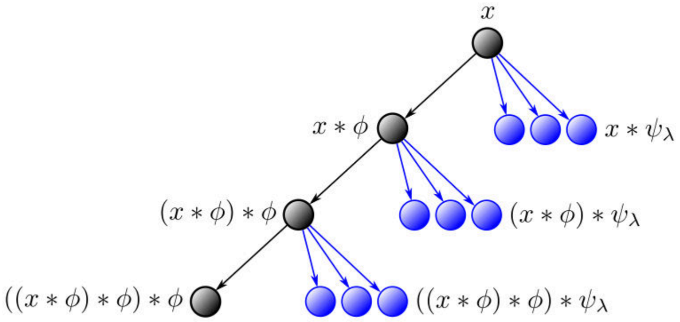


Fig. 1: Diagram of a wavelet transformation

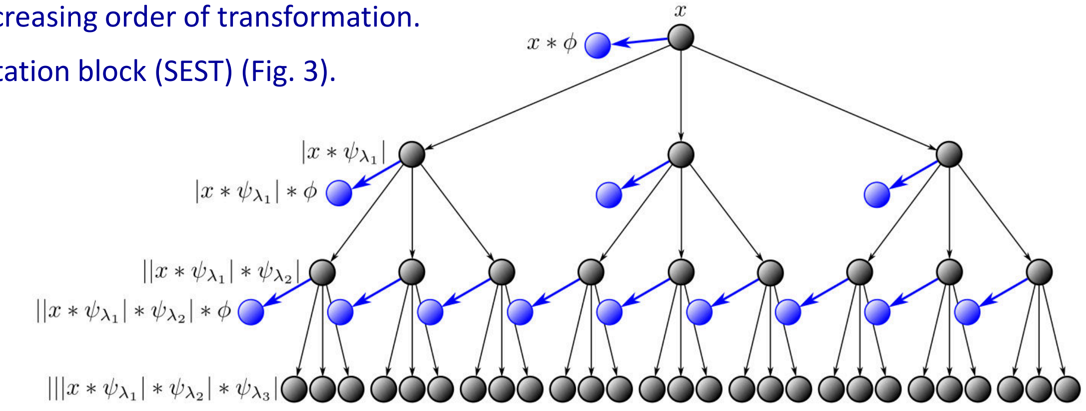


Fig. 2: Diagram of a scattering transformation

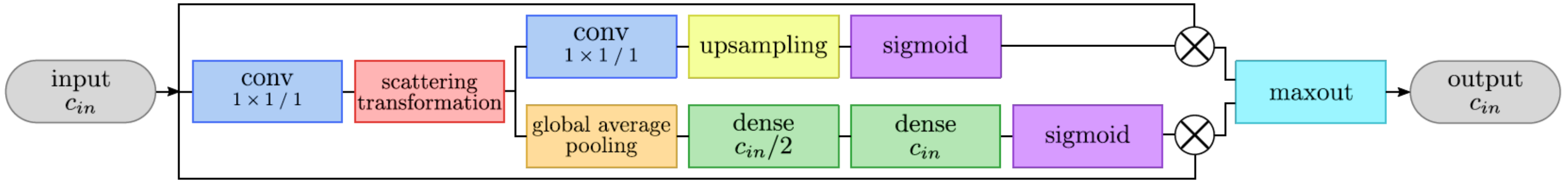


Fig. 3: Diagram of the proposed squeeze and excitation block with scattering transformation (SEST) block

TUHH Hamburg University of Technology

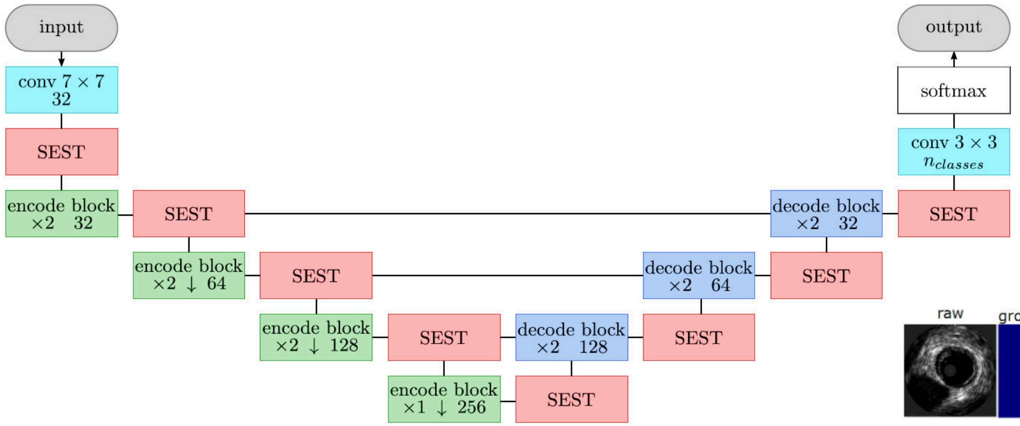
European Union European Regional Development Fund

Medical Technology | Intelligent Systems

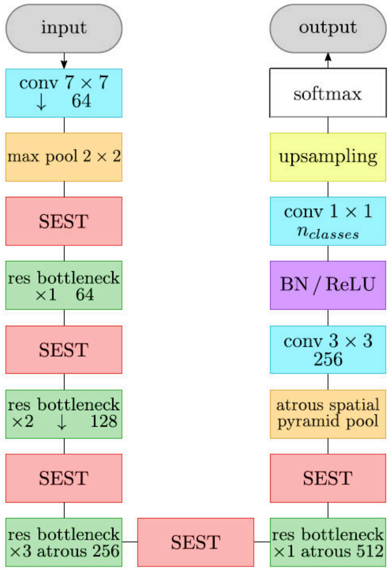
MIDL Lübeck 2021

CNN Architectures

U-Net Res SEST



DeepLabV3 SEST



Data sets

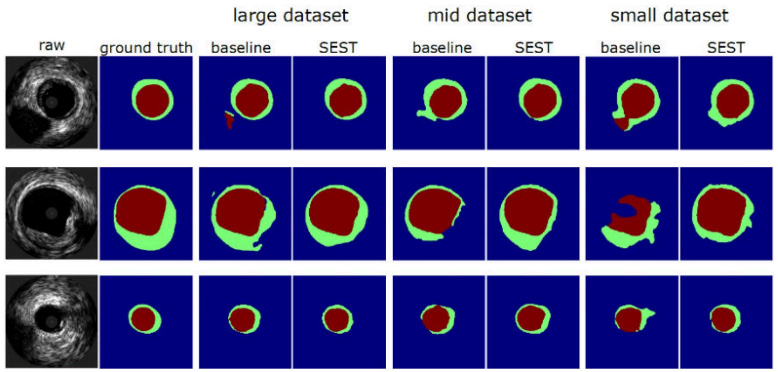
Calcium segmentation

- training images
  - large: 318
  - mid: 145
  - small: 90
- test images: 114

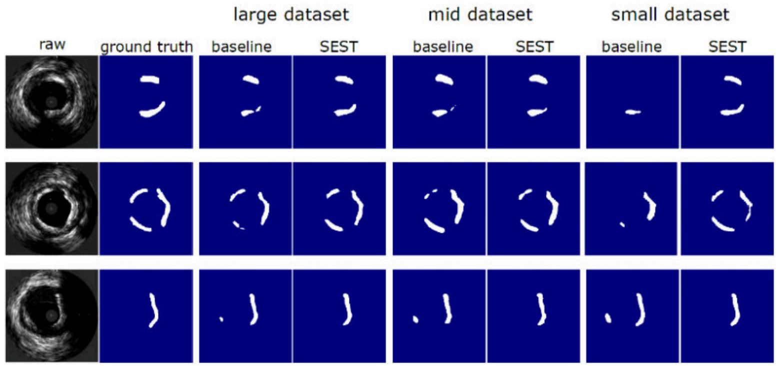
Lumen/vessel wall segmentation

- training images
  - large: 289
  - mid: 146
  - small: 73
- test images: 121

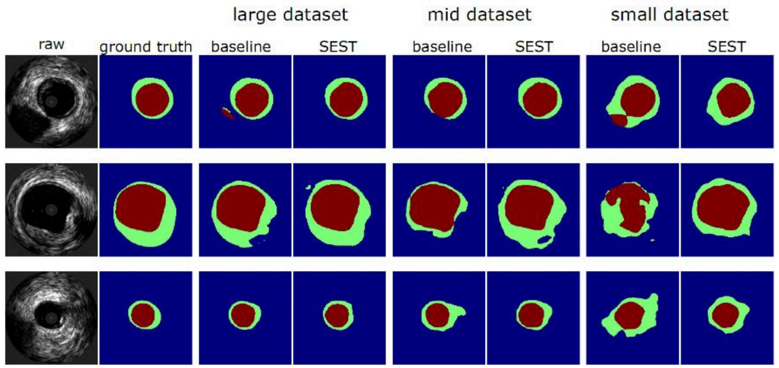
Lumen/Wall: U-Net Res



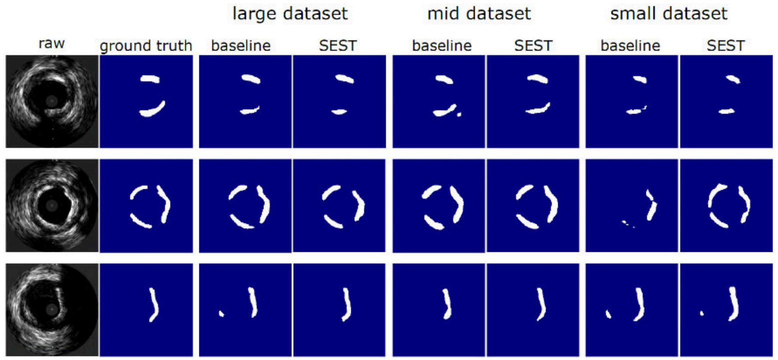
Calcium: U-Net Res



Lumen/Wall: DeepLabV3



Calcium: DeepLabV3



Hamburg University of Technology

European Union
European Regional
Development Fund

Medical Technology | Intelligent Systems

MIDL Lübeck 2021

Results and Discussion

- Calcium segmentation (Tab. 1): improvements by SEST are statistically significant for all data set sizes.
- Improvements are larger on smaller data sets.
- Largest improvements are 6% (relative) for the Dice coefficient and 21% for the average Hausdorff distance.
- Vessel wall (Tab. 2) and lumen (Tab. 3) segmentation: improvements by SEST are almost only statistically significant for the smallest data sets.
- On small data sets, U-Net Res produces better results for vessel wall and lumen segmentation compared to DeepLabV3.

Tab. 1: Results of calcium segmentation.

			Dice coefficient [%]		ave. Hausd. dist. [px]	
model	dset size	method	value	p-value	value	p-value
U-Net Res	large	wavelet	66.94 ± 0.48	$< \mathbf{0.01}$	7.92 ± 0.60	$< \mathbf{0.01}$
		baseline	66.20 ± 0.90		8.89 ± 1.12	
	mid	wavelet	64.74 ± 0.69	$< \mathbf{0.01}$	10.32 ± 1.06	$< \mathbf{0.01}$
		baseline	63.69 ± 0.96		11.96 ± 1.29	
	small	wavelet	58.62 ± 1.46	$< \mathbf{0.01}$	13.31 ± 1.20	$< \mathbf{0.01}$
		baseline	55.38 ± 2.99		16.89 ± 3.45	
DeepLabV3	large	wavelet	66.57 ± 0.34	$< \mathbf{0.01}$	8.09 ± 0.48	$< \mathbf{0.01}$
		baseline	66.00 ± 0.42		8.61 ± 0.50	
	mid	wavelet	62.36 ± 0.43	$< \mathbf{0.01}$	11.83 ± 0.68	$< \mathbf{0.01}$
		baseline	61.38 ± 0.77		12.93 ± 0.94	
	small	wavelet	59.71 ± 0.95	$< \mathbf{0.01}$	11.51 ± 0.88	$< \mathbf{0.01}$
		baseline	55.18 ± 3.86		15.30 ± 4.56	

Tab. 2: Results of vessel wall segmentation.

			Dice coefficient [%]		ave. Hausd. dist. [px]	
model	dset size	method	value	p-value	value	p-value
U-Net Res	large	wavelet	79.51 ± 0.57	0.14	1.85 ± 0.10	$< \mathbf{0.01}$
		baseline	79.29 ± 0.50		2.03 ± 0.11	
	mid	wavelet	76.15 ± 0.61	0.08	2.56 ± 0.18	0.02
		baseline	75.86 ± 0.47		2.69 ± 0.15	
	small	wavelet	67.05 ± 1.23	0.19	4.80 ± 0.44	$< \mathbf{0.01}$
		baseline	66.63 ± 1.39		5.36 ± 0.43	
DeepLabV3	large	wavelet	77.86 ± 0.52	0.33	2.16 ± 0.14	0.31
		baseline	77.78 ± 0.49		2.18 ± 0.08	
	mid	wavelet	74.44 ± 0.58	$< \mathbf{0.01}$	2.69 ± 0.16	0.03
		baseline	73.79 ± 0.72		2.85 ± 0.27	
	small	wavelet	62.20 ± 1.30	$< \mathbf{0.01}$	5.07 ± 0.25	$< \mathbf{0.01}$
		baseline	60.91 ± 1.37		5.80 ± 0.48	

Tab. 3: Results of lumen segmentation.

			Dice coefficient [%]		ave. Hausd. dist. [px]	
model	dset size	method	value	p-value	value	p-value
U-Net Res	large	wavelet	90.54 ± 0.36	0.39	1.40 ± 0.17	0.05
		baseline	90.50 ± 0.34		1.51 ± 0.17	
	mid	wavelet	90.12 ± 0.60	0.68	1.38 ± 0.19	0.09
		baseline	90.22 ± 0.49		1.53 ± 0.39	
	small	wavelet	86.59 ± 1.07	$< \mathbf{0.01}$	2.94 ± 0.97	$< \mathbf{0.01}$
		baseline	84.63 ± 0.58		4.25 ± 0.56	
DeepLabV3	large	wavelet	90.12 ± 0.41	0.07	2.16 ± 0.14	0.07
		baseline	89.93 ± 0.26		1.57 ± 0.13	
	mid	wavelet	89.81 ± 0.41	0.01	1.40 ± 0.20	0.06
		baseline	89.44 ± 0.46		1.58 ± 0.38	
	small	wavelet	84.61 ± 1.06	$< \mathbf{0.01}$	3.05 ± 0.83	$< \mathbf{0.01}$
		baseline	83.51 ± 0.83		3.96 ± 0.86	

Conclusion

- Inserting scattering transformations into CNNs via an attention mechanism (SEST) improves segmentation results on small intravascular ultrasound datasets.
- We can therefore conclude that the features extracted by the scattering transformations inside the SEST blocks provide meaningful information.
- The approach works better for segmentation of small structures like calcifications.
- The attention approach with SEST seems to be less effective for larger structures like lumen or vessel wall.
- SEST can be flexibly inserted into any CNN.

Affiliations:
[1] Hamburg University of Technology, Institute of Medical Technology and Intelligent Systems, Hamburg, Germany
[2] Department of Cardiology, University Heart & Vascular Center Hamburg, Hamburg, Germany
[3] Philips Research - Hamburg, Germany
[4] Philips Research - Eindhoven, The Netherlands

This work was partially funded by the European Regional Development Fund (ERDF) and the Free and Hanseatic City of Hamburg in the Hamburgische Investitions- und Förderbank (IFB)-Program PROFI Transfer Plus under grant MALEKA.