Real-Time Quantitative Ultrasound and Radar Knowledge-Based Medical Imaging

Tom Sharon, Hila Naaman, Yonathan Eder, Yonina C. Eldar
Weizmann Institute of Science, Rehovot, Israel, E-mail: tom.sharon@weizmann.ac.il

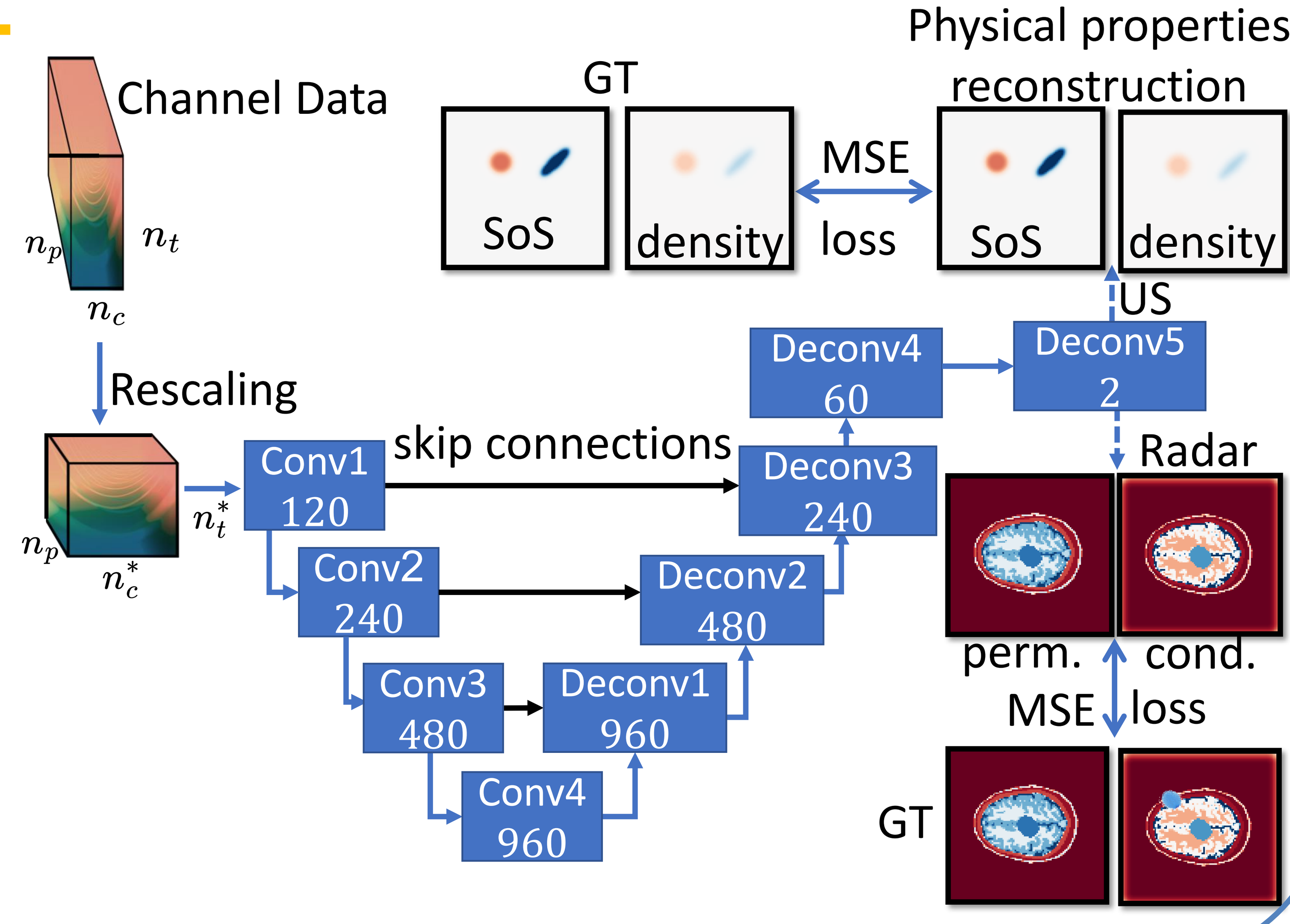
The paper on OpenReview:
MIDL Nashville 2023

Background and Motivation

- Ultrasound (US) and radar are non-invasive and non-ionizing signals for medical imaging.
- Channel Data (CD) which is the receiving signals, is used for imaging.
- Traditional imaging lacks physical interpretation, which is beneficial for medical applications such as fatty liver diagnosis and fast stroke imaging.
- Quantitative Medical Imaging (QMI) provides the necessary physical visualization of the scanned medium.
- The standard QMI method is Full Waveform Inversion (FWI), a non-learning optimization algorithm that is time-consuming and often converges to local minima.
- Previous learning methods reconstruct only one physical property, needed hundreds of receiving elements, and tested on simple synthetic data.

QUARK-MI

- We introduce QUARK-MI, a U-Net based network to reconstruct multiple physical properties from CD of radar or US.
- We integrate a spatial representation of the CD into the network design, referring to the time samples and receiving channels dimensions as spatial dimensions in the convolution layers. This improvement allows exploiting of the symmetries in the CD in the network layers.
- The U-Net based block consists of stride convolutions, skip connections and batch normalizations, all allowing the network to learn from a global receptive field, while preserving fine details.

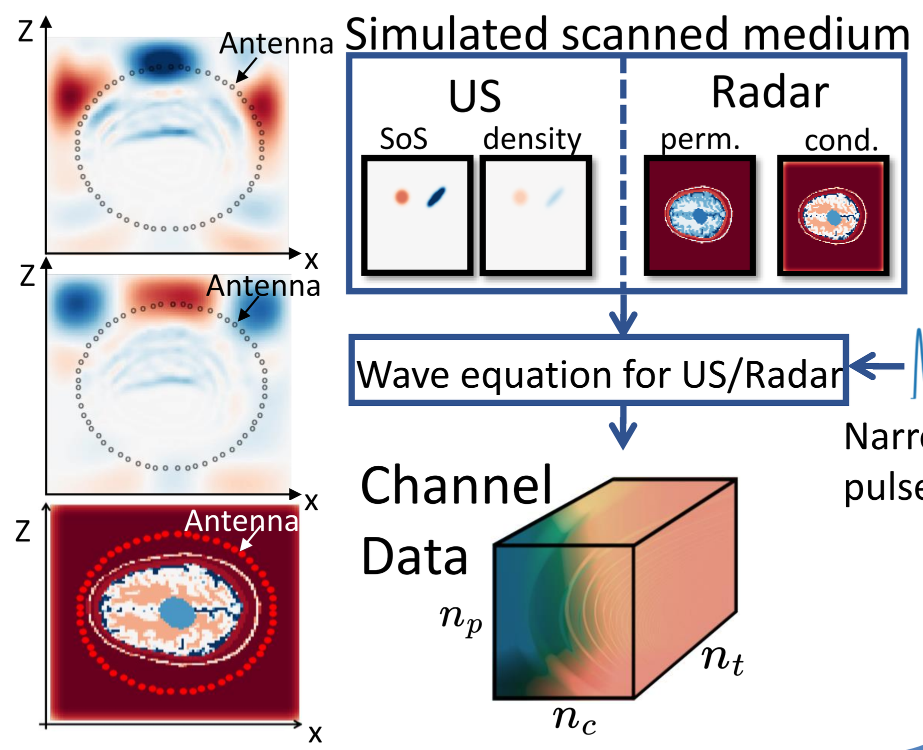


Contribution

- We introduce QUARK-MI, (Quantitative Ultrasound and Radar Knowledge-Based Medical Imaging), a neural network for real-time QMI for multiple physical properties, from CD.
- Our method reconstructs from either US or radar signals the properties such as density, speed-of-sound, conductivity and relative permittivity.
- Our approach achieves accurate results for complex and nonhomogeneous data, such as realistic brain slices.

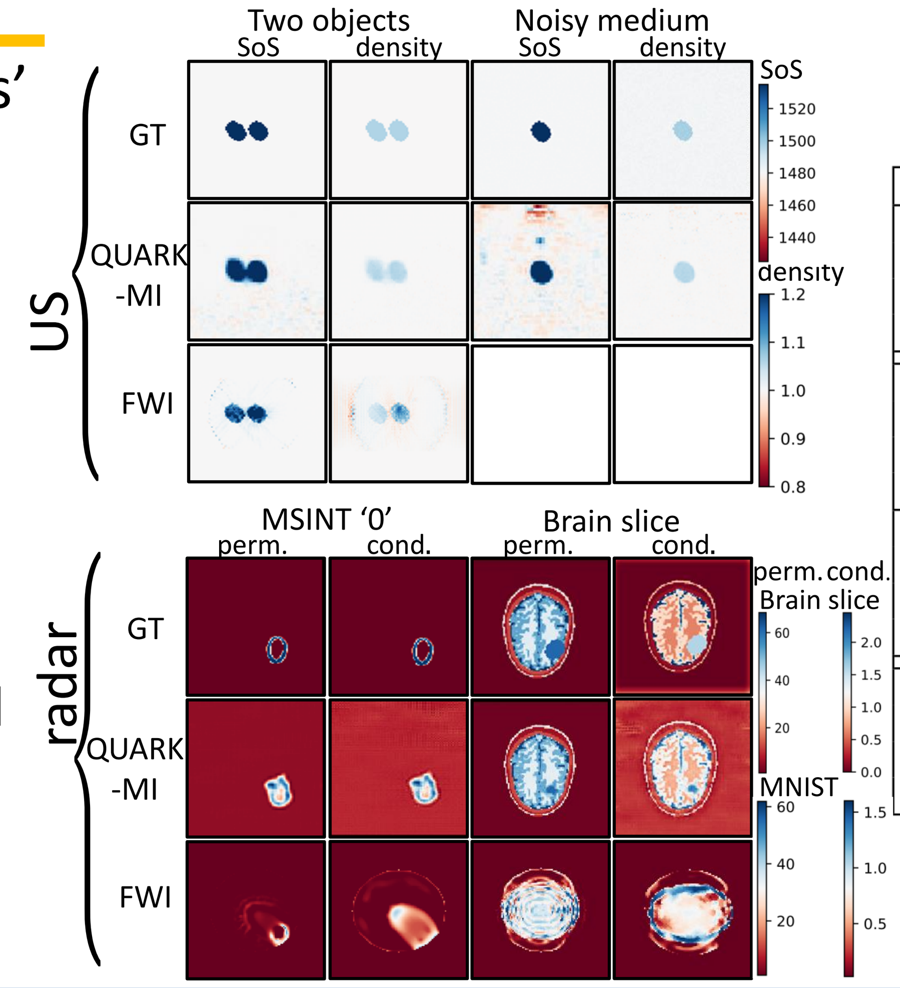
Experimental Setup and Data Creation

- 60 elements are placed in a circle around the scanned object. The pixels' values represent the physical properties values in each position.
- Training channel data is created using a simulated medium and known wave equations.
- Simulated medium for the US case: random oval with liver properties on a water background.
- Simulated medium for the radar case: MNIST undefined digits shapes with blood properties on air background, or realistic brain slices with random stroke.



Results

- Compared to FWI, better reconstruction of shape, size, location and pixels' properties values using numerical matrices (higher PSNR up to 6.16% and SSIM up to 28.32%, lower MSE up to 42.19%).
- Reconstruction of two objects from US CD with one object per sample in the training set, that demonstrate our network generalization.
- Reconstruction of realistic brain with stroke from radar CD despite signal quality decrease caused by the skull.
- High-quality reconstruction for nonhomogeneous backgrounds when FWI diverges.
- Real-time results in less than 0.15 seconds, unlike 0.75-2 hours for FWI.



Scenario	Property	Method	NRMSE	PSNR	SSIM
2 objects (US)	SoS	**QUARK-MI**	**0.073**	**62.08**	**0.82**
		FWI	0.087	61.93	0.97
	Density	**QUARK-MI**	**0.072**	**6.30**	**0.97**
		FWI	0.162	5.60	0.86
Noisy medium (US)	SoS	**QUARK-MI**	**0.06**	**62.13**	**0.60**
		FWI	NaN	NaN	NaN
	Density	**QUARK-MI**	**0.103**	**5.85**	**0.88**
		FWI	NaN	NaN	NaN
MNIST '0' (radar)	Perm.	**QUARK-MI**	**0.076**	**35.55**	**0.95**
		FWI	0.075	35.57	0.91
	Cond.	**QUARK-MI**	**0.078**	**7.83**	**0.87**
		FWI	0.11	7.50	0.38
Brain slice (radar)	Perm.	**QUARK-MI**	**0.027**	**36.35**	**0.98**
		FWI	0.202	34.63	0.62
	Cond.	**QUARK-MI**	**0.062**	**7.64**	**0.48**
		FWI	0.175	6.75	0.43

Conclusions

- Our proposed method achieved real-time reconstruction of multiple physical properties, using radar or US CD.
- Incorporating the symmetries of the CD into the network design, enhances the reconstruction of complex and realistic nonhomogeneous mediums.
- This method provides reliable physical interpretation with the potential for new clinical goals like fast stroke imaging and cancer detection.