LED-based photoacoustic image post-processing in real-time with a deep learning network

Avijit Paul and Srivalleesha Mallidi

Department of Biomedical Engineering, Tufts University, Medford MA 02155

Introduction

Photoacoustic imaging:-

Detection of ultrasound signals due to the thermoelastic expansion of objects absorbing the optical energy illuminated upon them [1].

With Laser:

- **Pros:** Hybrid, non-invasive and non-ionizing
- **Cons:** Non-portable, costly, and low pulse repetition frequency (PRF)

With Light-emitting diode (LED):

- **Pros:** Portable, low-cost, and high PRF
- **Cons:** Low fluence - Averted with time-intensive high frame averaging [2]

Goal: Achieve a high signal-to-noise ratio (SNR) in real-time imaging.

Recent attempts with Deep learning:

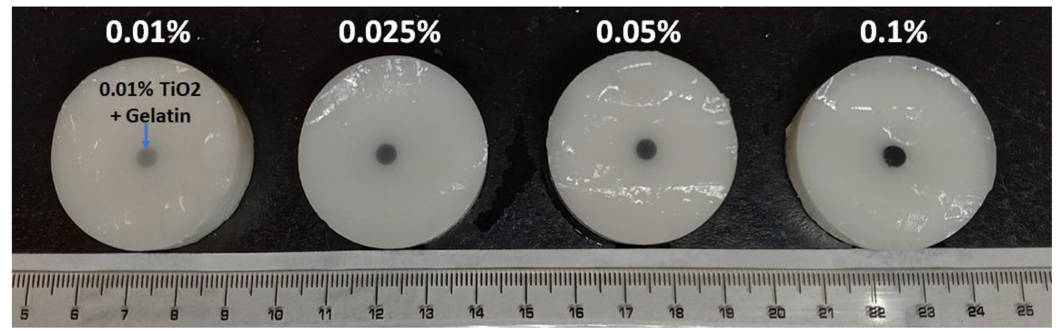
- High network complexity; Huge training data [3,4]
- Train & test dataset from a similar distribution and no *in vivo* experiment [5]

Our solution: Build a **noise invariant deep neural network** (U-net) trained with an **unbiased** dataset & tested with a highly **different data distribution**

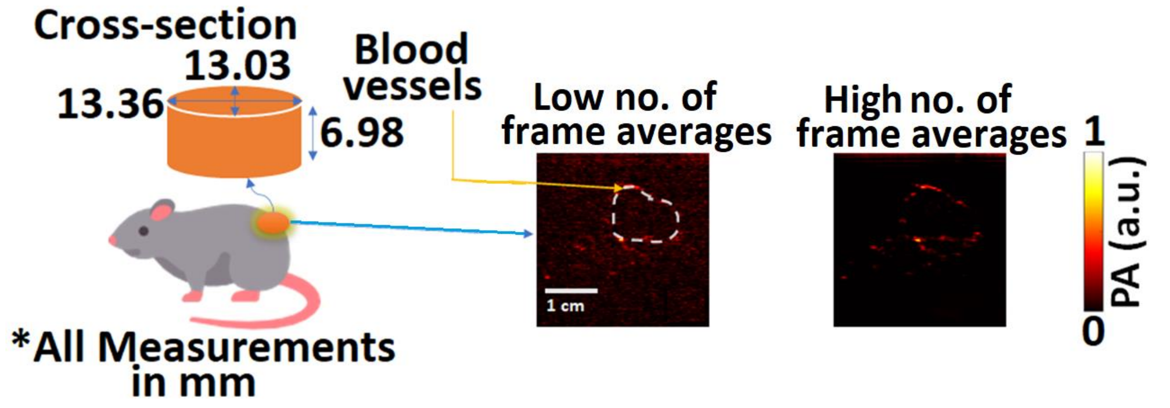
Methods

Test models:-

***In vitro*:** Cylindrical graphite ink inclusion in gelatin



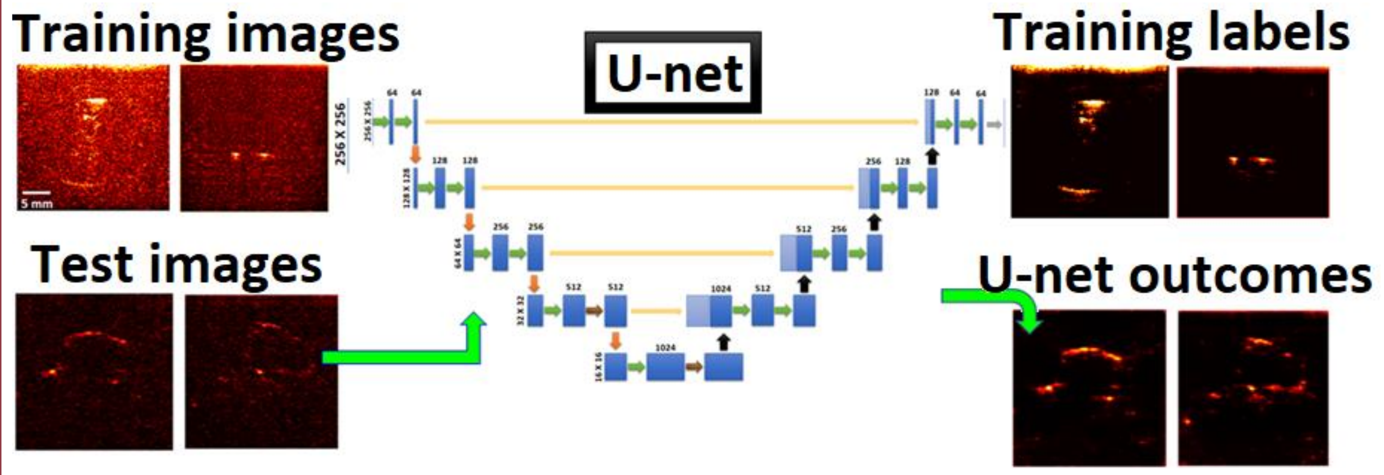
***In vivo*:** Subcutaneous xenograft tumor model (human pancreatic adenocarcinoma (**AsPC-1**))



Methods (Continued)

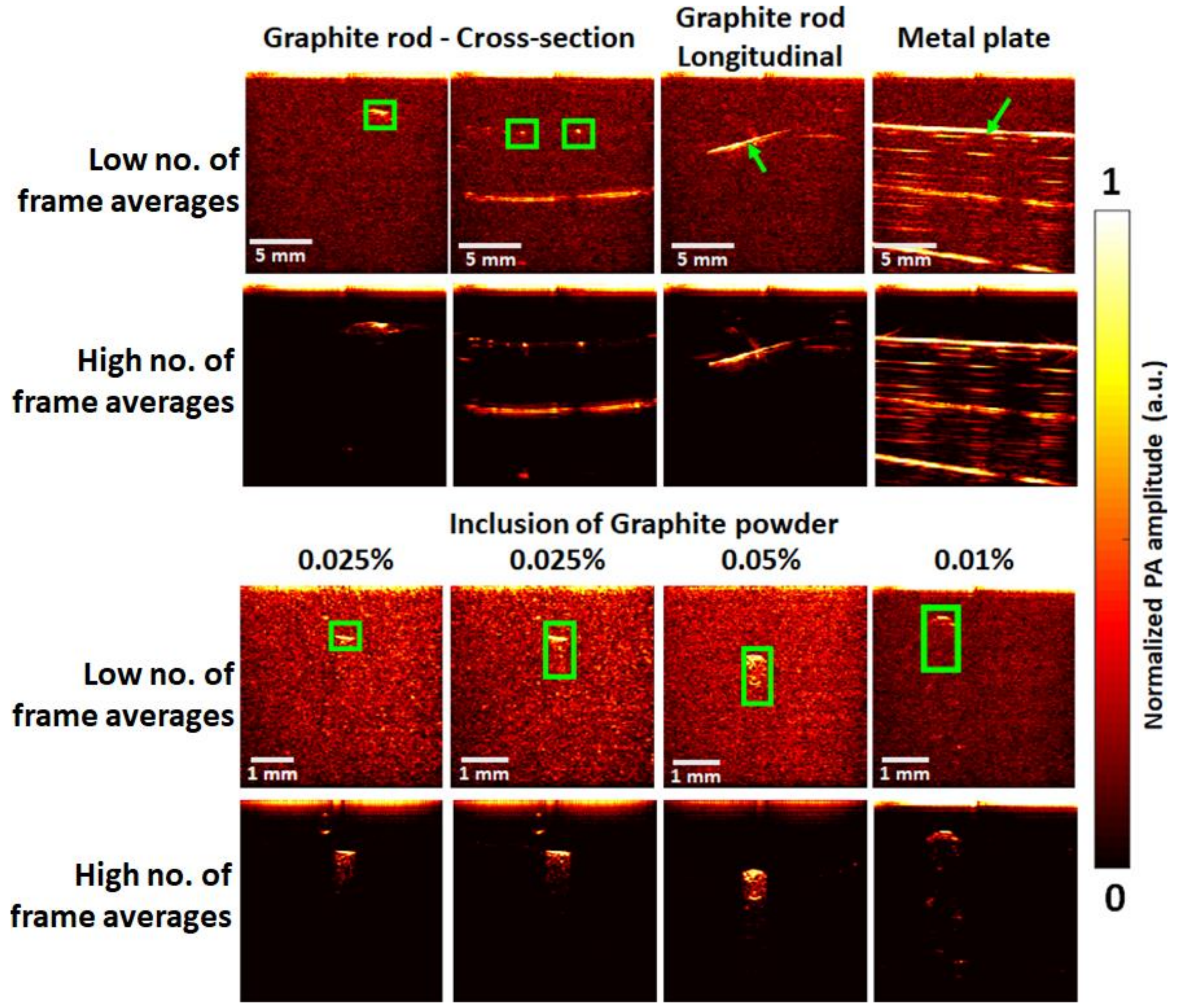
U-net architecture:-

- **Noise removal algorithm:** Fully convolutional U-net deep learning network in Google Colab platform with Keras on TensorFlow where a replacement optimization algorithm (*Adam* with 0.0001 as the initial learning rate) and *Mean squared error* loss function were used.



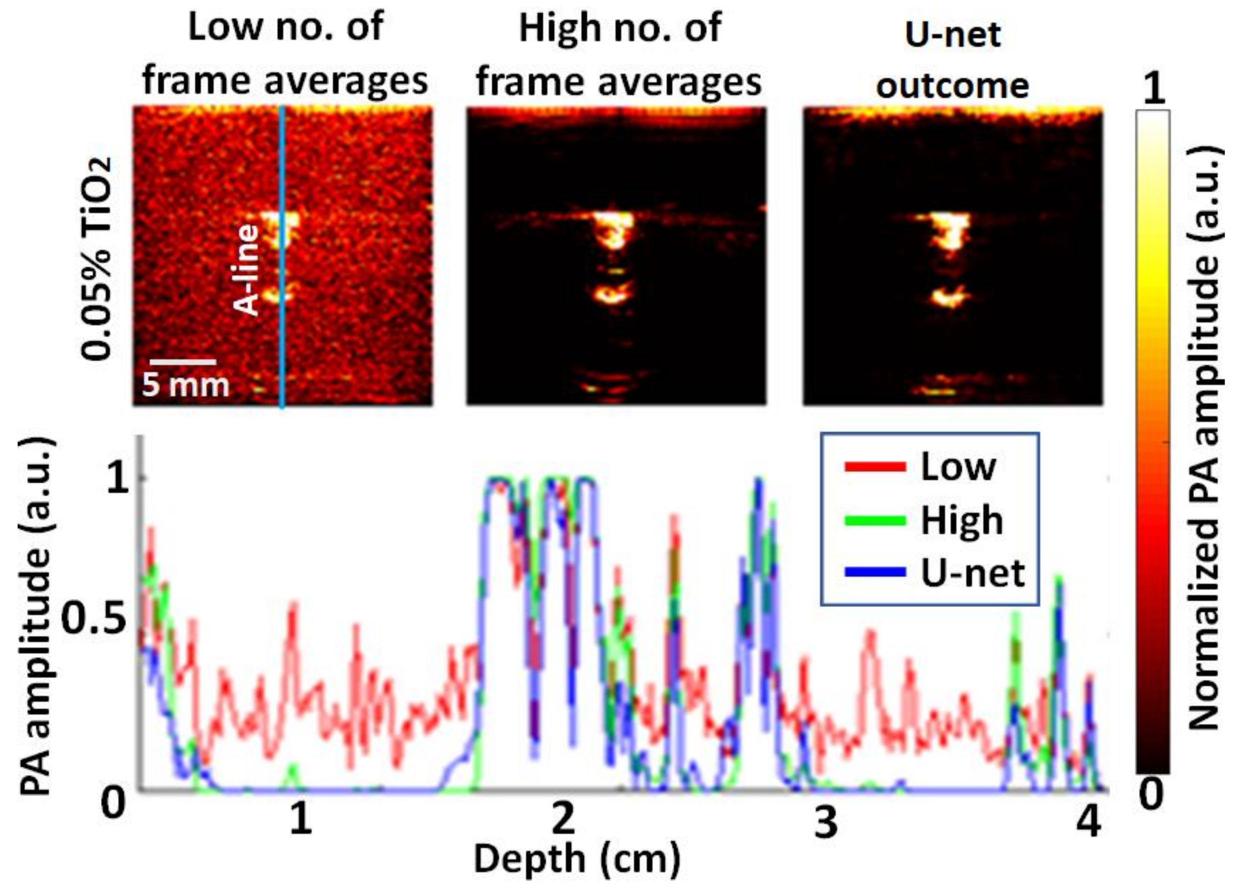
Details of training data:-

- **Image capturing:** Acoustic X with 7 MHz transducers and 850 nm LED arrays
- **Training inputs:** 256X256 low number of frame averaged images
- **Training labels:** 256X256 corresponding high number of frame averaged images



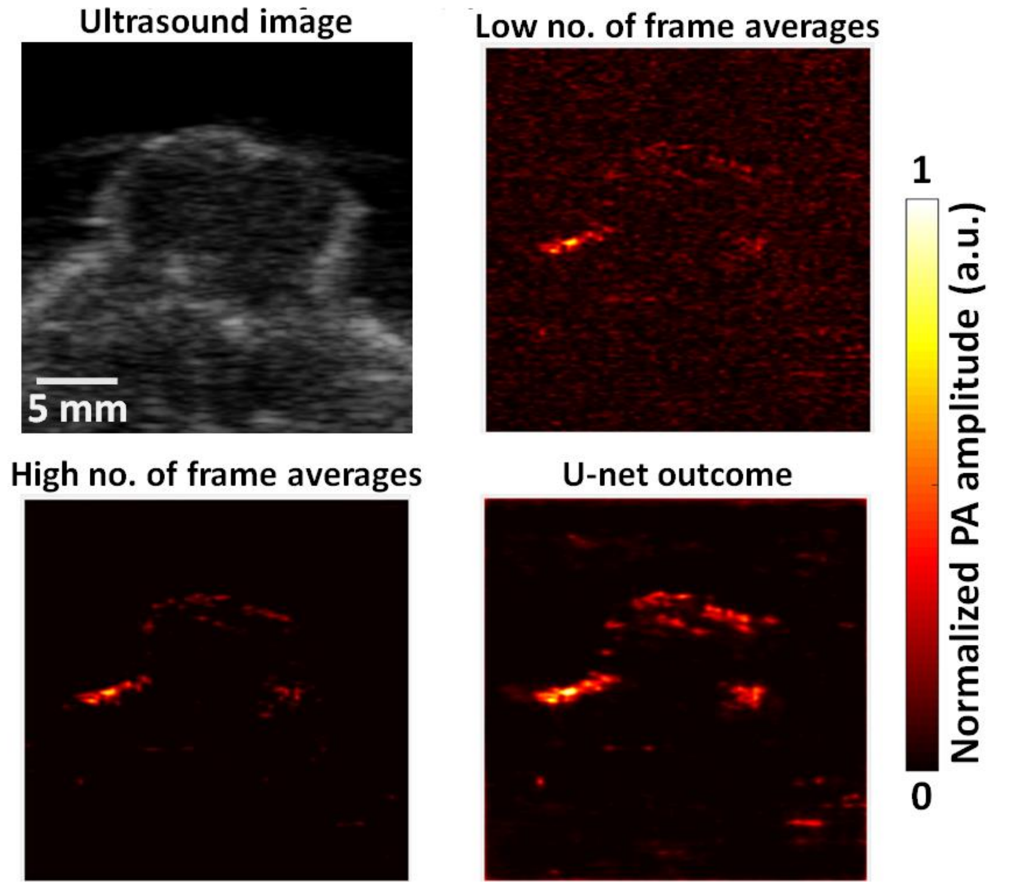
Results

Evaluation of tissue-mimicking phantoms:-



Top panel: Images of graphite powder inclusion in a gelatin base. **Bottom panel**: A-line across the center of images. PA amplitudes for high no. of frame averaging and U-net are similar and less noisy than the low no. of frame averaging.

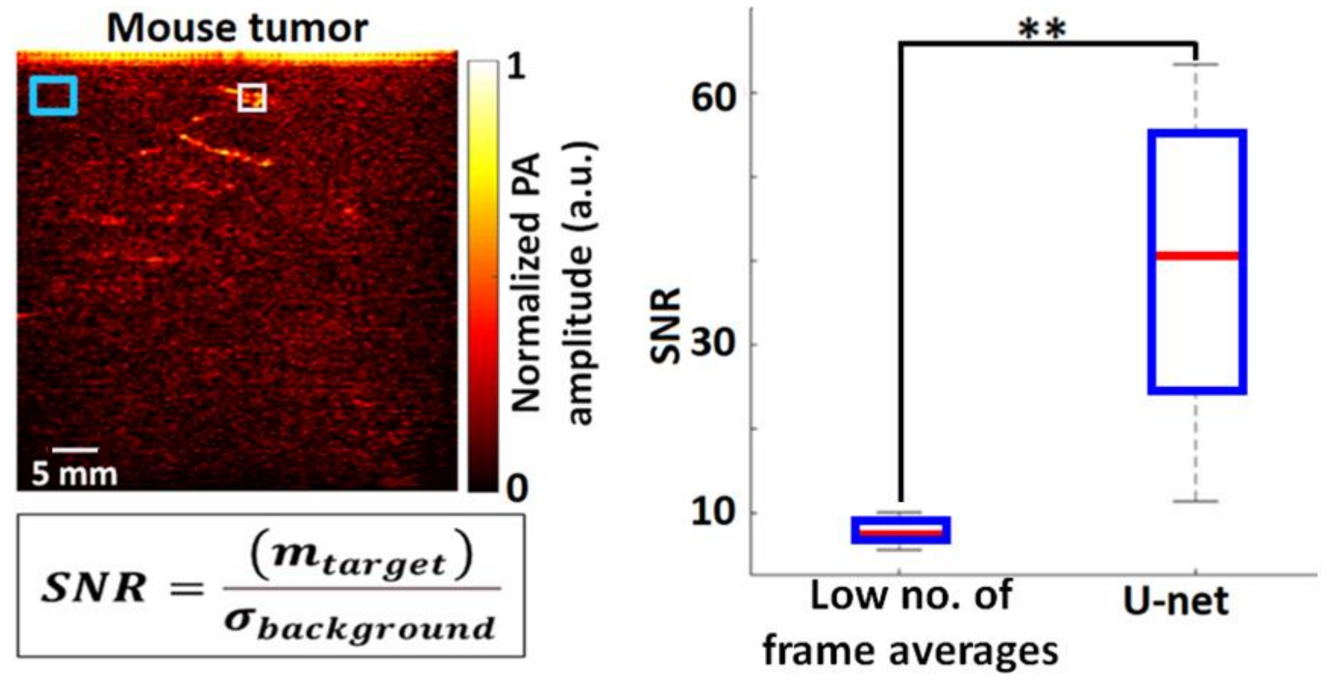
Evaluation of mouse tumor models *in vivo*:-



Ultrasound & Photoacoustic images of subcutaneous tumor for low, high no. of frame averages, and U-net outcomes. The similarity of high no. of frame averaging and U-net outcomes indicates that U-net efficiently removed noise for *in vivo* tumors.

Results (continued)

Quantitative Image quality metrics analysis:-



$$SNR = \frac{\langle m_{target} \rangle}{\sigma_{background}}$$

Left panel:- *White box:* Region of interest; *Blue box:* Background. **Right panel:-** SNR of U-net is significantly higher than that of the low no. of frame averaged images

Conclusions

- We achieved a noise invariant & generalized simple deep learning framework with a low amount of training data which might work in various tumor models.
- In the future, we plan to:
  - Train and compare with multiple systems at multiple frequencies
  - Test with more varied types of tumor biology
  - Network architecture improvement with transfer learning for more generalization to work with varied tumor biology

References & Acknowledgements

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