# Asclepius: Exploring the Feasibility of Remote Cardiac Auscultation Using Earphones

Paper Review by Raheem Idowu - 10/07/25

# Outline

What is Asclepius? (System Design and Results)

Why was it made? (Motivation and Background)

How was it made? (Challenges and Contributions)

What’s next? (Limitations and Future Work)

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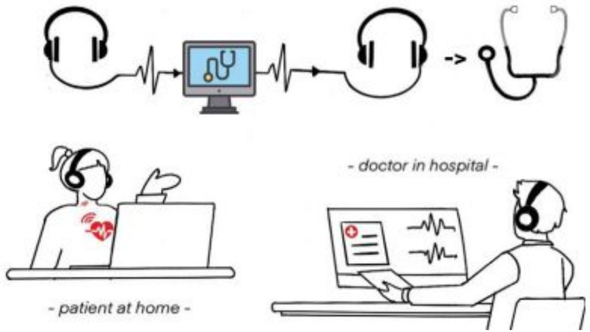
## What is Asclepius?

Auscultation = Stethoscope

Cardiac, lung, abdominal

Assess health & function

Asclepius: **remote** cardiac auscultation



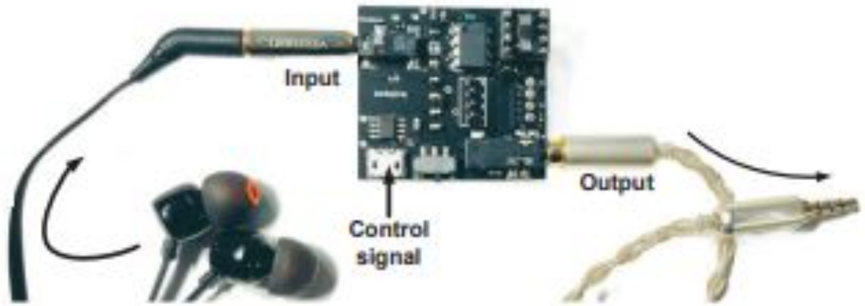
## Asclepius Design

Hardware-software solution

$5 PCB circuit

Use any earphones

No microphone needed (structure reciprocity!)



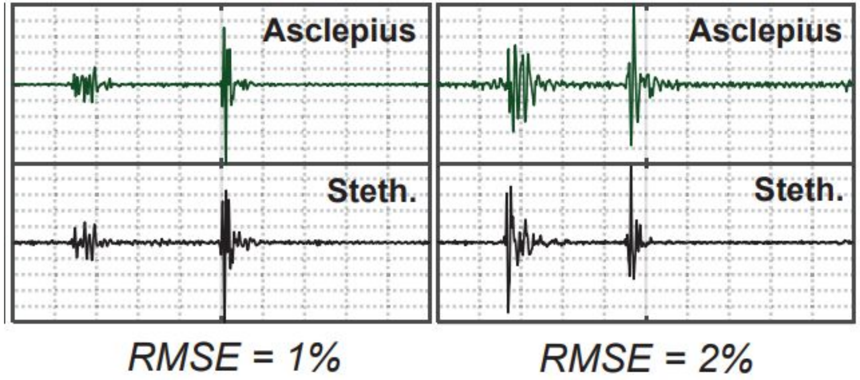
## Results

Mean RMSE 1.34%

Resilient to gender & age

SOTA HeadFi 2x worse

Similar diagnosis performance as stethoscope



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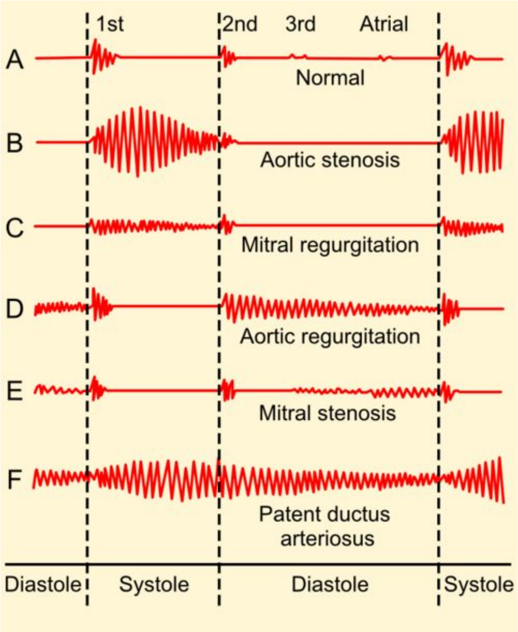
# Background: Phonocardiogram

First heart sound (S1)

Second heart sound (S2)

Higher pitched sounds like murmurs

Helps diagnose heart diseases/abnormalities



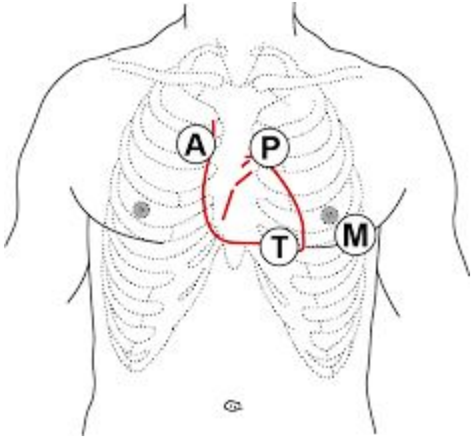
# Motivation

Video visits, pre-screening

More convenient & safer i.e. Covid-19

But in-home stethoscopes expensive ($500)

Hard to operate for patients



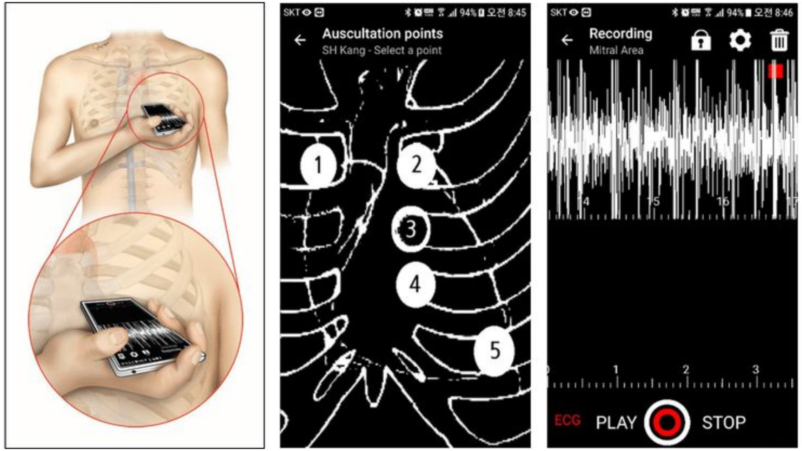
## Motivation: Earphones?

Smartphones vs. earphones:

Fewer ambient noises

Easier to operate

More accessible



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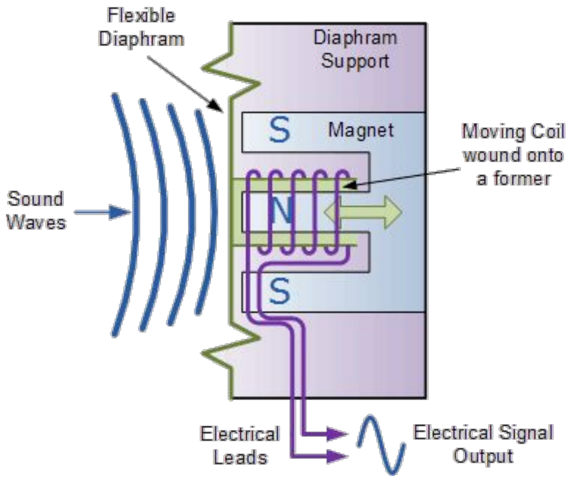
# Challenges

1) Attenuation & multipath from heart to ear (bones, muscles, fat, skin)

2) Earphone speaker not optimized as mic

3) Impedance matching (device + earphone)



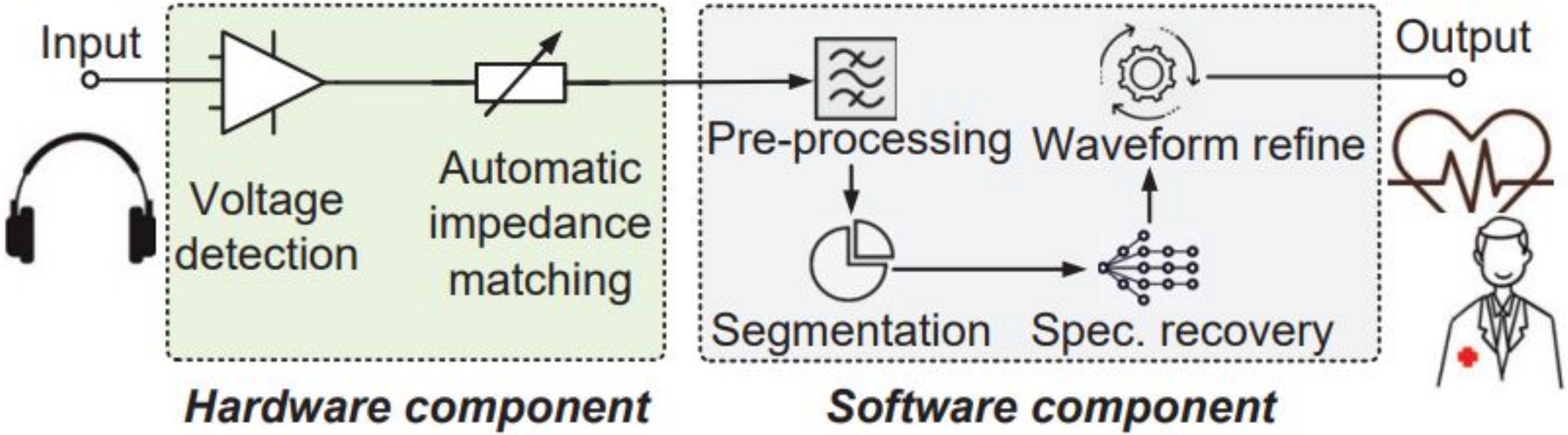
# Contributions

Hardware amplification, denoising (2)

Hardware online impedance matching (3)

On device de-reverberation, segmentation, correction (1)

# Contributions



# Contributions

**Hardware amplification, denoising**

Hardware online impedance matching

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# Hardware Signal Processing

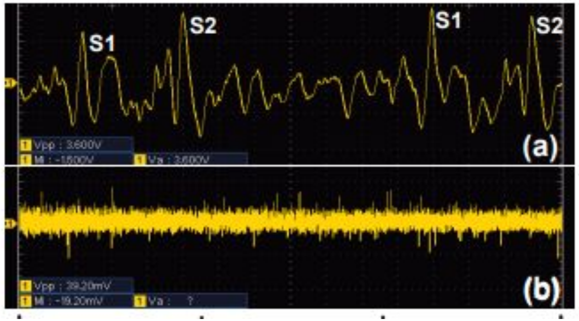
Operational amplifier

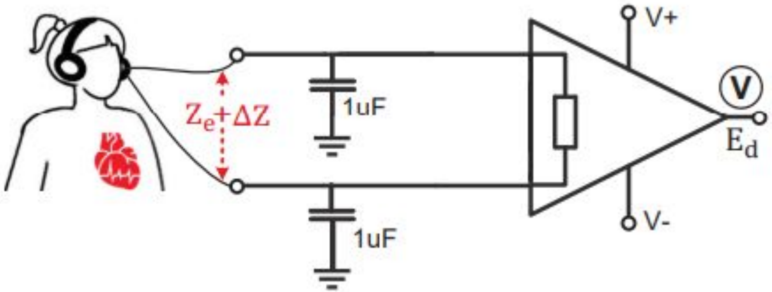
Good freq. response < 1kHz

Bypass capacitors for filtering

Already quite effective

(Only uses left ear - closer to heart)



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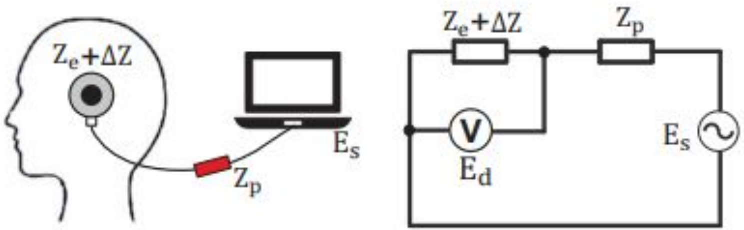
# Theoretical Background

First some theoretical background




$$E_d = \frac{Z_e + \Delta Z}{Z_e + Z_p + \Delta Z} \cdot E_s$$

can be simplified to

$$E_d = \frac{Z_e + \Delta Z}{Z_e + Z_p} \cdot E_s$$

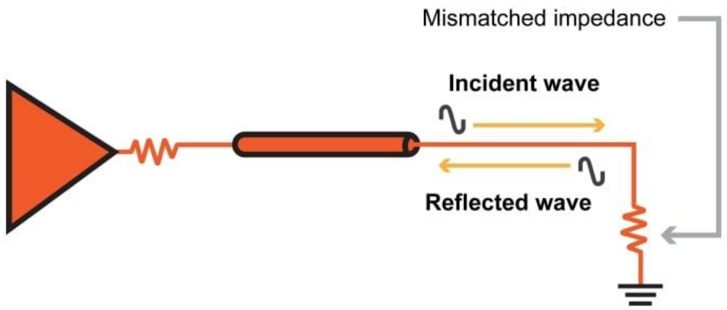
## Impedance Matching

Laptop impedance Z_s != earphone impedance Z_e

Laptop won’t measure full E_d

Z_s and Z_e unknown

Use digital potentiometer (SPI)



# Conventional Impedance Matching

Can’t do conventional impedance matching

(Increase Z_p so Z_p + Z_e = Z_s)

Reduces voltage signal E_d (see eqn.)

Need to tune dynamically instead

$$E_d = \frac{Z_e + \Delta Z}{Z_e + Z_p} \cdot E_s$$

# Online impedance matching

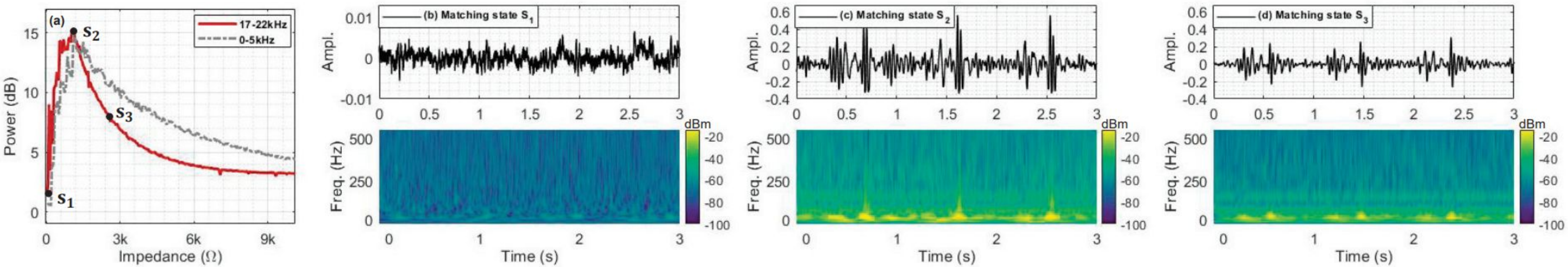



Figure 7: (a): received signal power in different impedance $Z_p$ settings. (b): the signal profile in the initial, unmatched state ($E_{recv}$ = -62dBm); (c): the signal profile in the optimal, unmatched state ($E_{recv}$ = -25dBm); (d): the signal profile in the fully matched state ($Z_p + Z_e = Z_s$, $E_{recv}$ = -33dBm).

# Online impedance matching

How to find the optimal point? (s_2)

Tune impedance for max PCG SNR

Not heart rate, too slow (1-2Hz)

Solution: Active probing signal from right ear

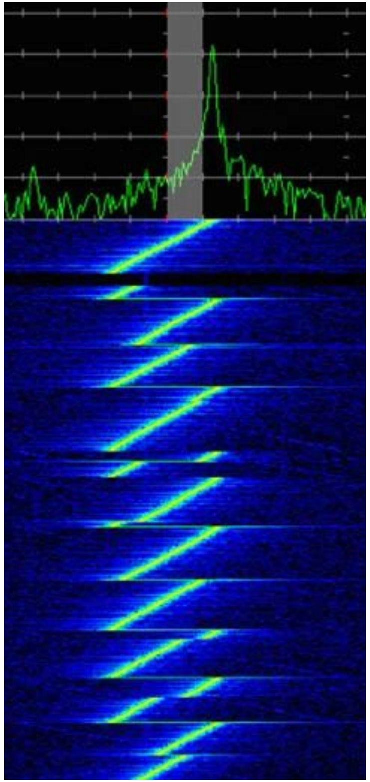
# Probing signal design

Short symbol time (10ms)

10 seconds to get optimal

Ultrasound (17KHz to 22 KHz)

Chirp signal = low power required



# Probing signal design

Test Impedance Candidate (range 0-10kΩ)

Compute SNR after filtering, convolution (SW?)

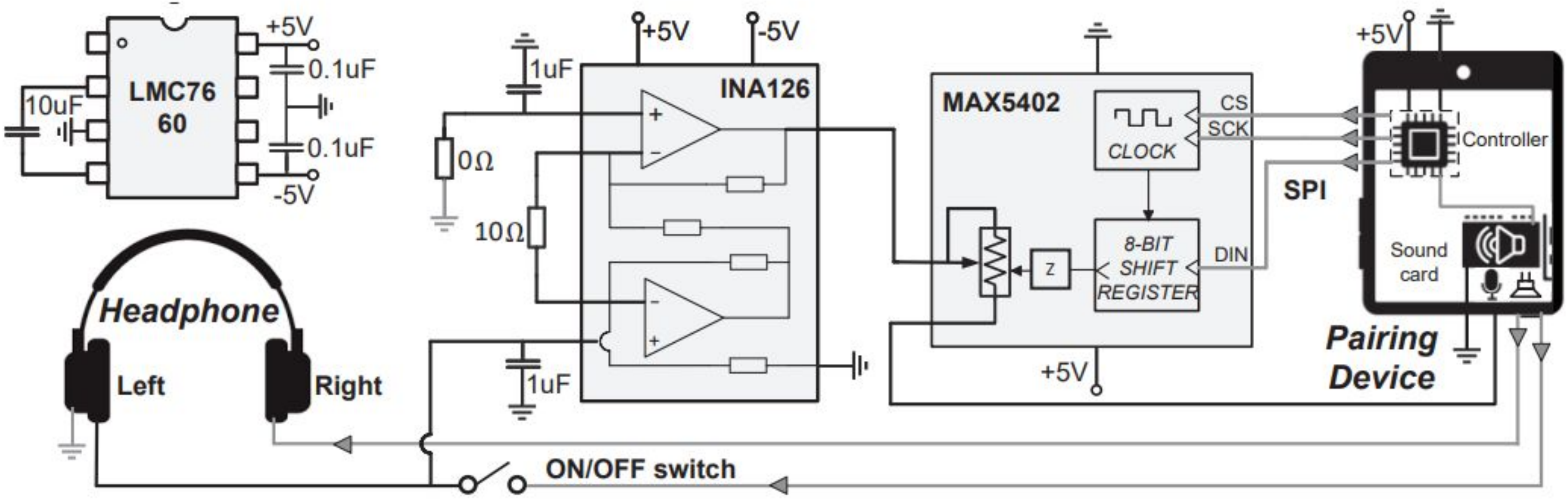
Pick one with best SNR

Ultrasound SNR matches PCG SNR

**Algorithm 1:** Online impedance matching

```
input  : Z_p ← i_Z_p; {i_E_recv} ← {};
output : Optimal matching status;
Function ActiveMatching():
    for i_Z_p ← 0 to MAX do
        curr_E_recv ← CompEnergy(i_Z_p);
        {i_E_recv} ← curr_E_recv;
    end
    opt_Z_p ← maxitem({i_E_recv});
    return opt_Z_p;
Function CompEnergy(i):
    capture audio symbol S_i;
    S_i^* ← BPF(S_i);
    S_i^** ← LPF(S_i^* · f_tone);
    S_i^+ ← Conv(S_i^**, template);
    i_E_recv ← PSD(S_i^+);
    return i_E_recv;
```

# Hardware schematic ($5)



# Contributions

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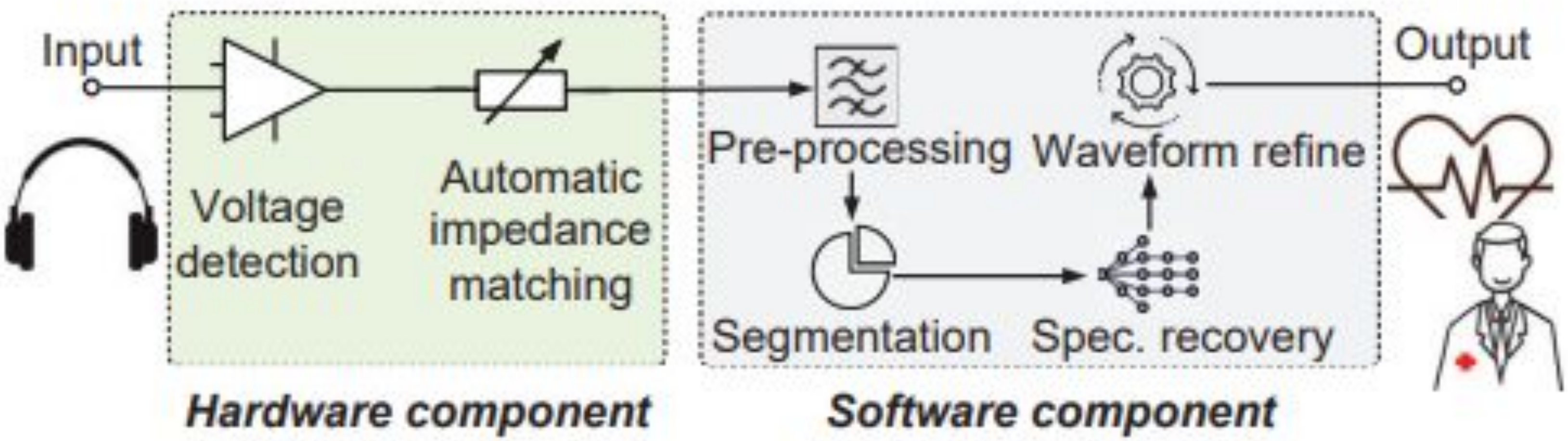
**On device de-reverberation, segmentation, correction**

# Software Design



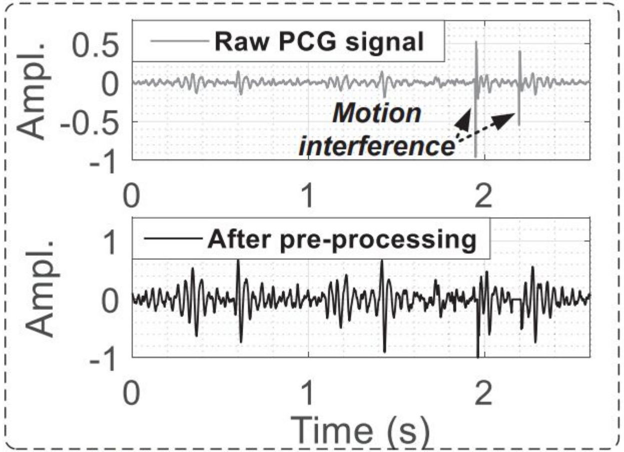
# Preprocessing

Butterworth low-pass filter (500Hz)

Spike removal (maximum absolute amplitudes)

(Spikes because of friction)

Normalization to [-1, 1]

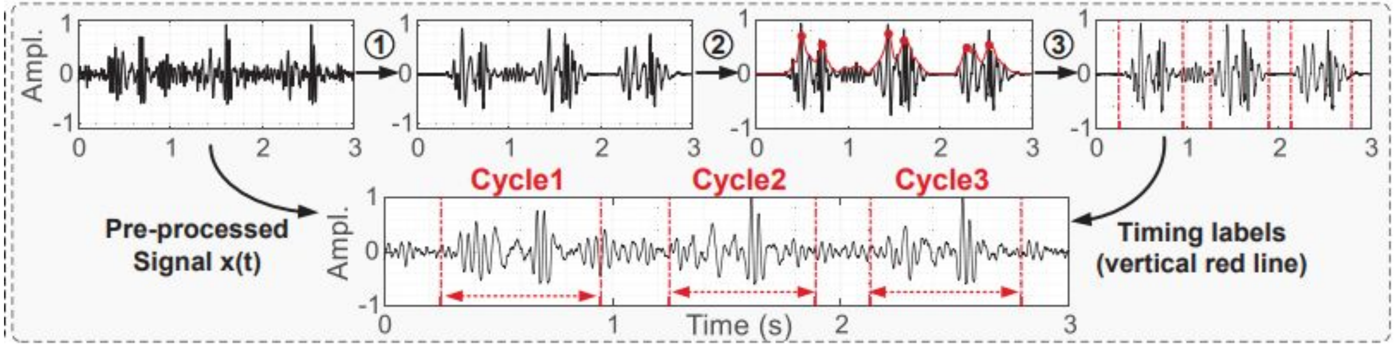



(a) *Signal pre-processing*

## Segmentation (why?)

De-reverberation (due to multi-path) - Wiener filter (1)

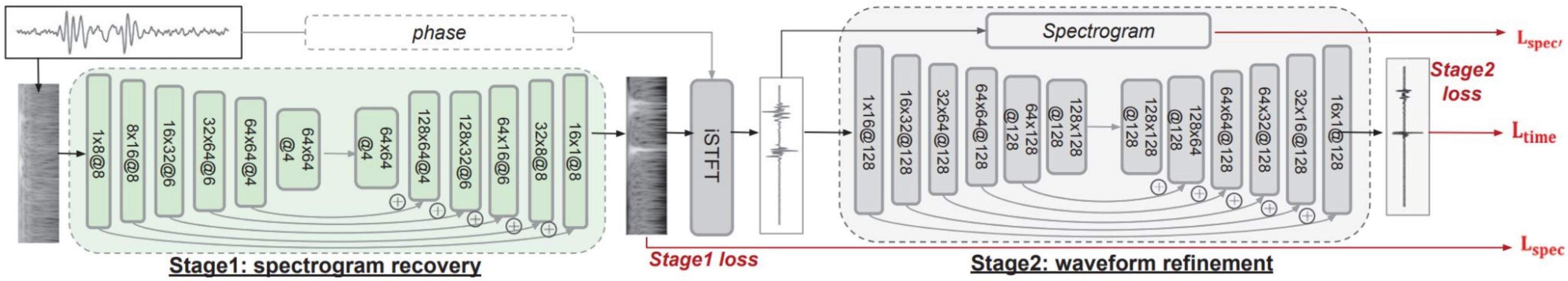
Envelope detector (2) + refinement with hidden Markov Model (3)



# Spectrogram Recovery + Waveform Refinement

UNet (6+6) architecture + L1 loss against ground-truth spectrogram

Differential STFT layer + UNet (6+6) + L1 loss (PCG waveform)



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# Limitations

Small evaluation set (30)

High RMSE with  in-ear headphones

No clinic studies with patients

(pork belly test instead)

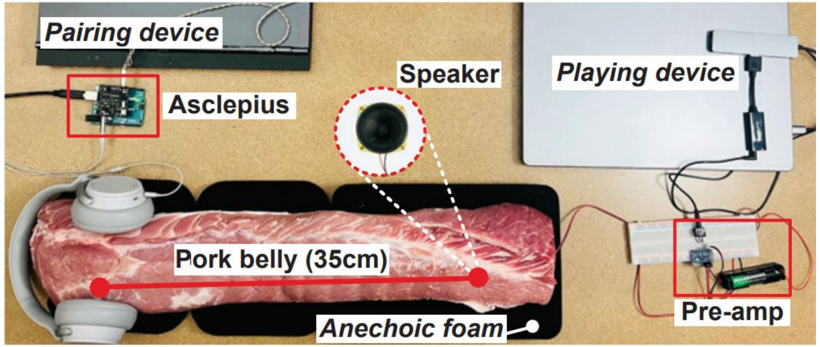


Figure 17: Experiment setup.

# My Opinion & Ideas for Future Work

Near perfect paper (won best paper)

Combined many different methods

Extend this for other vitals?

Fuse left and right earphones?

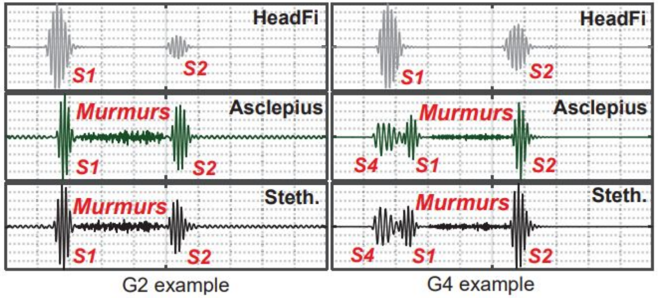


Figure 19: Example pathological signals recovered by HeadFi, Asclepius, and ground-truth (Steth.).

# Thank you for listening!

Time for Perusall discussion…