

#### Towards Efficient Methods FOR Transcranial Ultrasound Monitoring & Control

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#### Need to Monitor & Control Cavitation in Real-Time

- FUS & microbubbles localize forces
- Stable Cavitation
  - Correlated with reversible BBB opening<sup>1,2</sup>
- Inertial Cavitation
  - Associated with ablation<sup>3</sup>





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<sup>1</sup> Arvanitis et al. *PLoS One* **7**(9) (2012)

- <sup>2</sup> Arvanitis et al. Phys. Med. Biol. 58(14) (2013)
- <sup>2</sup> <sup>3</sup>Xu et al., *IEEE Trans. Ferroelectr. Freq. Control* **51**(6) (2004)

# Monitor Passive Acoustic Mapping (PAM)



# Passive Acoustic Mapping (PAM)

**Receiver Array** 







# **Pro:** ASA is Frequency Selective





# **Pro:** ASA is Frequency Selective



# **Pro:** ASA is Sensitive





# **Con:** ASA Does Account for Aberration



**Receiver Array** 



# ASA-PAM Benefits

- Fast Milliseconds vs Minutes
- Sensitive Robust to Noise
- Frequency-Selective Identify Bubbles
- Assumes Uniform Medium

#### **Challenge:** Adapt ASA for Heterogeneity



# <u>HASA FOR Passive Acoustic Mapping</u> Heterogeneous





**Medium Properties** 



# HASA Improves Accuracy

# Receiver Vessel Region 2 cm

Sound Speed [m/s] 1500 2100



# HASA Improves Accuracy



Sound Speed [m/s] 1500 2100



# HASA Improves Accuracy



# Control PAM-Based Cavitation Control



#### Harmonic Level Quantifies Cavitation

- Harmonics and Ultraharmoics indicate Stable Cavitation
- Broadband Emissions indicate Inertial Cavitation



#### Frequency-Selective PAMs Visualize Cavitation

• Form PAMs at Harmonic and Broadband frequencies



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#### Idea: Use Harmonic Levels to Adjust Excitation



Tech

#### Levels are Function of Pressure





20

#### Sign of Step: Relative to Target



How Big of a Step?







# Controller Parameters Chosen

Smooth

- Third harmonic (H3) for target (direction)
- Third ultraharmonic (U3) for model (size)
- Broadband (BB) for safety
- Two control law shapes:



#### Controller Performance





#### Controller Performance – Proximity Ratio





#### PAM Allows Spatial Specificity





### Emissions Associated with K<sup>trans</sup> Increase



# Conclusions

#### • ASA can Image Cavitation Passively

- Can form frequency-selective maps in real time
- Type and location of activity can be discerned
- Fast correction developed to deal with heterogeneity
- ASA can Enable Cavitation Control
  - Frequency selectivity allows characterization
  - Mapping enables spatial control
  - Fast enough for real-time feedback



# Thanks!



# Ultrasound Biophysics Lab









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