Carleton UNIVERSITY

Monitoring Lung Disease using Electronic Stethoscope Arrays

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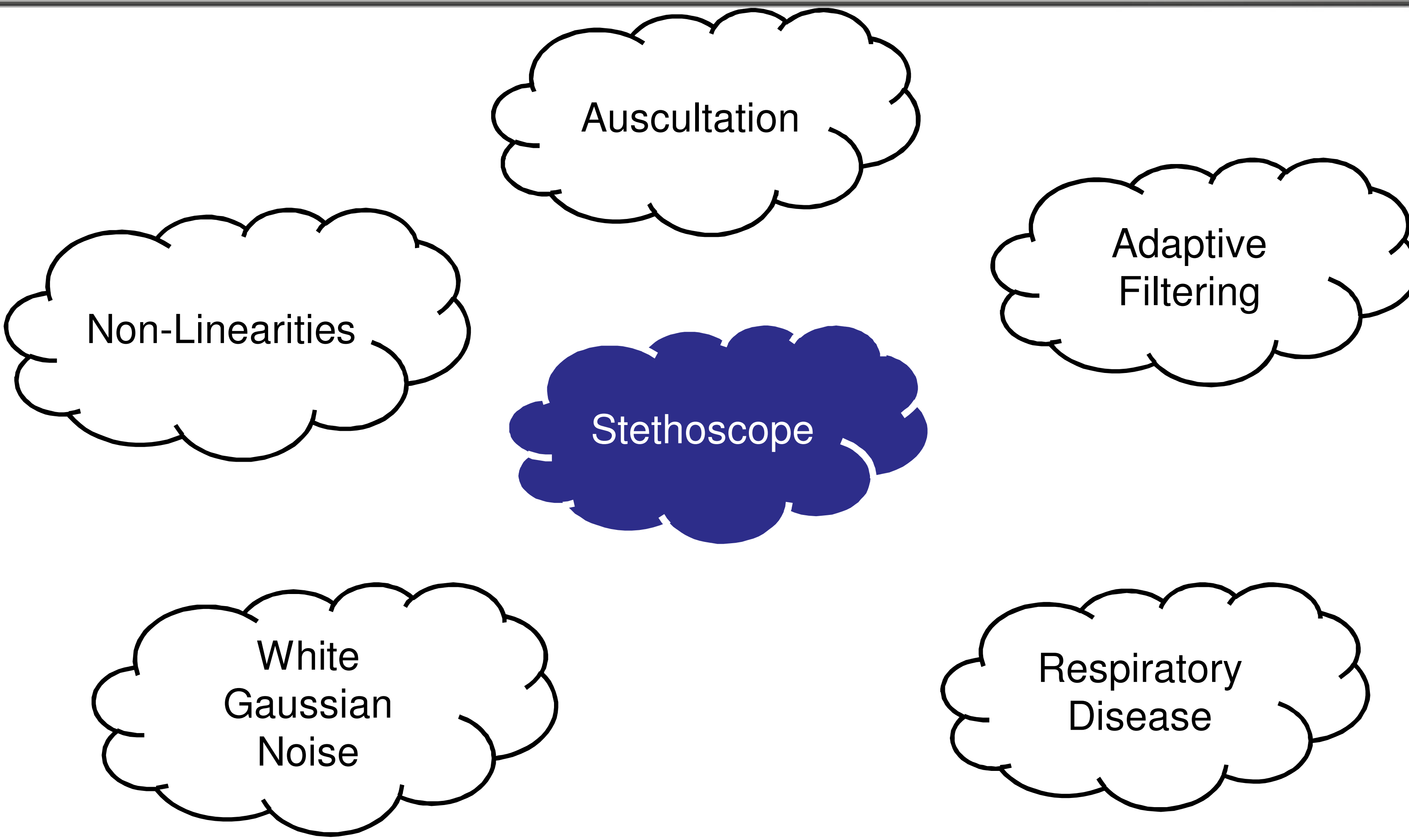
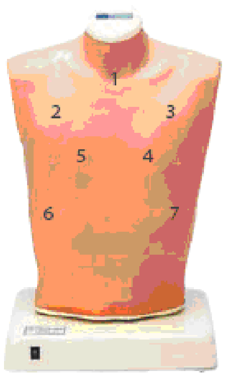
Agenda

- Background
- Motivation
- Solution
- Medical Instrument Development
- Data Processing Algorithm
- Phantom Models
- Experimental Results
- Conclusions

Background


Auscultation
Non-Linearities
Adaptive Filtering
Stethoscope
White Gaussian Noise
Respiratory Disease

What is stethoscope auscultation?

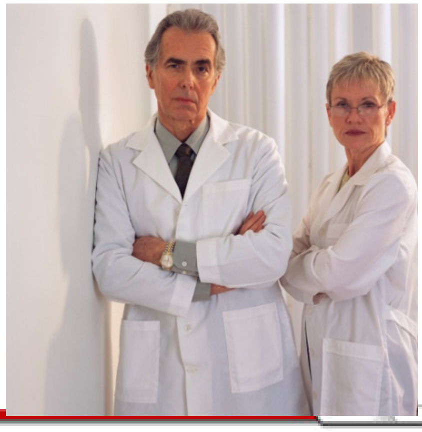


Anterior area

1 trachea
2 upper right lung field
3 upper left lung field
4 middle right lung field
5 middle left lung field
6 lower right lung field
7 lower left lung field

Posterior area

0 upper left lung field
1 upper right lung field
2 middle right lung field
3 middle left lung field
4 lower left lung field
5 lower right lung field
6 right costophrenic angle
7 left costophrenic angle



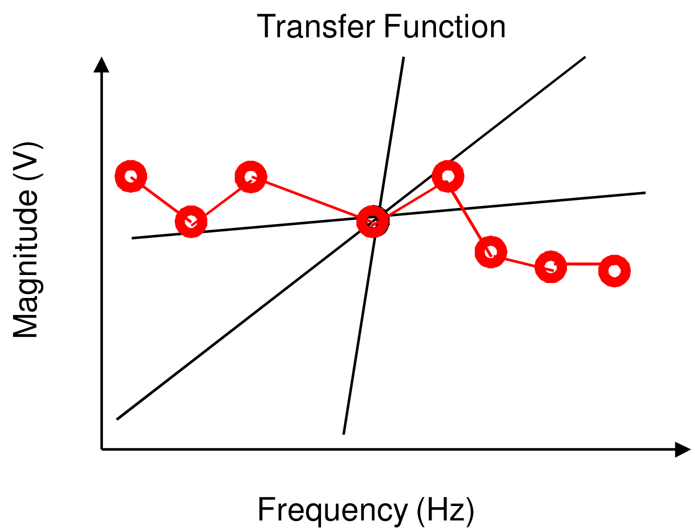
Respiratory Diseases

- This project focuses on airway obstructions caused by excess mucus in related diseases including:
  - Pneumonia
  - Bronchitis
  - Emphysema
  - Asthma

White Gaussian Noise

- White Gaussian Noise is a randomly generated signal across a range of frequencies
- Useful for system identification due to wide frequency band and linear phase

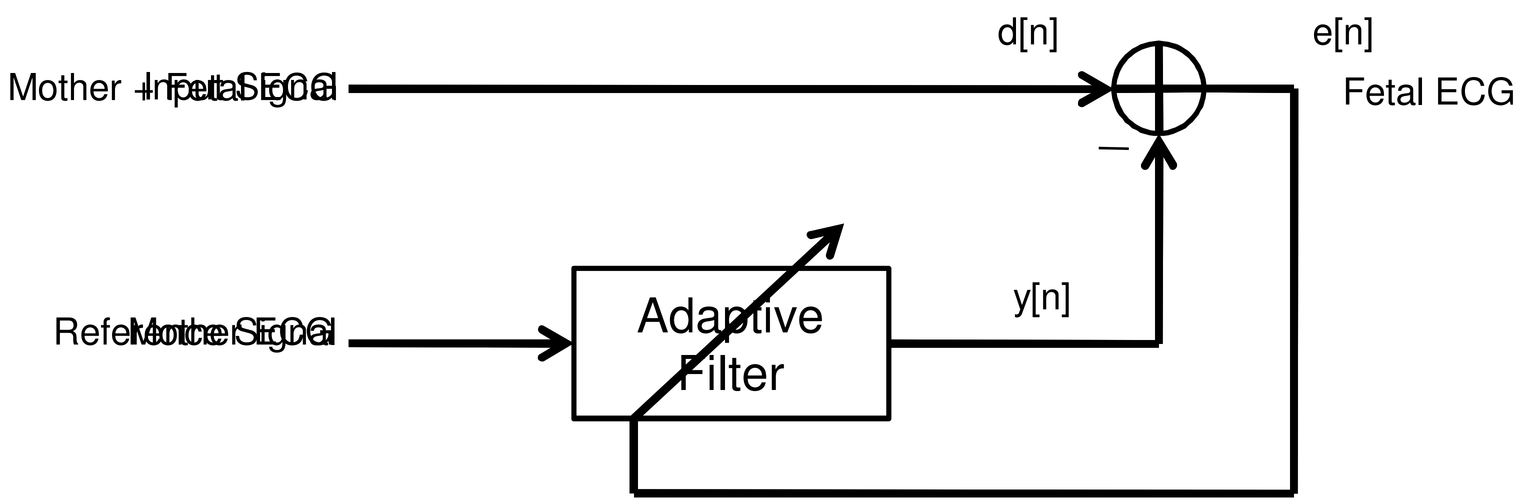
Input Signal Frequency	Output Signal Frequency
1 Value (500 Hz)	1 Value (500 Hz)
Range (0 – 4 kHz)	Range (0 – 4kHz)



Adaptive Filtering

- Easily determine behaviour of unknown linear systems
- Implemented using a Finite Impulse Response filter with a set number of updatable coefficients
- Coefficients are updated with each iteration of the algorithm by the equation:

$$w[n+1] = w[n] + 2\mu e[n] I[n]$$

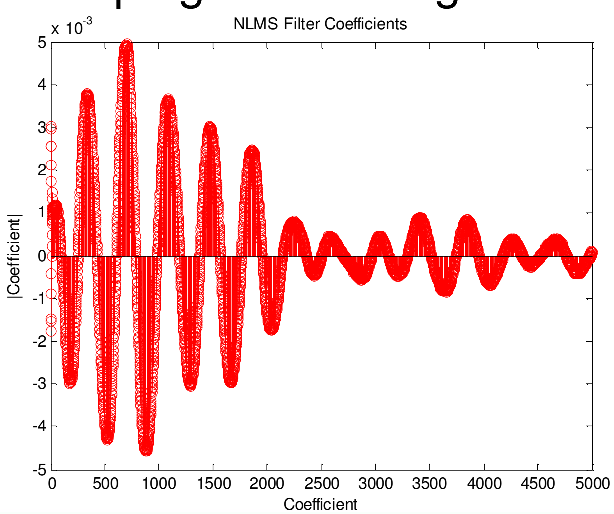


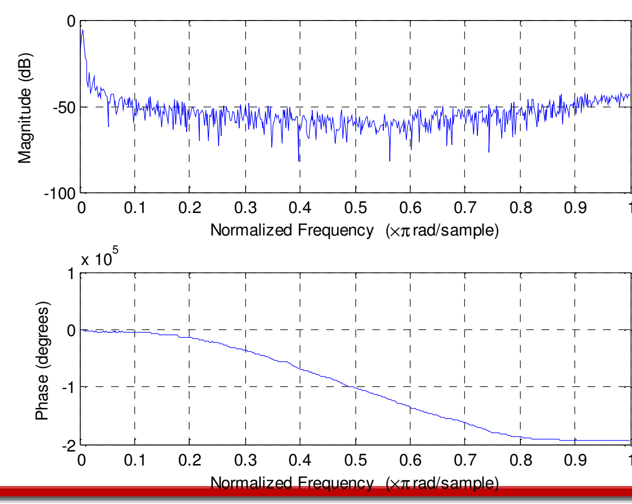
Impulse Response and Transfer Function

- The impulse response is derived from the adaptive filter coefficients upon convergence of the algorithm
- The coefficient that has the highest value designates the dominant transmission path of the input signal through the system to the measurement point
- The transfer function of a system dictates the system's behavior to any input signal. Obtained using the equation for the impulse response

$$H[z] = b_0 + b_1 z^{-1} + b_2 z^{-2} + \ldots$$

and sweeping over a range of frequencies (typically 0 – π rads/sample)





Non-Linearities

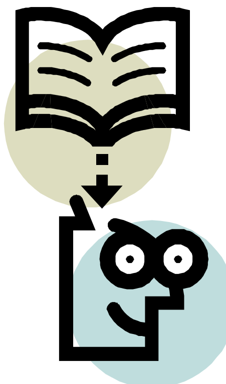
- A non-linear system is that in which its output is not linearly proportional to the input into the system and thus cannot be described by a simple linear equation
- The performance of the algorithm depends on what excites the non-linear components of the system
- Caused by loudspeaker

Motivation

- Improve patient health by reducing ventilator induced lung injury (VILI) and help in the selection of optimal ventilation parameters
- The instruments currently available either don't provide regional information (ie SpO2), or temporal information (ie X-ray CT)
- Breath Variability between auscultation points
- Auditory training variability between physicians

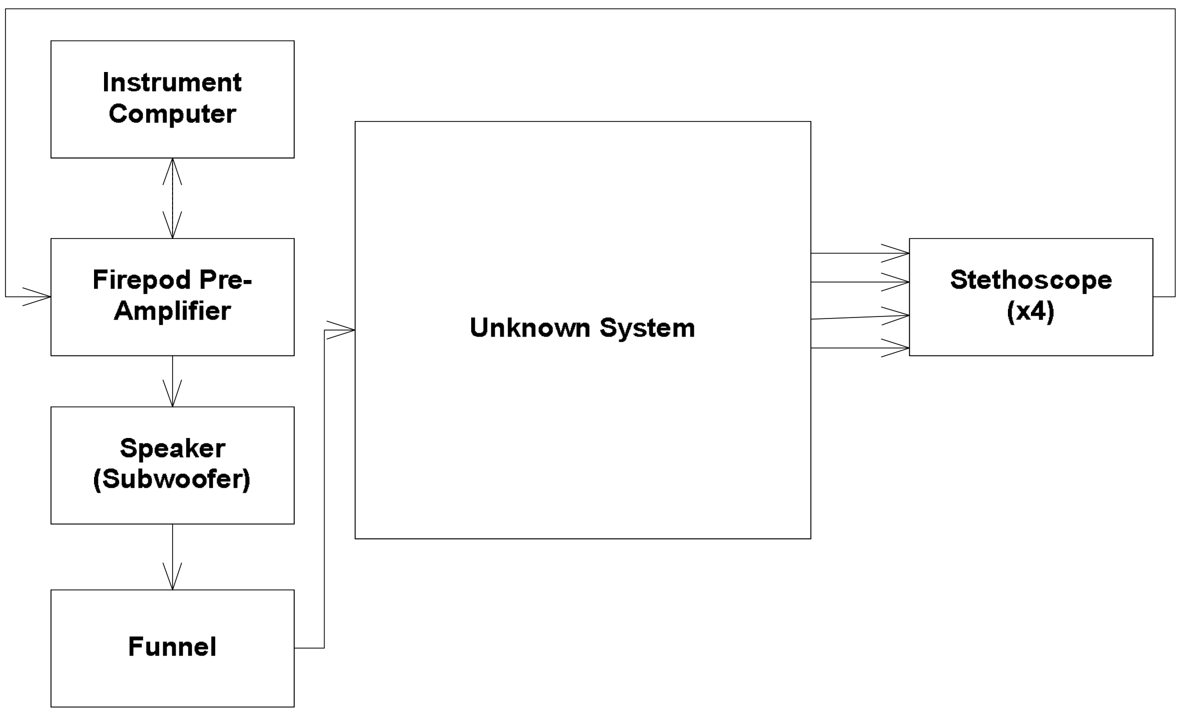
Solution

- Take advantage of signals generated from electronic stethoscopes and adaptive filtering techniques to develop an instrument capable of measuring changes in the distribution of lung fluid and tissue densities within the respiratory system
- Use an array of stethoscopes and a low frequency input sound projected into the mouth



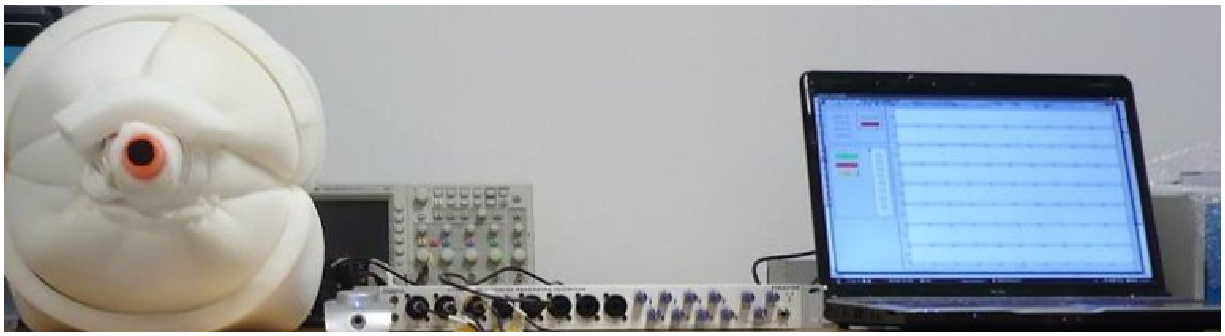
Instrument Development

- Basic Structure

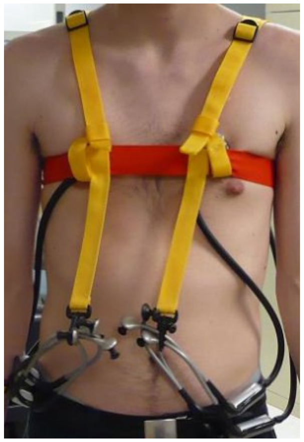


Instrument Development cnt.

- Actual Components with Participant



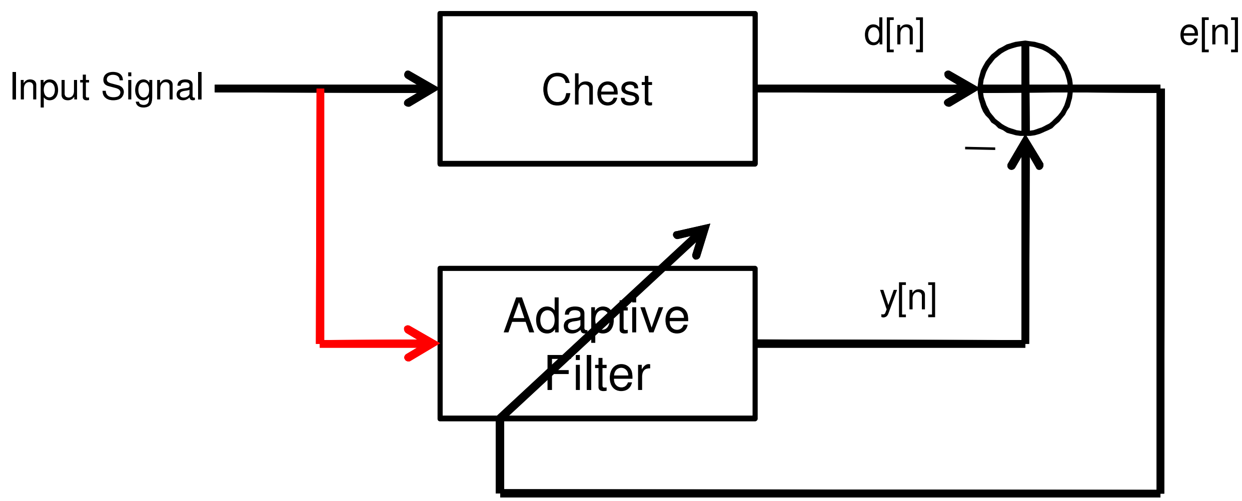
Sound Generator Pre-Amplifier Computer



Stethoscope Array and Harness Attached to a Participant

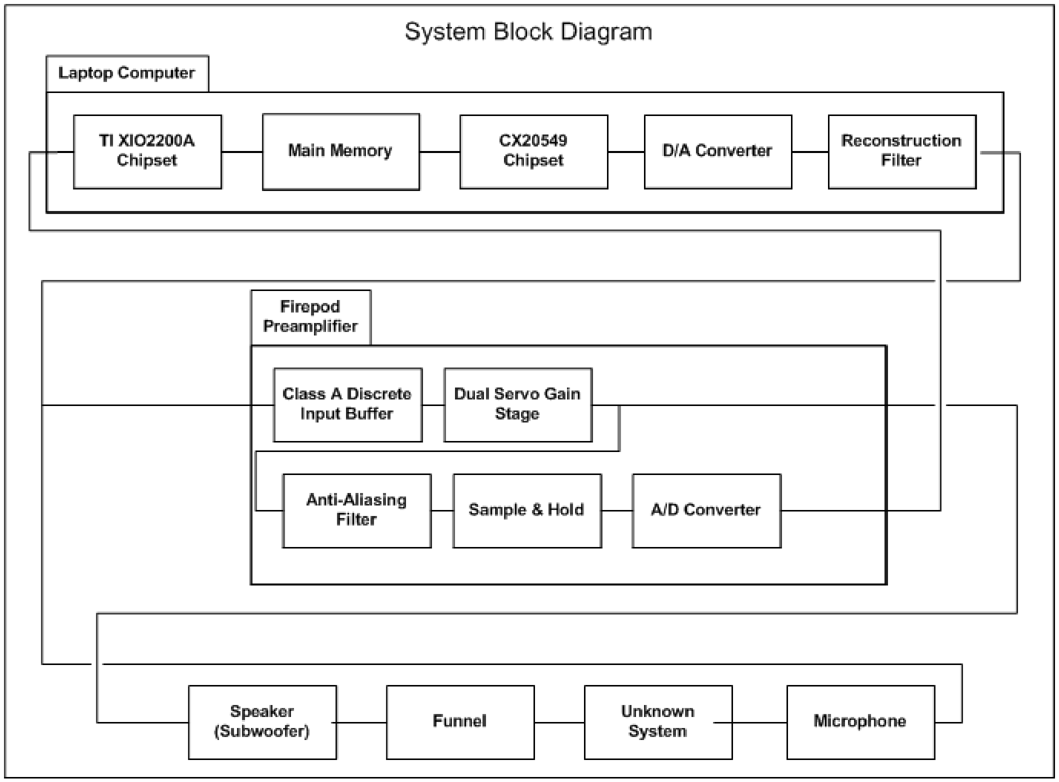
Data Processing Algorithm

- Used adaptive filtering setup that employed the Normalized Least Mean Squared (NLMS) algorithm
- Number of Coefficients = 1500
- Step Size µ = 0.296
- Input Signal = Reference Signal = WGN (0 – 4 KHz)



Instrument Calibration

- Sound propagation delay must not take into account the delay of the instruments emitting and acquisition devices.

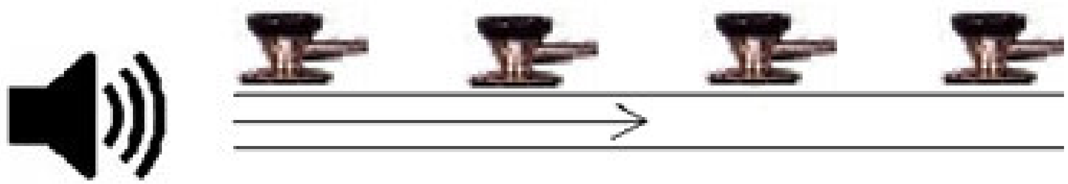


Phantom Models

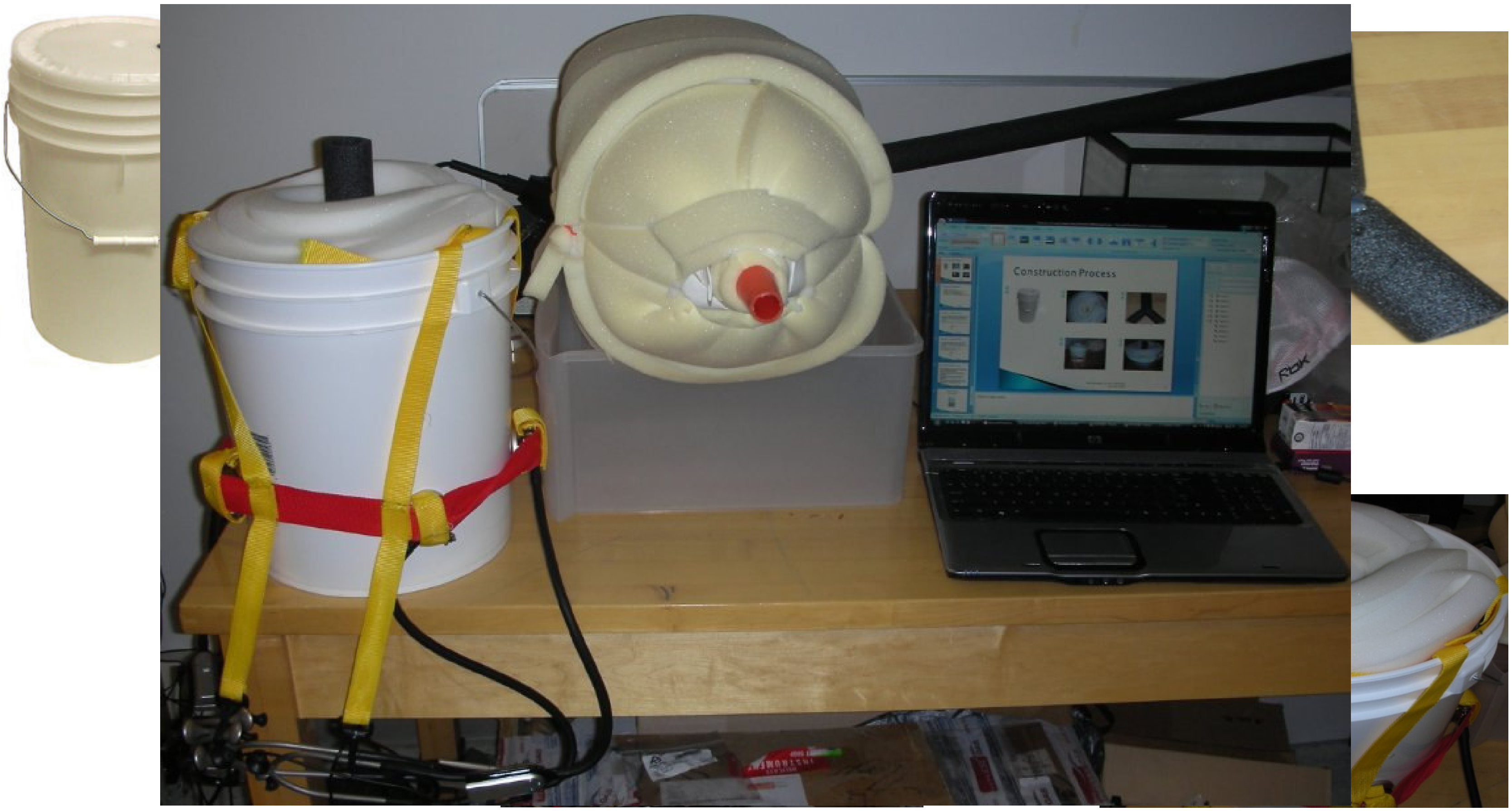
- Verify algorithm functionality using known predictable sound propagation models
- Add complexity in an effort to simulate actual human chests

Open Air Column Model

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

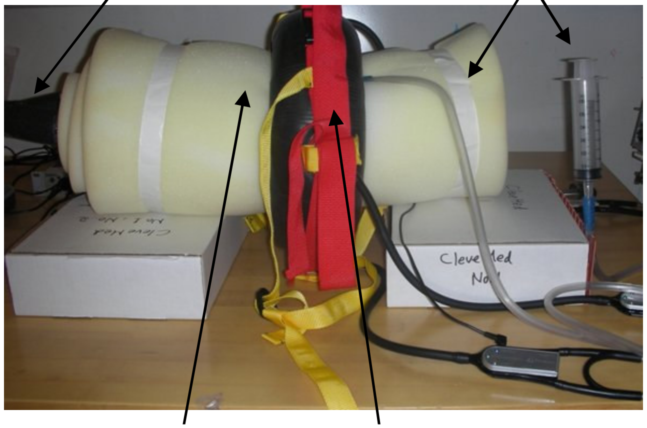


Plastic Bucket Model



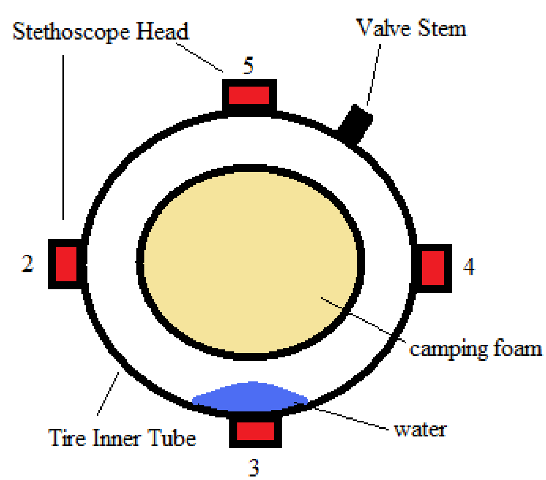
Chest Phantom Model

- Modified Plastic Bucket Model to provide a better phantom-stethoscope head interface.



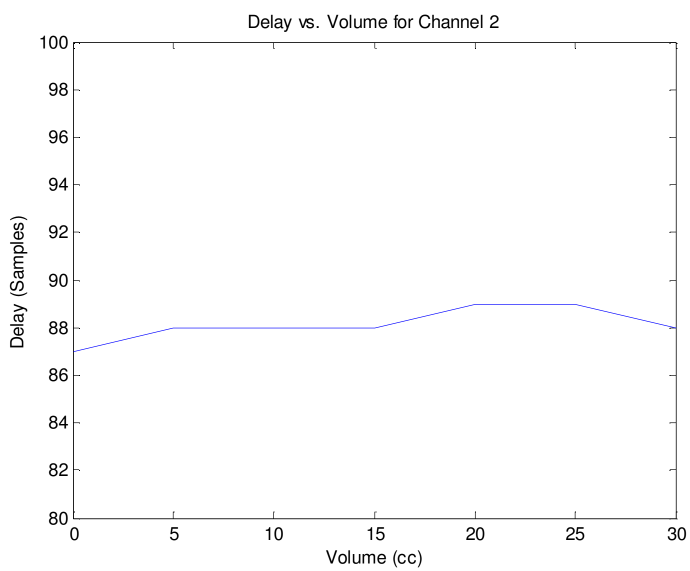
Chest Phantom Experiment

- 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

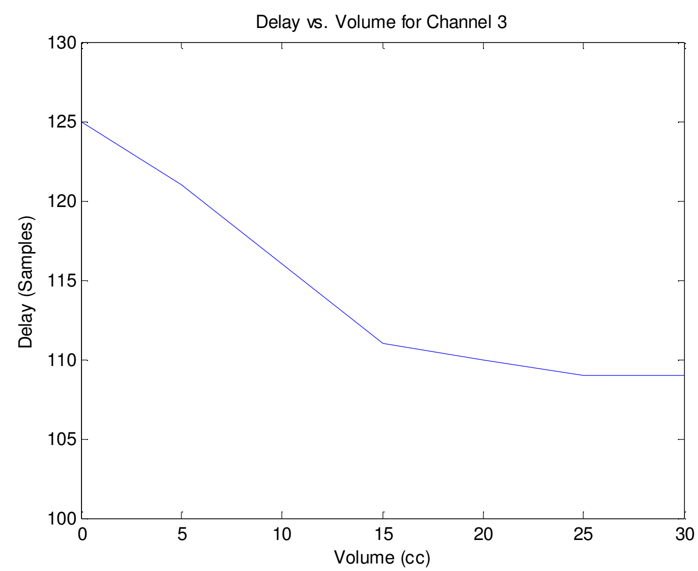


Delay Estimation and Volume Location using the Impulse Response

No Water in FOV



Water in FOV



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