Mapping the Cardiac Acoustome: Biosensing and Computational Modeling Applied to Smart Diagnosis and Monitoring of Heart Conditions

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Motivation

- Cardiac Auscultation: science and art of diagnosing heart conditions via the stethoscope
- Potential, non-invasive diagnostic modality limited by:
  - incomplete understanding between cause effect (sound)
  - human-in-the-loop
  - sequential (unilocal) measurement technique
  - high level of noise
  - large array of heart sounds
  - declining auscultatory skills

- Vision: Rescue this valuable diagnostic modality from obsolescence by deploying new tools and ideas from computational science, biosensing and signal processing.

Objectives

- Goal: Develop an approach to automated heart sound measurement and localization via a compact acoustic sensor array (the “StethoVest”)
  1. Develop image-based computational hemoaoustic models (CHM).
  2. Validate CHMs and develop/test generative (model based) statistical pattern recognition algorithms for abnormal heart conditions using thoracic phantoms.
  3. Investigate the physics of murmurs associated with aortic valve (AV) disease using integrative biosensing-CM approach.
  4. Evaluate auscultome-map based screening for hypertrophic obstructive cardiomyopathy (HOCM)

Impact

- Revolutionize the management of heart disease
  - Inexpensive, non-invasive, accurate
  - Screening of wide range of heart conditions
  - 24/7 continuous, at-home health monitoring
  - Dobutamine stress echocardiography and undererved areas
  - Leverage telemedicine, bioinformatics & wearable sensor revolution
- Health care: reactive, expensive and hospital-centric → smart, proactive, patient-centric and cost-effective
- Advance medicine, mechanics and modeling, computing, electrical engineering, biosensing, and BIGDATA science.
- Training of undergraduates, graduate students and postdocs in a highly cross-disciplinary environment.

Technical Approach

- High-Fidelity Hemoaoustic Modeling and Simulation
  - Biophysics of auscultation involves:
    - Flow perturbation
    - Propagation of acoustic wave through thorax (lung, bone, muscle, fat)
    - Sensing by stethoscope
  - Integrated multiphysics analysis required to understand the physical basis of auscultation

- Computational & experimental modeling and analytics
- Sensors, signal processing and pattern classification

- Sensing & signal processing
- Pattern Classification
- Clinical Testing and Evaluation
- StethoVest

Team

- W. Reid Thompson (MS)
- Theodore Abraham (MD)

- Rajat Mittal (PhD)
- Mechanical Engineering

- Andreas Andreou (PhD)
- Electrical Engineering

Research Question

- Multi-scale hemoaoustic model
- 1D thermo-hemodynamic simulation
- 3D/4D anatomical model
- Coupled Navier-Stokes and acoustic PDEs

Simulation and Experiments

- Surface fluctuation on the chest
- Structural wave Propagation
- Pressure fluctuation in the Heart

Data

- Time delayed source of traveling wave is separated into static responses at the time-differentiated sources

Biophysical Source Localization using Gradient Flow (GF)[7]

Characterizing different sensors

Transducer: HP 3505DA

Photograph: HP 3505DA

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- Adam C. Cardin (BME, JHU), Richard George (Cardiology, JHU), Sharon Gersten and Michael Bakshaei (Chemical and Biosystem engineering, JHU), Enid Baxter (Radiology, JHU), Frederick Arsenio (Electrical Engineering, JHU)

References & Misc. Information

- References
- Project homepage: http://engineering.jhu.edu/flag/integrative/project_homepage/