Equitable Medical Imaging

Muyinatu A. Lediju Bell

John C. Malone Associate Professor

Department of Electrical and Computer Engineering

Department of Biomedical Engineering

Department of Computer Science

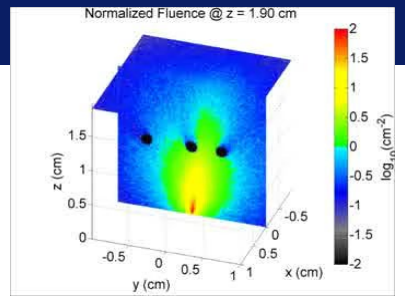
Department of Oncology

JOHNS HOPKINS UNIVERSITY

PULSE

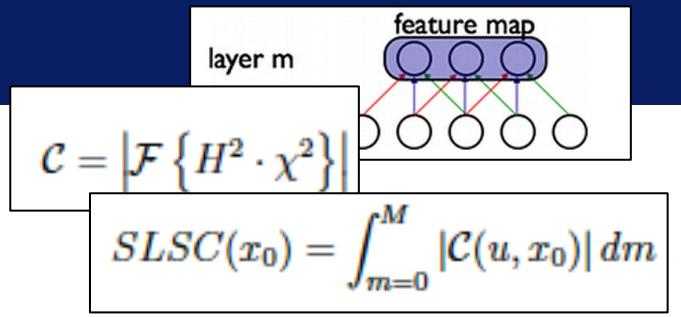
PHOTOACOUSTIC & ULTRASONIC SYSTEMS ENGINEERING LAB

PULSE Lab Overview

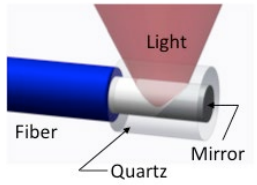


Theory, Modeling, and Simulations

Design Beamformers and Imaging Probes



Photoacoustic (PA) ⇄ Ultrasound (US)



Improve PA & US

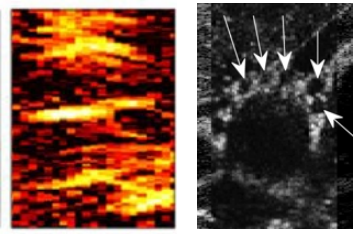


Image Quality

Build and Test Prototypes

System Integration

Clinical Studies

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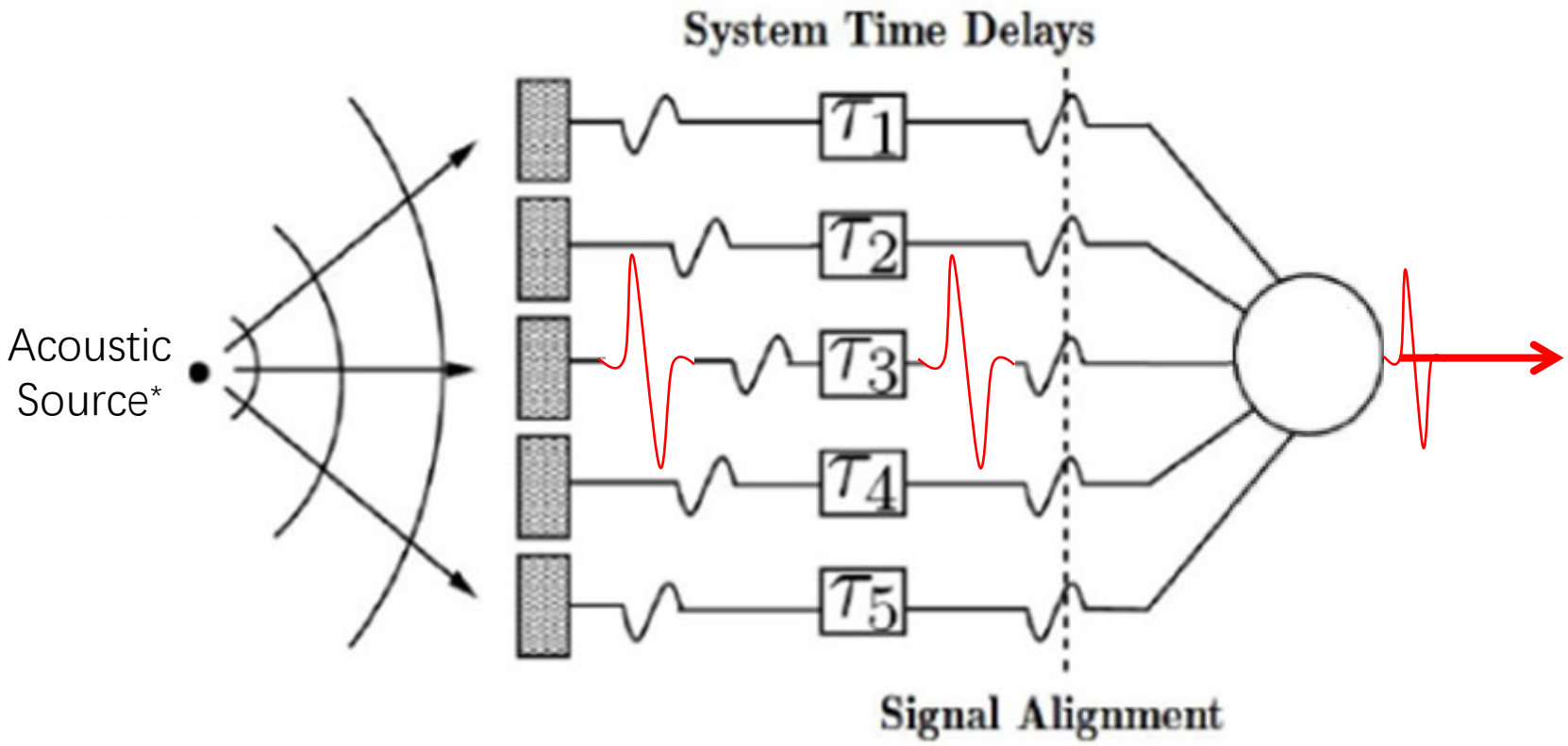
Beamforming



Coherence-Based Beamforming
(Lediju *et al.* 2011)

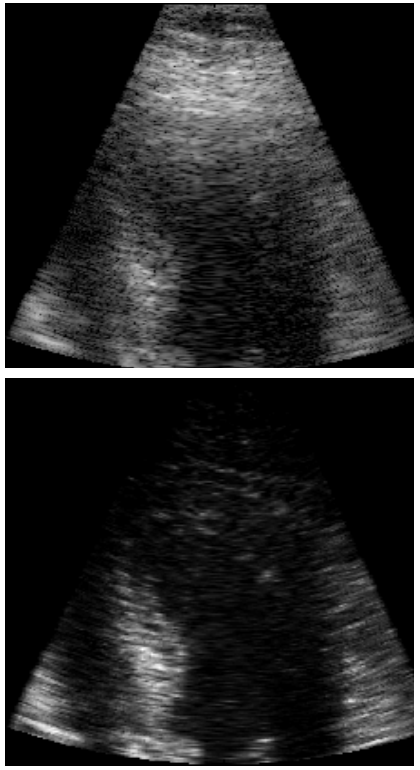
*generated from light (PA) or sound (US) transmission

Improvements with Coherence-Based Beamforming

Cardiac Images

Amplitude

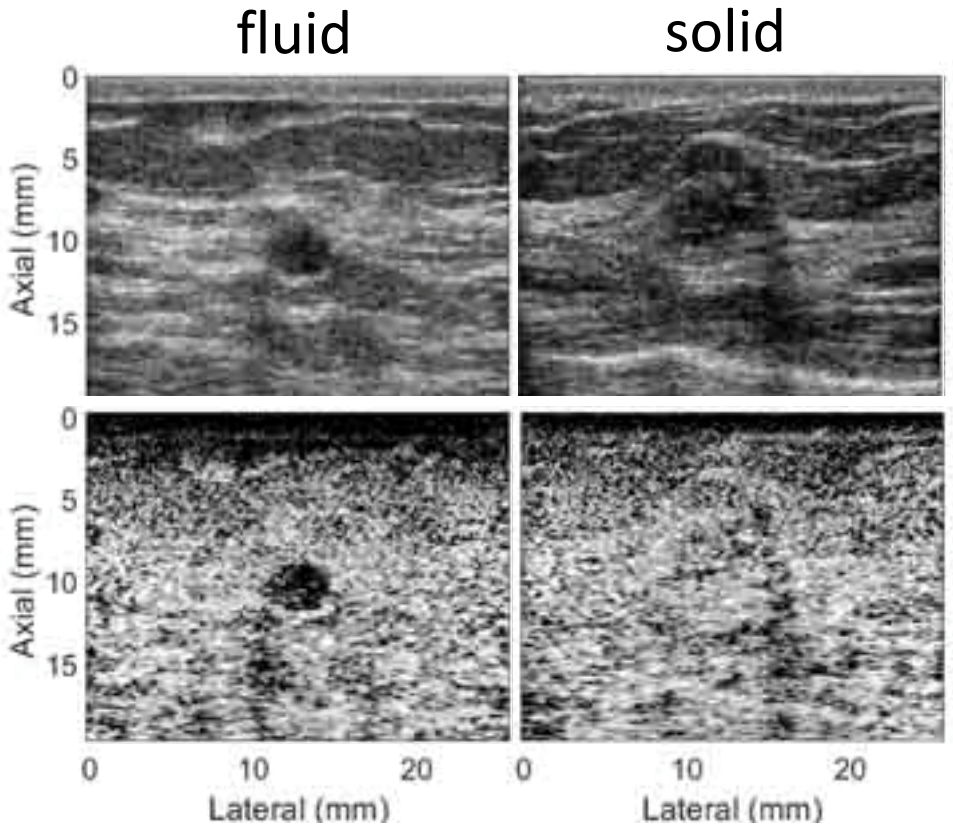
Coherence



Bell *et al.* 2012

→Improved image quality in **overweight and obese** patients

Breast Masses



Wiacek *et al.*, 2020

Wiacek *et al.*, 2023

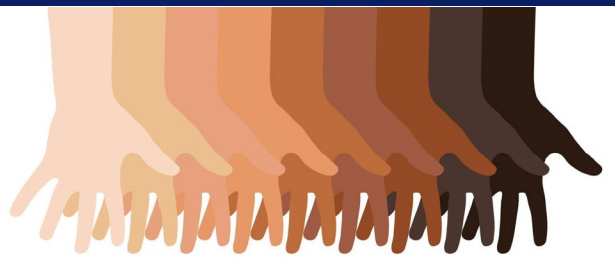
Sharma *et al.*, 2024

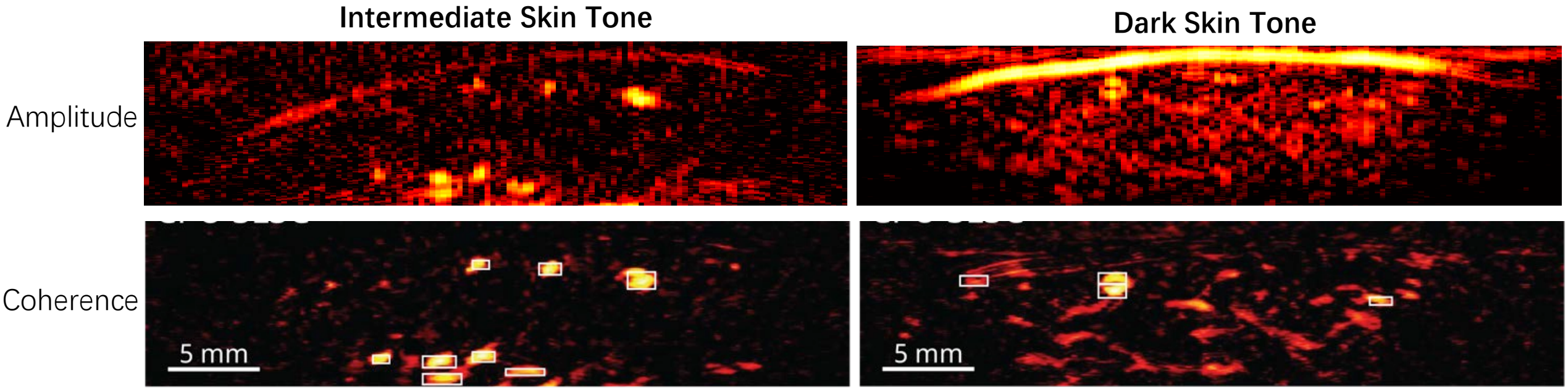
→Reduced number of fluid breast masses recommended for biopsy from 43.3% to 13.3%

→Promising for **women with dense breast tissue**

Coherence-Based Photoacoustic Imaging

- Optical penetration depths limited by melanin absorbers, which cause acoustic clutter
- Leads to inherent skin tone bias with amplitude-based techniques
- Coherence-based beamforming will reduce clutter in **patients with darker skin tones**



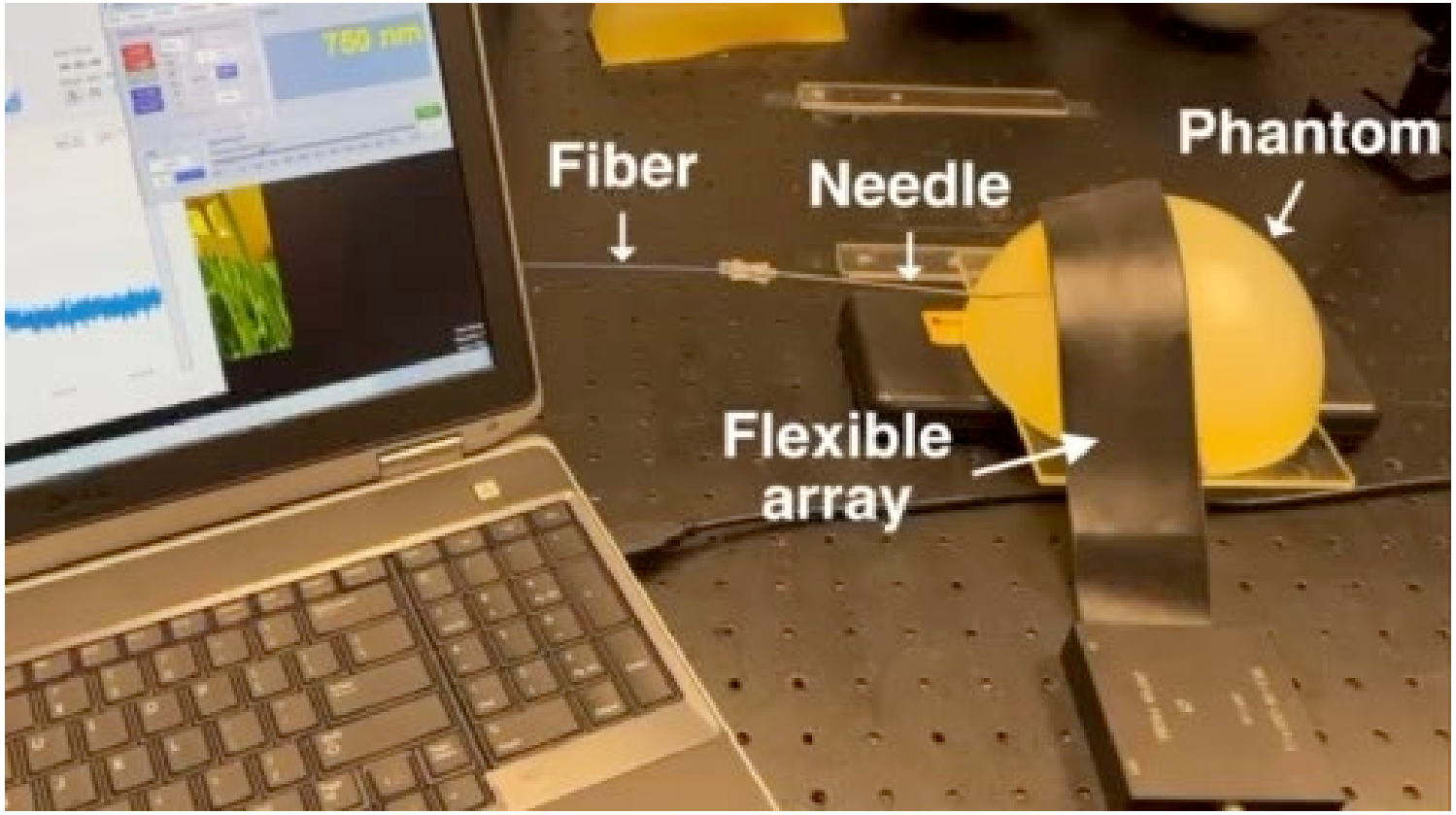


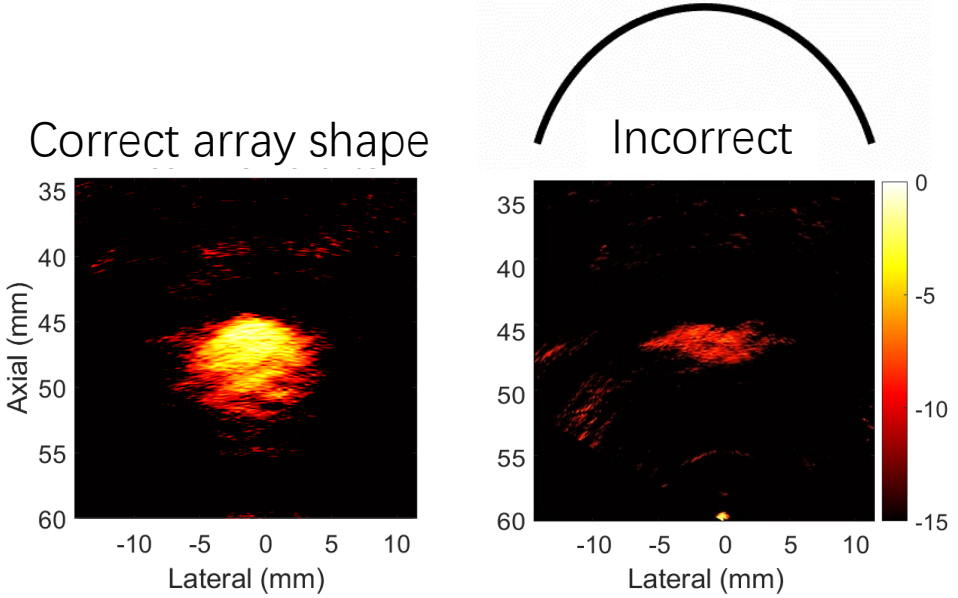
Fernandes *et al.*, *Photoacoustics*, 2023

Featured on CNN

Flexible Array for Photoacoustic Guided Surgery

✔ Conforms to **different body shapes** ✖ Unknown array shape





Bell, *Journal of Applied Physics*, 2020
Zhang *et al.* Biomedical Optics Express, 2023
Zhang *et al.* SPIE Photonics West, 2024

Summary

- Single signal processing technique enables more equitable medical imaging
- Diversity drives innovation
  - Datasets (e.g., overweight and obese, dense breasts, dark skin tones)
  - Personnel (e.g., 9 current PhD students: 1 BME, 7 ECE, 1 CS)
  - Background (e.g., MechE, BME, CS, Physics, ECE, Oncology)
- Ignore traditional disciplinary silos when innovating new ideas, yet introduce boundaries when grant writing, publishing, etc.

Acknowledgements

Follow @MuyinatuBell

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- **Graduate Students:**
  - Alycen Wiacek
  - Jiaxin Zhang
  - Eduardo González
  - Arun Nair
  - Michelle Graham
  - Mardava Gubbi
  - Ole Marius Hoel Rindal
  - Guilherme Fernandes
  - Ziwei Feng
  - Nethra Venkatayogi
  - Mahban Golijafari
  - Junior Arroyo
  - Junhao Zhang
- **Undergraduate Students:**
  - Khaijat Kokumo
  - Brooke Stephanian
  - José Tmaná
  - Rhea Rasquina
- **Postdocs:**
  - Arunima Sharma
  - Md Ashikuzzaman
- **Collaborators:**
  - Susan Harvey, MD
  - Kelly Fabrega-Foster, MD
  - Eniola Falomo, MD
  - Kelly Myers, MD
  - Emily Ambinder, MD
  - Lisa Mullen, MD
  - Kai Ding, PhD
  - Tiffany Fong, MD
  - Theo Pavan, PhD
  - Trac D. Tran, PhD

NIH Trailblazer Award
NIH K99/R00 EB018994
NIH R01 EB032960
NIH R01 EB032358

Junior Faculty Enhancement Award

NSF CAREER Award
ECCS 1751522
NSF EEC 1852155
NSF IIS 2014088

JHU Discovery Award
JHU Catalyst Award

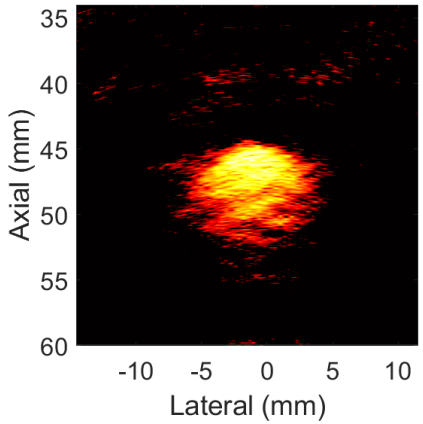
Flexible Array Technology for PA-Guided Surgery

✔ **Conforms** to different surfaces

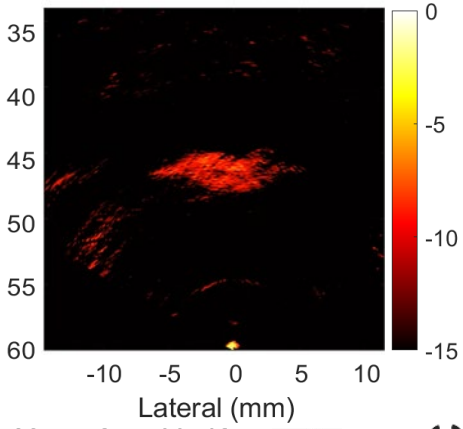
✘ Unknown **array shape**

✘ Unknown **sound speed**

Correct array shape

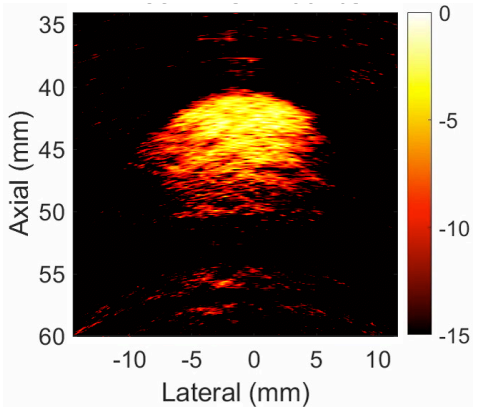


Incorrect array shape

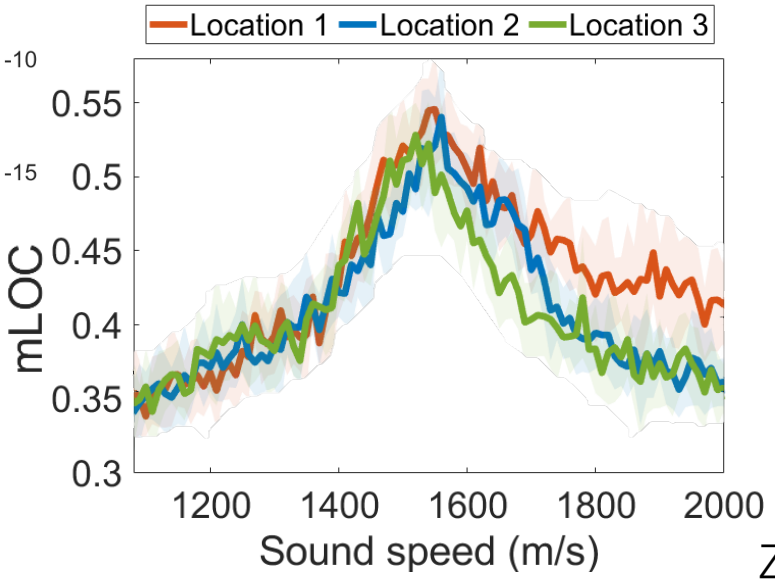


Sound speed

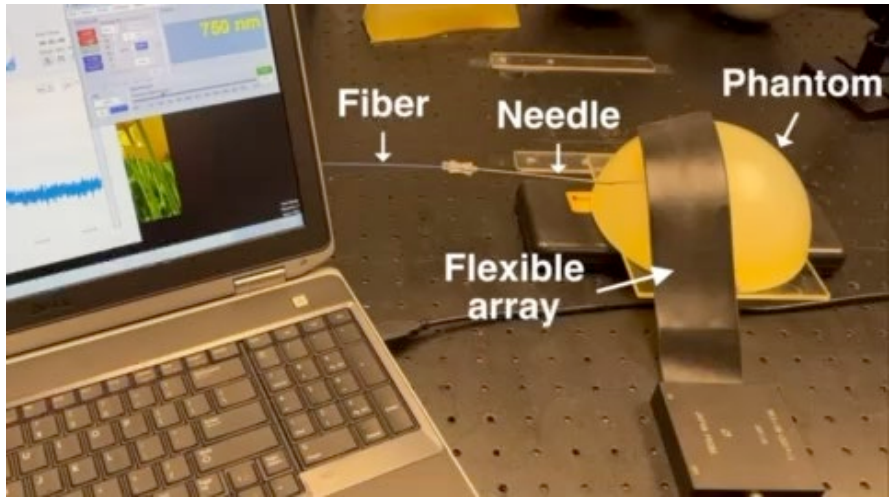
1400 m/s



mLOC = maximum lag-one coherence within a region of interest surrounding photoacoustic target



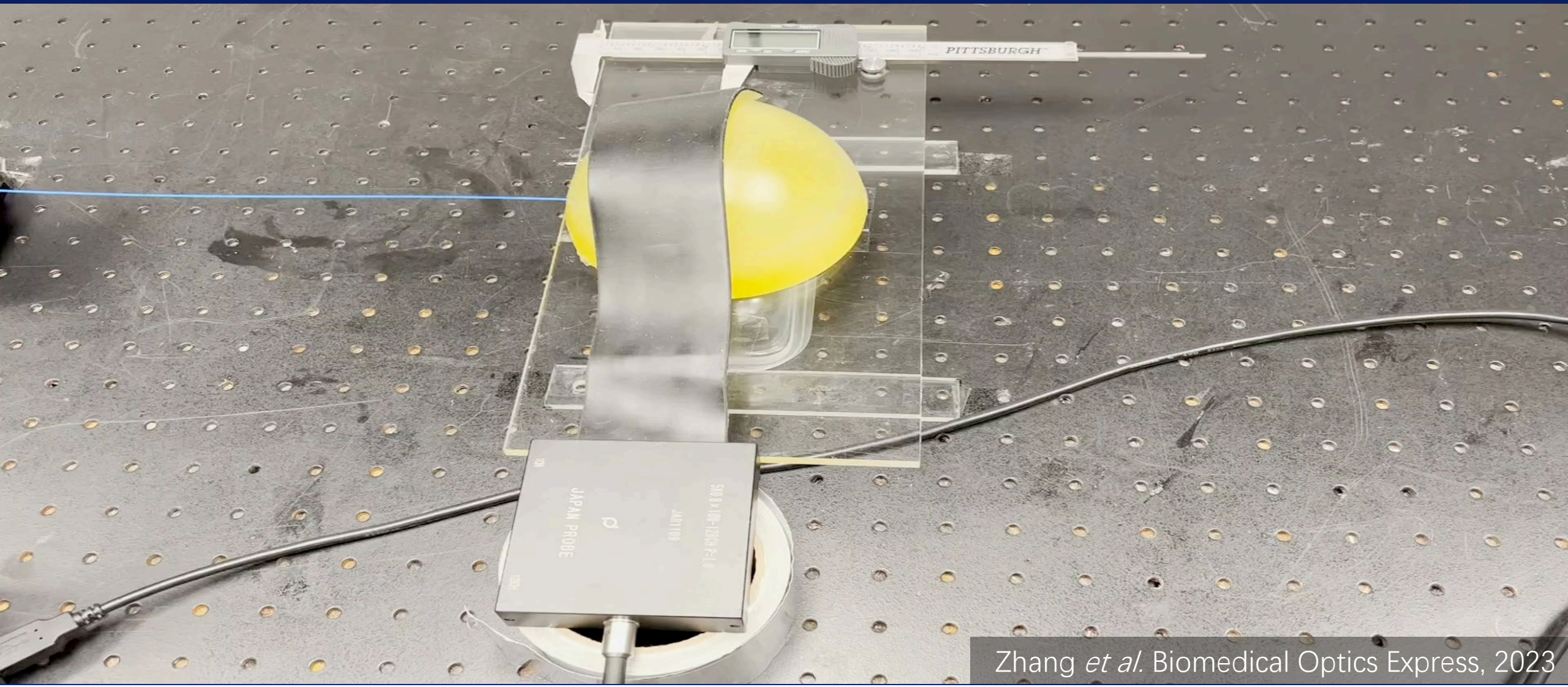
Accuracy range: 97-100%



Zhang *et al.* Biomedical Optics Express, 2023

Zhang *et al.* SPIE Photonics West, 2024

Flexible Array Technology for PA-Guided Surgery



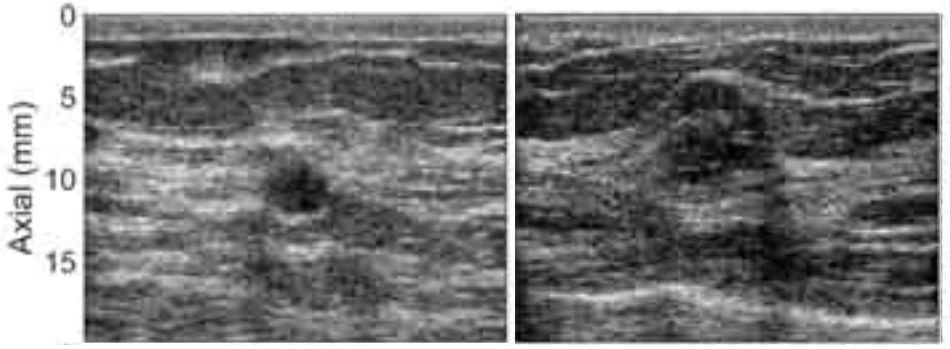
Zhang *et al.* Biomedical Optics Express, 2023

Detection of Mass Contents in Dense Breasts

Difficult to distinguish fluid masses (benign) from solid masses (benign or malignant) with **DAS beamforming**

- → High false positive rates
- → Biopsies, aspiration, follow-up
- → Patient anxiety

Fluid Mass **Solid Mass**



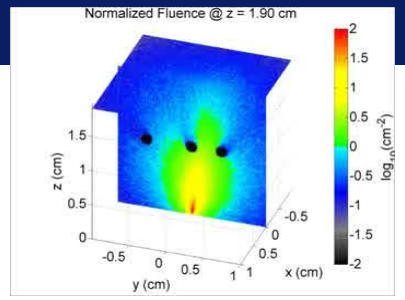
Promising Solution: **Coherence-Based Beamforming**

- →Reduced number of fluid masses recommended for biopsy from 43.3% to 13.3%
- →Related LOC metric promising for dense breast tissue

Wiacek *et al.*, Ultrasound in Medicine & Biology, 2020
Wiacek *et al.*, Ultrasound in Medicine & Biology, 2023
Sharma *et al.*, IEEE TUFFC, 2024

(funded by NIH R01 EB032960)

PULSE Lab Overview



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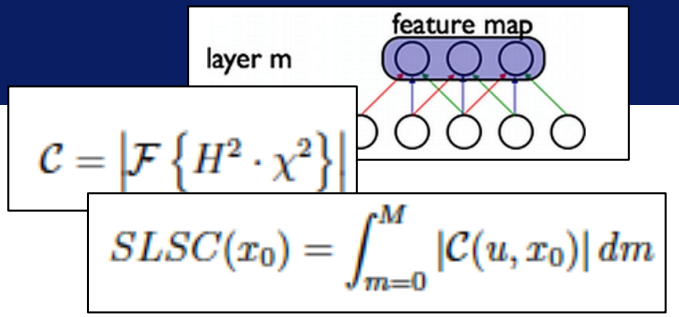

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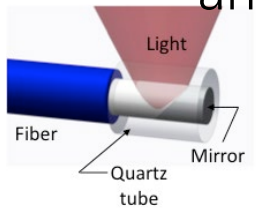

Improve PA & US

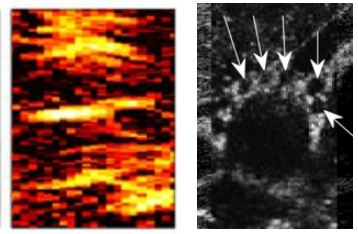

Image Quality

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Acknowledgements

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Summer 2022

Summer 2023

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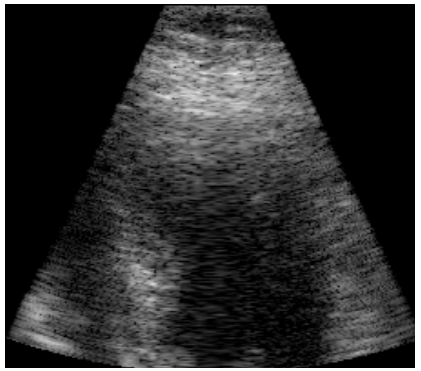
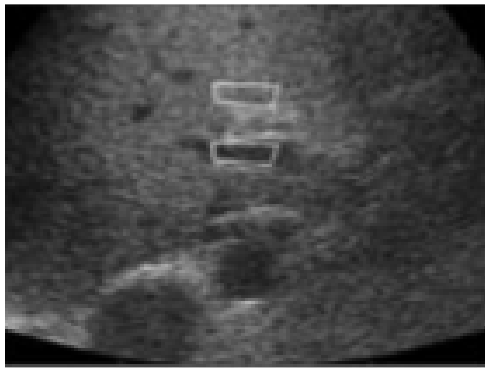
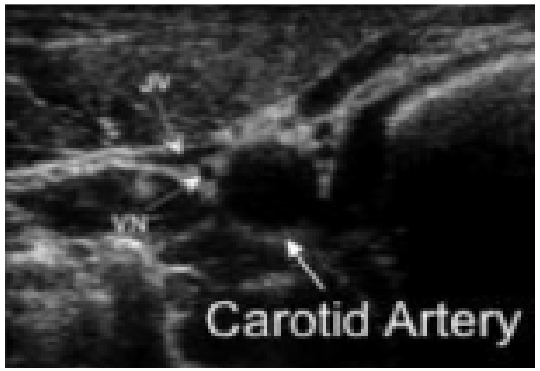
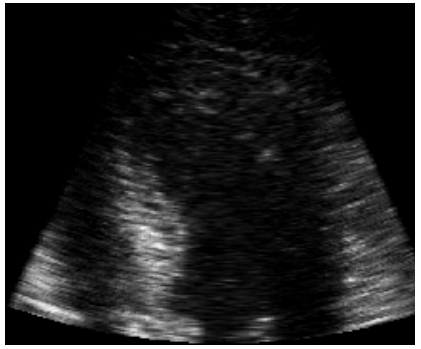
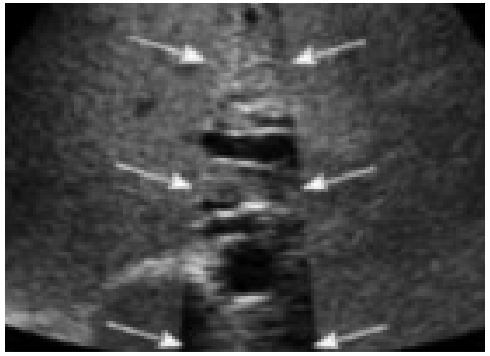
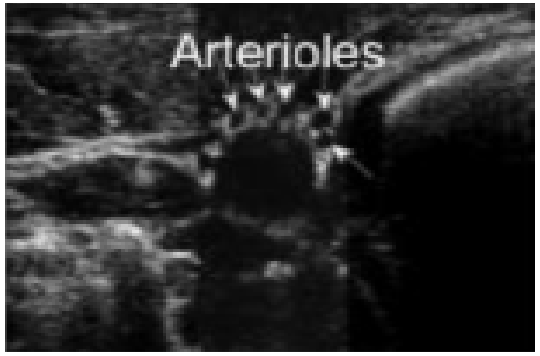
ECCS 1751522
NSF EEC 1852155
NSF IIS 2014088

JHU Discovery Award
JHU Catalyst Award

Cutting Edge Surgical, Inc.

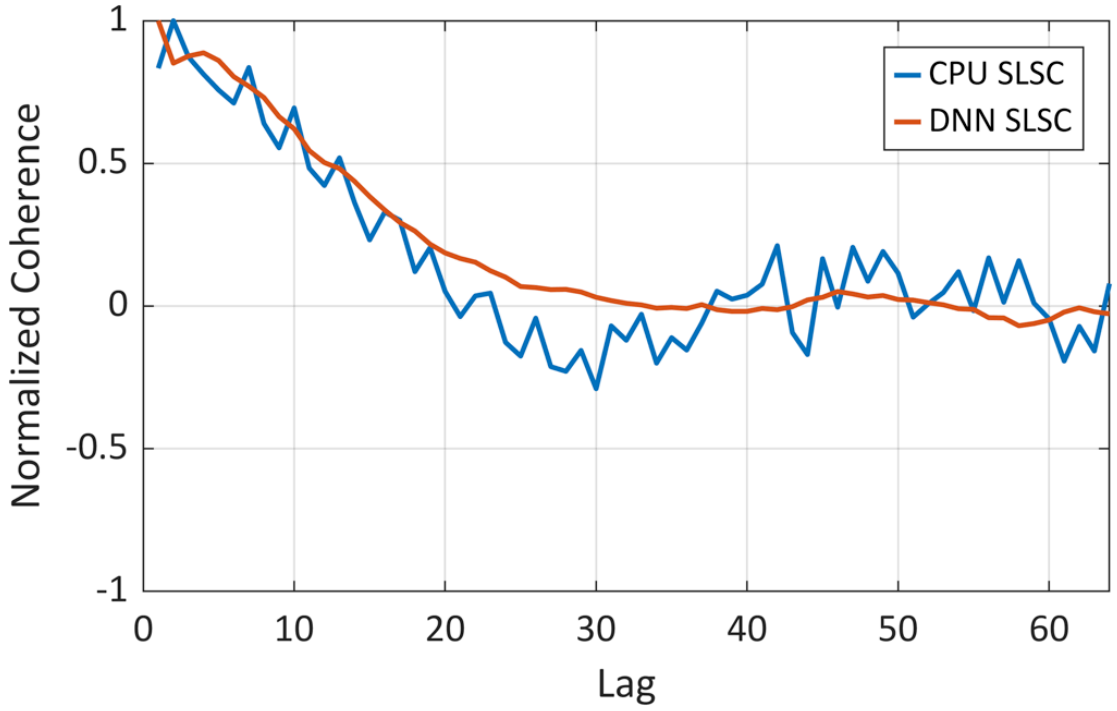
Improved Image Quality in Overweight & Obese Patients

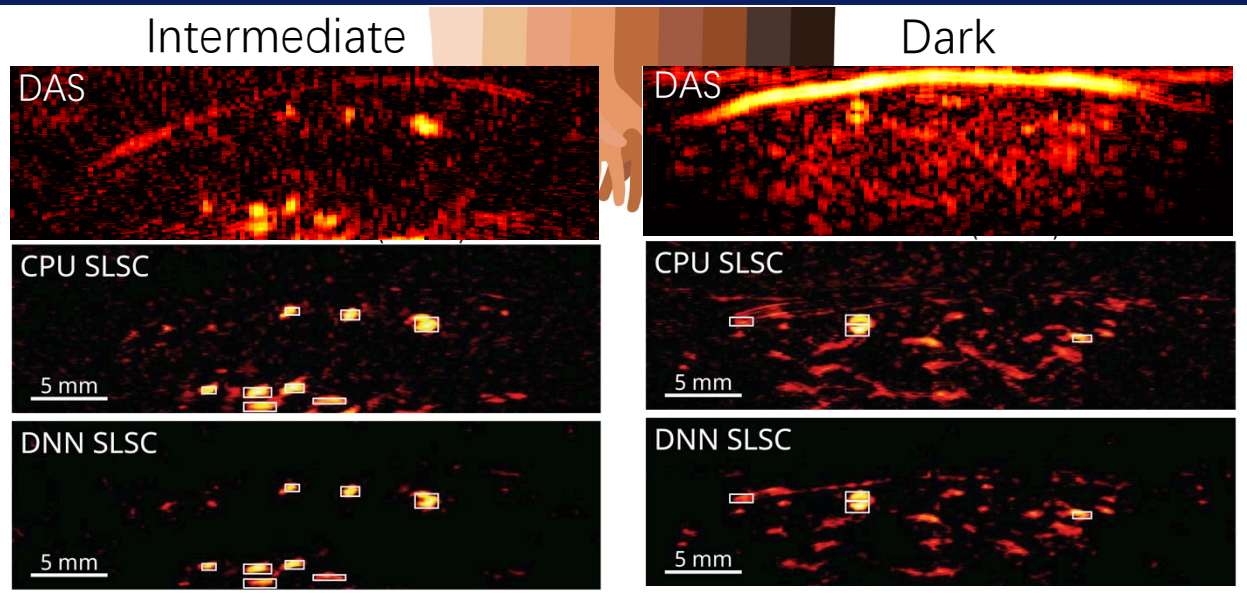
	heart	liver	fetus	vessels
Amplitude (Delay & Sum)				
Coherence (SLSC*)				
	Bell *et al.* 2012	Jakovljevic *et al.* 2013	Kakkad *et al.* 2015	Dahl *et al.* 2011

*SLSC = Short-Lag Spatial Coherence, **Patented in 2016**

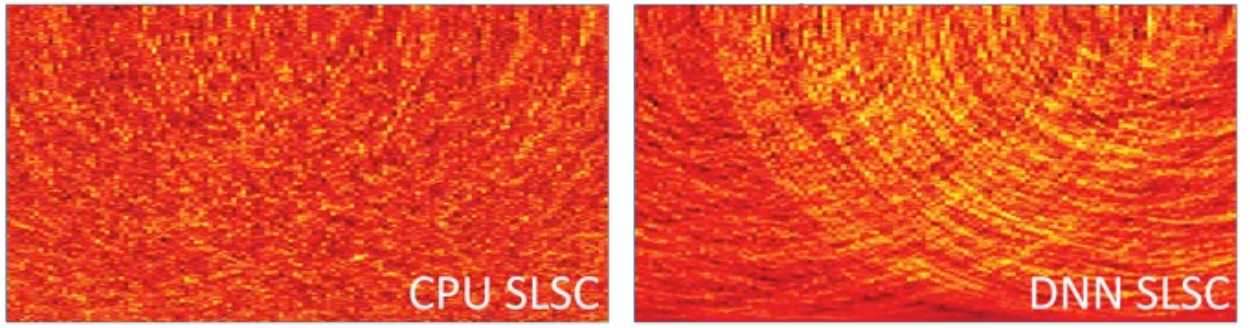
Applications in Deep Learning

- Photoacoustic coherence functions were learned to provide SLSC images for a diversity of skin tones[1]
- Reduces clutter and skin tone bias present in traditional amplitude-based images[2]





Overfitting detection with Gaussian input[3]



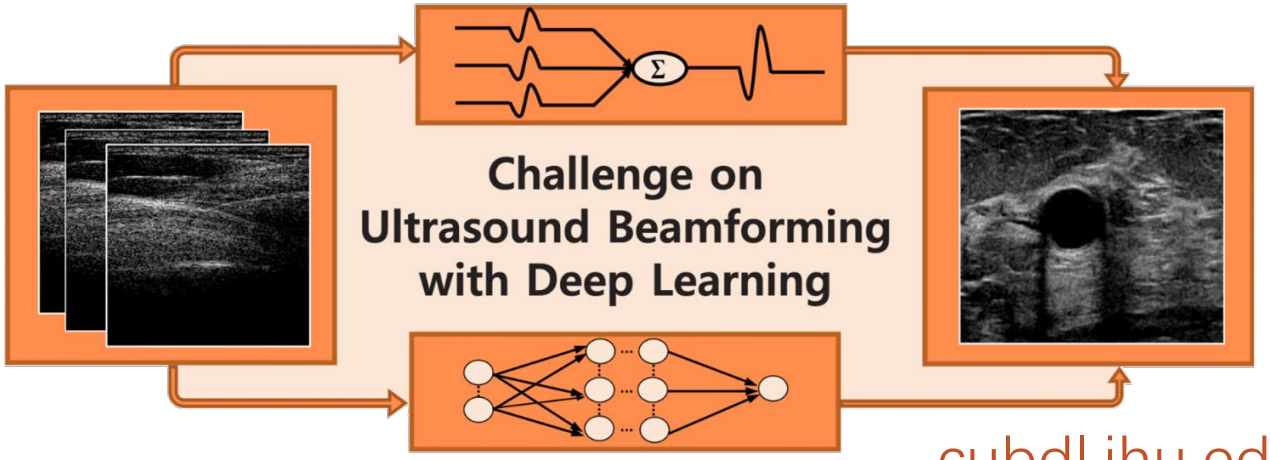
[1]Timaná, Fernandes, Pavan, Bell, *IEEE IUS,* 2023
[2]Fernandes *et al. Photoacoustics,* 2023
[3]Zhang *et al. IEEE IUS 2022*

Open-Source Datasets, Code, Resources

UltraSound ToolBox

MATLAB toolbox for processing ultrasonic signals

www.ustb.no



cubdl.jhu.edu

PICMUS is part of the IEEE IUS 2016, Tours, France.

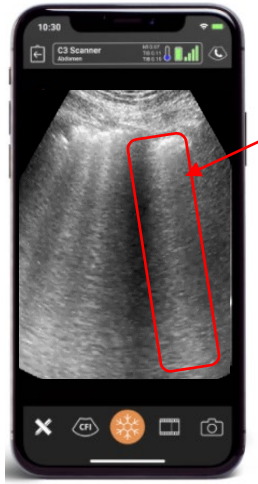
www.creatis.insa-lyon.fr/Challenge/IEEE_IUS_2016/download

COVID-19 Detection with Artificial Intelligence

wireless probe

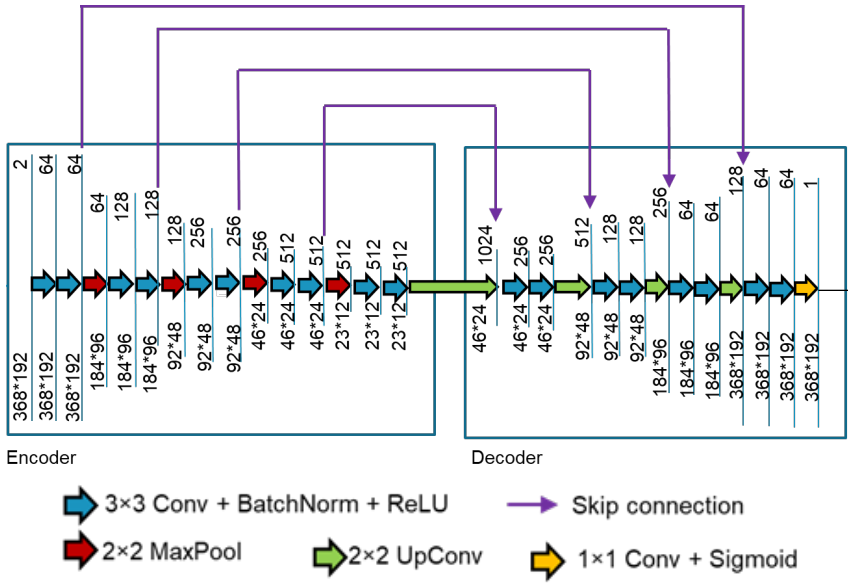
+

smart phone

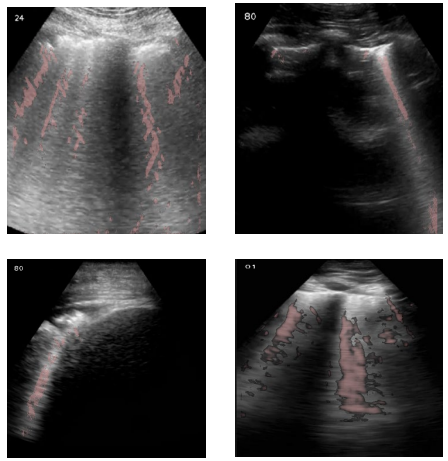


B-lines

(can be deployed in remote locations)



Example Results with Lung Ultrasound Images



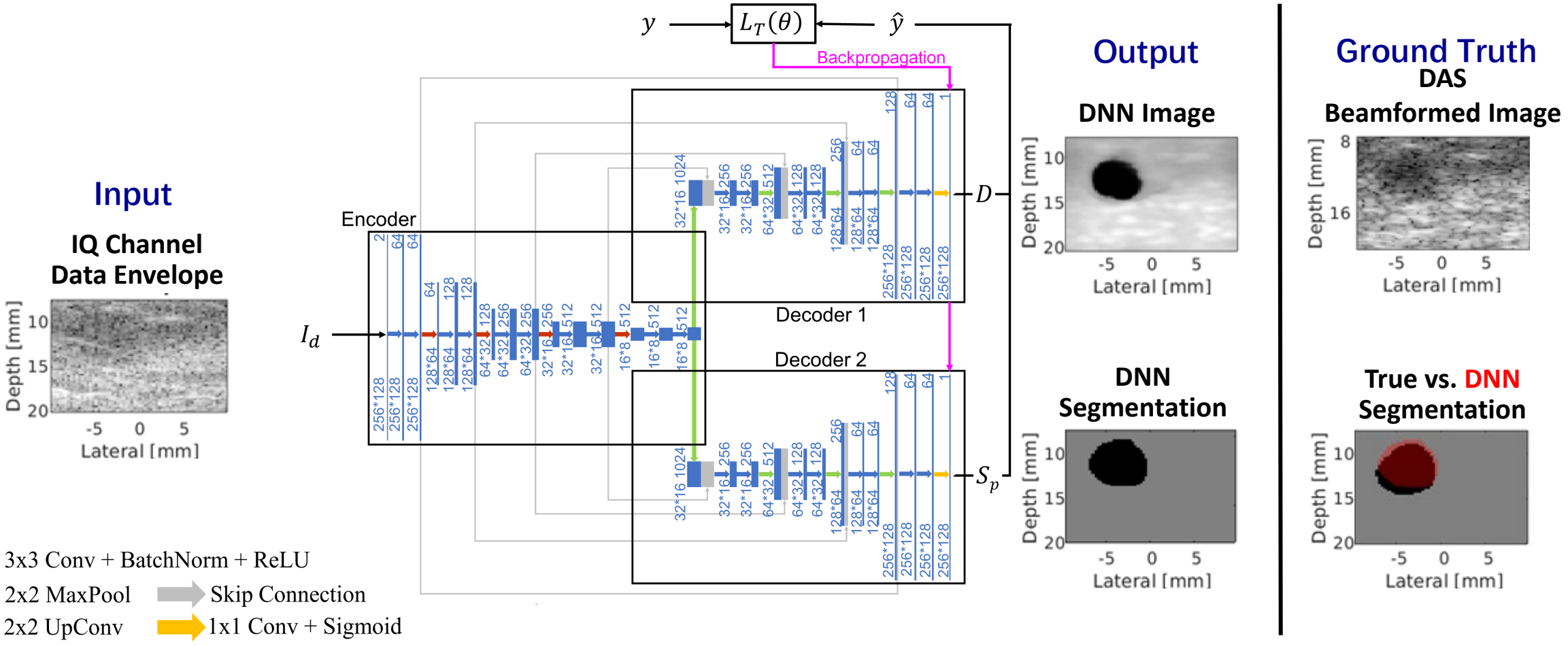
- First to train DNNs with simulated lung ultrasound data
- Accuracy better than training on *in vivo* data when applied to *in vivo* patient images
- Assists with identifying and monitoring COVID-19 and other lung diseases

*Data, code, and segmentation labels are public: https://gitlab.com/pulselab/covid19

L Zhao, T Fong, MAL Bell, *Nature Communications Medicine*, 2024

(funded by NIH Trailblazer Supplement NIH R21 EB025621-03S)

In Vivo Breast Cyst Detection with Deep Learning



Nair, *et al.* "Deep learning to obtain simultaneous image and segmentation outputs from a single input of raw ultrasound channel data." *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, 2020

CUBDL Resources

Largest database of ultrasound channel data!

Crowd-sourced training & testing data

IEEE DataPort™

- 1_CUBDL_Task1_Data
- 2_Post_CUBDL_JHU_Breast_Data
- 3_Additional_CUBDL_Data
- CUBDL_Data_Release_Agreement.pdf
- CUBDL_Phantom_Details.xlsx
- README.txt

Open source evaluation code

GitLab

Name		Last update
cubdl		4 days ago
datasets	Update README.	2 hours ago
images	Added image to README.md.	1 year ago
scoring	Add top submitted networks and make min...	2 hours ago
submissions	Add top submitted networks and make min...	2 hours ago
.gitignore	Merge development branch into master	4 days ago
README.md	Update README.	2 hours ago

README.md

CUBDL - Challenge on Ultrasound Beamforming with Deep Learning

Description

This repository is for the 2020 IEEE International Ultrasonics Symposium Challenge on Ultrasound Beamforming with Deep Learning. Example
onstrate the input data format and the metrics. This repository was later updated on July 1
CUBDL-related datasets.

PyTorch DAS beamformer

PYTORCH

```
class DAS_PW(torch.nn.Module):
    """ PyTorch implementation of DAS plane wave beamforming.

    This class implements DAS plane wave beamforming as a neural network via a PyTorch
    nn.Module. Subclasses derived from this class can choose to make certain parameters
    trainable. All components can be turned into trainable parameters.
    """
```

Trained network weights from CUBDL winners

- goudarzi
- rothlubbers

Hyun, Wiacek, Goudarzi, Rothlübbers, Asif, Eickel, Eldar, Huang, Mischi, Rivaz, Sinden, Sloun, Strohm, Bell, *IEEE TUFFC*, 2021

CUBDL Contributors

Lead Organizer

MAL Bell

CUBDL Co-Organizers

D Hyun

J Huang

RJG van Sloun

YC Eldar

M Mischi

Post-CUBDL Evaluator & Data Curator

A Wiacek

- **CUBDL Winners:** S Goudarzi, S Rothlübbers, A Asif, K Eickel, H Rivaz, D Sinden, H Strohm
- **CUBDL Data Contributors**
  - A Wiacek, J Huang, MAL Bell, E Oluyemi, and E Ambinder (Johns Hopkins University, **USA**)
  - Ping Gong and Shigao Chen (Mayo Clinic, **USA**)
  - Alessandro Ramalli and Piero Tortoli (University of Florence, **Italy**)
  - Ben Luijten and Massimo Mischi (Eindhoven University of Technology, **The Netherlands**)
  - Ole Marius Hoel Rindal (University of Oslo, **Norway**)
  - Vincent Perrot and Hervé Liebgott (CREATIS, INSA, University of Lyon, **France**)
  - Xi Zhang and Jianwen Luo (Tsinghua University, **China**)

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