Monitoring the Propagation of Lung Sounds using Electronic Stethoscope Arrays

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What problems are we trying to solve?

- Breath Variability between Auscultation Points
- Auditory Training Variability between Physicians
- Reduce Ventilator Induced Lung Injury (VILI)
- Effectiveness of Respiratory System Treatments
- Current technology cannot deliver both regional \( \text{SpO}_2 \) and temporal information (X-ray)
What is stethoscope auscultation?
Respiratory Disease

- Pneumonia
- Bronchitis
- Emphysema
- Asthma

Airway Obstructions Due to Excess Mucus Production
White Gaussian Noise

- Injected into the mouth
- Random signal across a range of frequencies
- Useful for system identification due to wide frequency band and linear phase

<table>
<thead>
<tr>
<th>Input Signal Frequency</th>
<th>Output Signal Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Value (500 Hz)</td>
<td>1 Value (500 Hz)</td>
</tr>
<tr>
<td>Range (0 – 4 kHz)</td>
<td>Range (0 – 4 kHz)</td>
</tr>
</tbody>
</table>
Solution

- Breath Variability between Auscultation Points
- Auditory Training Variability between Physicians
- Reduce Ventilator Induced Lung Injury (VILI) & Effectiveness of Respiratory System Treatments

Develop a medical instrument capable of measuring both regional and temporal information within the respiratory system.
Instrument Apparatus

• Basic Structure

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Instrument
Computer
Firepod Pre-Amplifier
Speaker
(Subwoofer)
Funnel
Unknown System
Stethoscope
(x4)

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Data Processing Algorithm

- Adaptive Filter implemented the Normalized Least Mean Squared (NLMS) coefficient update algorithm
- Number of Coefficients = 1500
- Step Size $\mu = 0.296$
- Input Signal = Reference Signal = WGN (0 – 4 KHz)
In vitro Experiments (Phantom Models)

- Verify algorithm functionality using known predictable sound propagation models (open air column model)
- Add complexity in an effort to simulate actual human chests (plastic bucket model, chest phantom model)
Chest Phantom Experiment

- Modified Plastic Bucket Model to provide a better phantom-stethoscope head interface.
- Inject sound into model
- Increase the volume of water inside the inner tube by 5cc until saturation
- Run NLMS Algorithm for 195 trials and plot average impulse response and retrieved delay
Delay Estimation and Volume Location using the Impulse Response


No Water in FOV

Propagation Delay of the Input Signal through the Chest Phantom vs. Volume for Channel 2

Water in FOV

Propagation Delay of the Input Signal through the Chest Phantom vs. Volume for Channel 3
Frequency Response for Varying Volumes of Water


- Two peak frequencies at 86.0 45.6Hz and 172.0 45.6Hz
- Cut-off frequency of 175.0 17.7Hz
In vivo Experiments

- 3 Healthy Male Participants (20 – 23 yrs. old)
- 5 Postures (Sitting, Lying Right, Lying Left, Flat on Back, Flat on Stomach)
- 15 Trials per Posture
- Plot Chest Transfer Functions
All 3 Participants Sitting vs. Flat

Transfer Functions for 3 Healthy Human Chests (Sitting)

Transfer Functions for 3 Healthy Human Chests (Lying on Back)
Comparing Lying on the Sides

Transfer Functions for 3 Healthy Human Chests (Side Right) Channel 3

Transfer Functions for 3 Healthy Human Chests (Side Right) Channel 5

Transfer Functions for 3 Healthy Human Chests (Side Left) Channel 3

Transfer Functions for 3 Healthy Human Chests (Side Left) Channel 5

CH3

CH5
All 3 Participants Stomach vs. Back

Transfer Functions for 3 Healthy Human Chests (Flat on Stomach)

Transfer Functions for 3 Healthy Human Chests (Lying on Back)
All 3 Participants – 4 Postures – 1 Stethoscope

We see the Effect!!

SAME
1 Participant – All Stethoscopes per Posture

- Frequency Response for 1 Participant on Back for all Stethoscopes
- Frequency Response for 1 Participant on Stomach for all Stethoscopes
- Frequency Response for 1 Participant (Side Right) for all Stethoscopes
- Frequency Response for 1 Participant (Side Left) for all Stethoscopes
Non – Linearity Experiment
Non – Linear Experimental Results

Normalized Impulse Response for Varying Signal Volumes

Coefficient Number

Magnitude

Normalized Impulse Response for Varying Signal Volumes

20%
40%
60%
80%
100%

50 100 150 200 250 300
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05

Coefficient Number

Magnitude

Normalized Impulse Response for Varying Signal Volumes

20%
40%
60%
80%
100%
Conclusion and Future Work

• A novel instrument has been developed to measure changes in propagation delay as the density of water increases within a chest phantom model.
• The instrument is capable of monitoring changes in the location of fluid within the chest phantom model.
• Preliminary human trials correlate nicely with chest phantom model results.
• Fine changes can be detected with posture movements.
THANK YOU!

QUESTIONS?
Open Air Column Model

- Hollow cylindrical tube with each stethoscope attached to the surface
- Use $v = \frac{d}{t}$, NLMS, Cross-Correlation to verify propagation delay of pulsed WGN input

<table>
<thead>
<tr>
<th></th>
<th>Theoretical Delay $t = \frac{d}{v}$ (ms)</th>
<th>NLMS Delay (ms)</th>
<th>Cross-Correlation Delay (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 2</td>
<td>0.6</td>
<td>1 0.2041</td>
<td>1 0.2041</td>
</tr>
<tr>
<td>1 – 3</td>
<td>1.34</td>
<td>1.25 0.4849</td>
<td>1.25 0.4849</td>
</tr>
<tr>
<td>1 – 4</td>
<td>1.808</td>
<td>2.875 0.7868</td>
<td>2.875 0.7868</td>
</tr>
</tbody>
</table>
Plastic Bucket Model
Sound propagation delay must account for delays of the instruments emitting and acquisition devices.