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mmHRR: Monitoring Heart Rate Recovery with Millimeter Wave Radar

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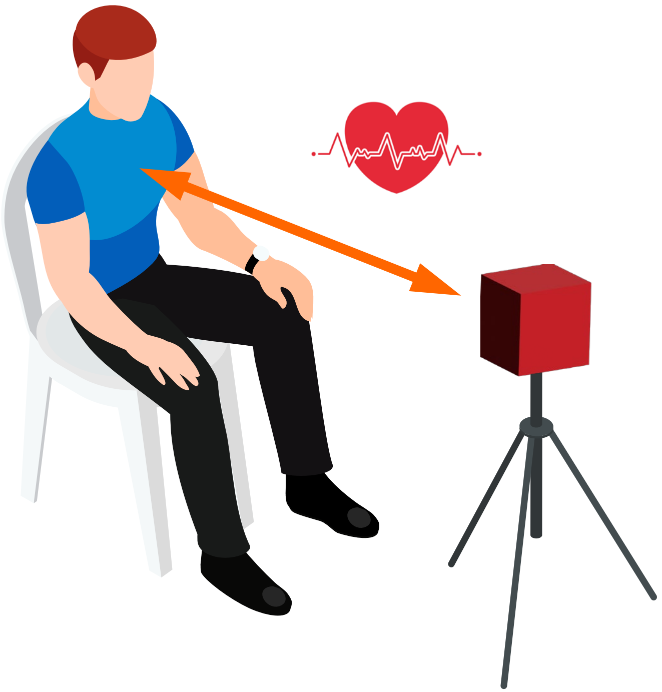
Background

- Cardiovascular disease (CVD) is the leading cause of human mortality worldwide.
- Heart rate recovery (HRR), i.e., the decrease in heart rate (HR) after exercise, is a measure of cardiac autonomic function in both CVD patients and healthy individuals.

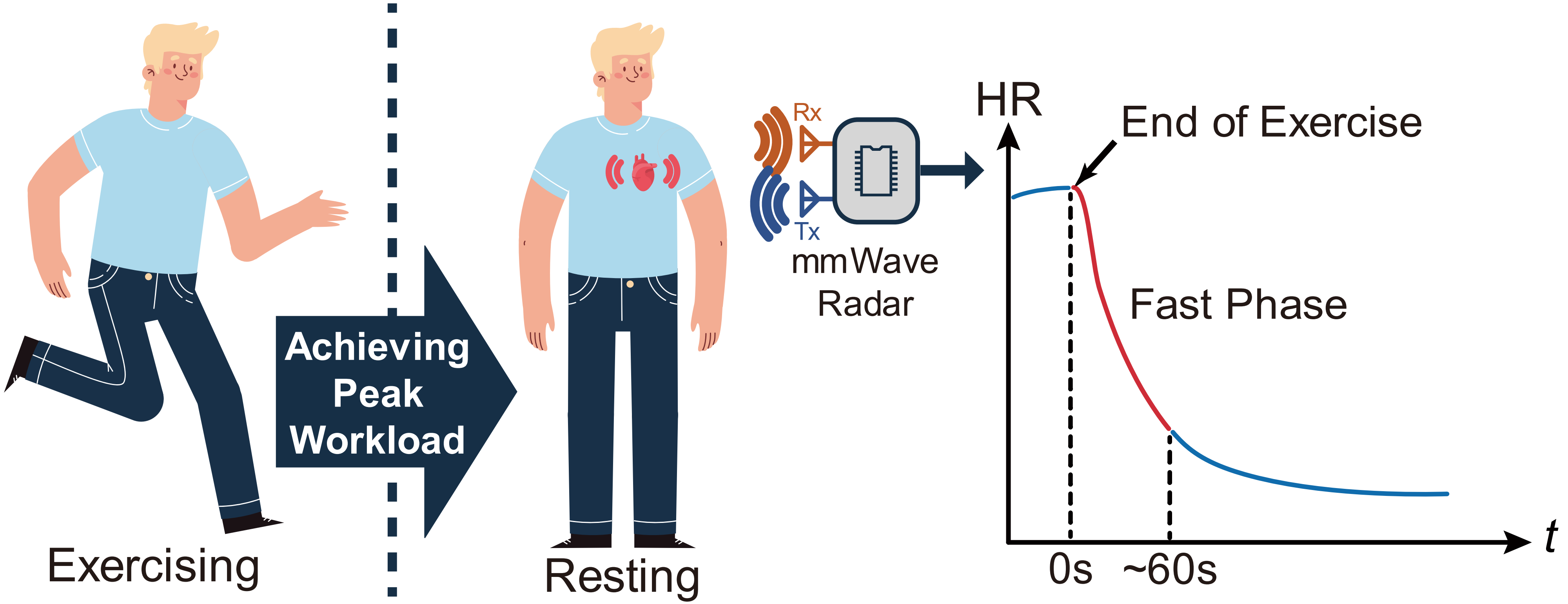
Limitations of Existing Work

- Users are still and relaxed, maintain a relatively low and stable HR.
- The heartbeat signal is seldom affected by the respiratory signal.



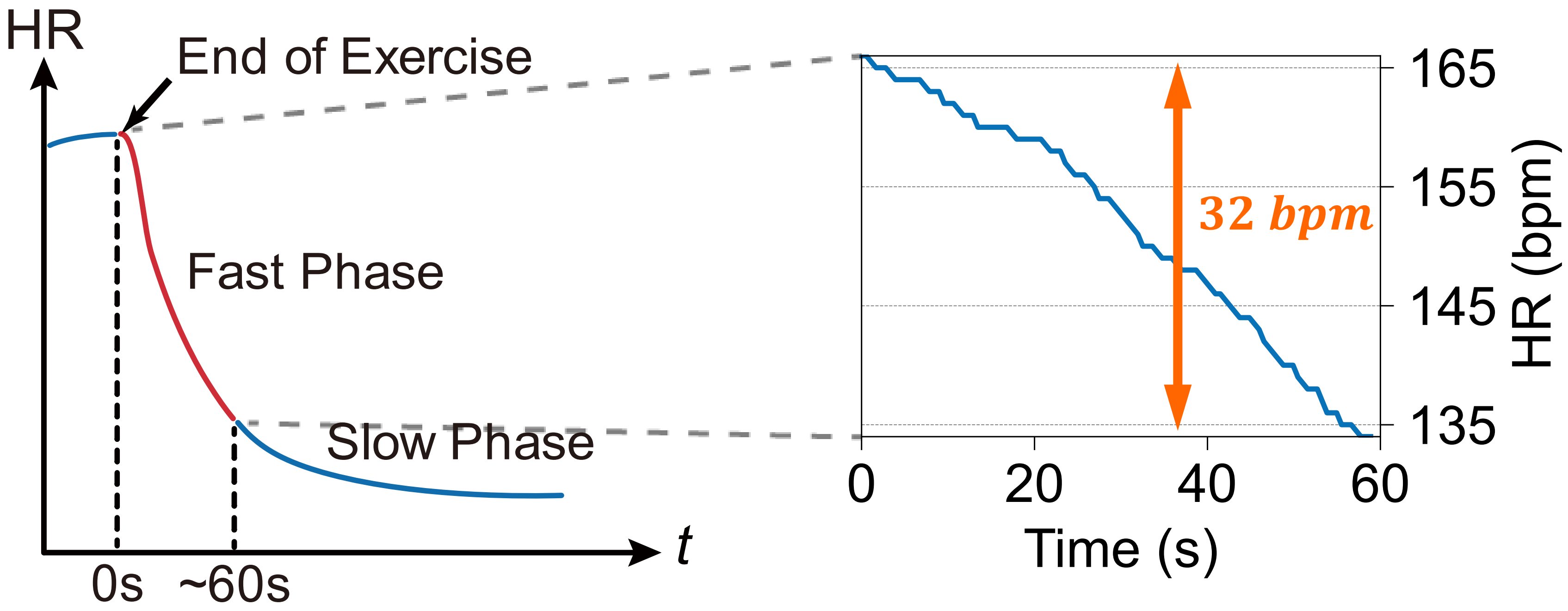
These characteristics are difficult to achieve in our scenario.

Monitoring HRR with mmWave Radar



Main Challenges

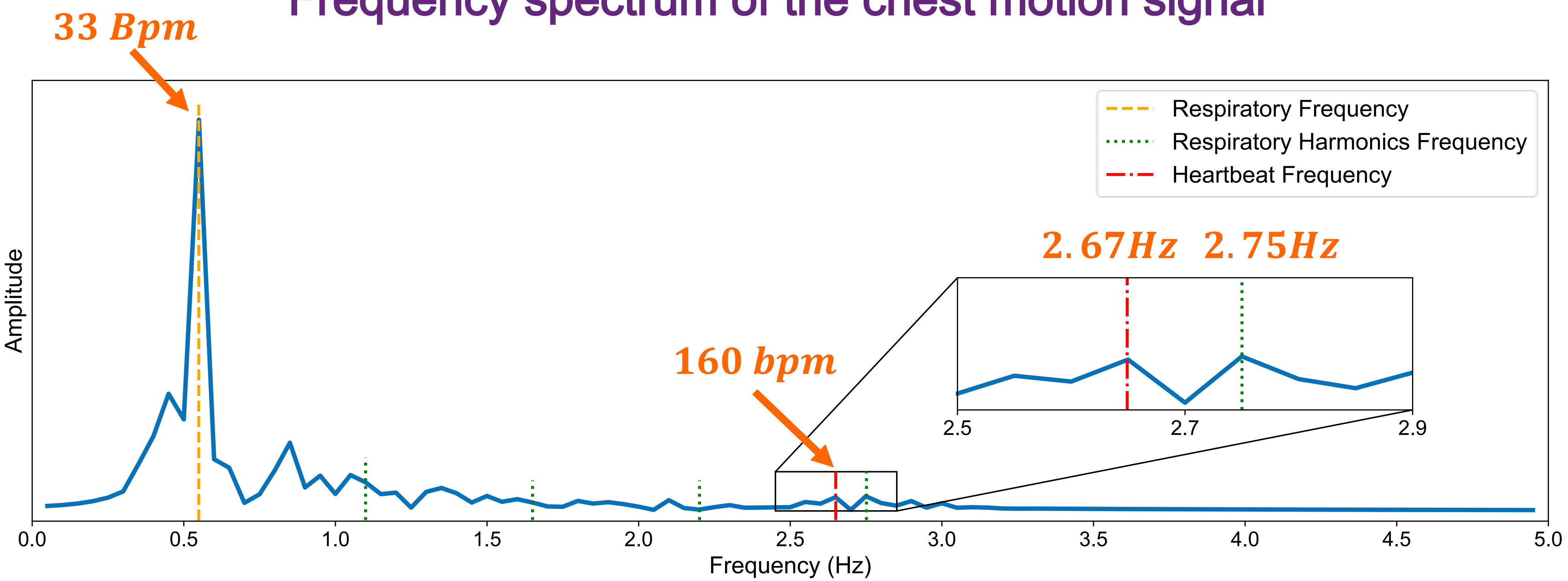
➢ ***Challenge 1: Non-stationary property of heartbeat signal***



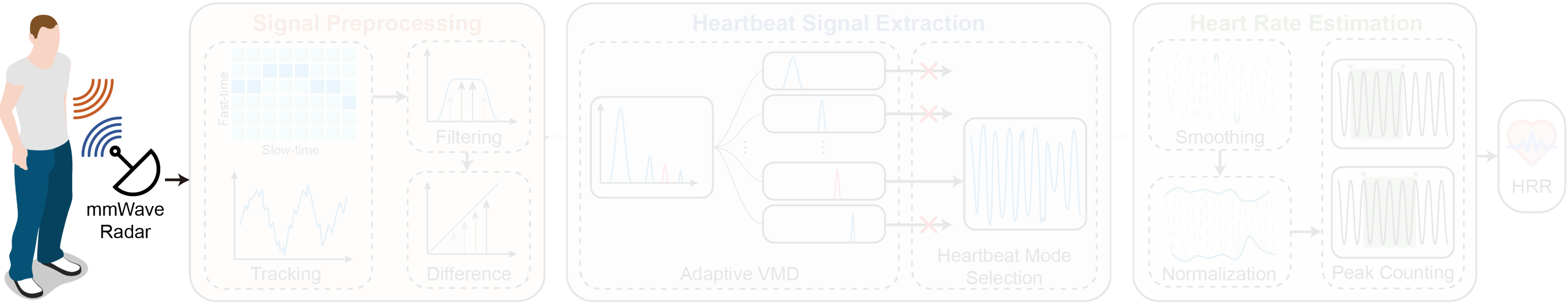
Main Challenges

- Challenge 1: Non-stationary property of heartbeat signal
- Challenge 2: Interference of Respiratory Harmonics

Frequency spectrum of the chest motion signal



mmHRR Overview



Challenge 2

Interference of Respiratory Harmonics

Challenge 1

Non-stationary property of heartbeat signal

Chest Motion

Mixture Model

$$x(t) = \underbrace{x_r(t)}_{\text{Respiratory}} + \underbrace{x_h(t)}_{\text{Heartbeat}} + \underbrace{n(t)}_{\text{Noise}}$$

Respiratory Signal

$$x_r(t) = \frac{a_{r0}}{2} + \sum_{n=1}^{\infty} a_{rn} \cos(n\omega t)$$

Similarity between modes

$$max\left\{ r_{ij} = \frac{E(u_i u_j) - E(u_i)E(u_j)}{\sqrt{D(u_i)D(u_j)}} \right\} < \mu_1$$

Information loss

$$p = \frac{\|f - \Sigma u_k\|_2^2}{\|f\|_2^2} < \mu_2$$

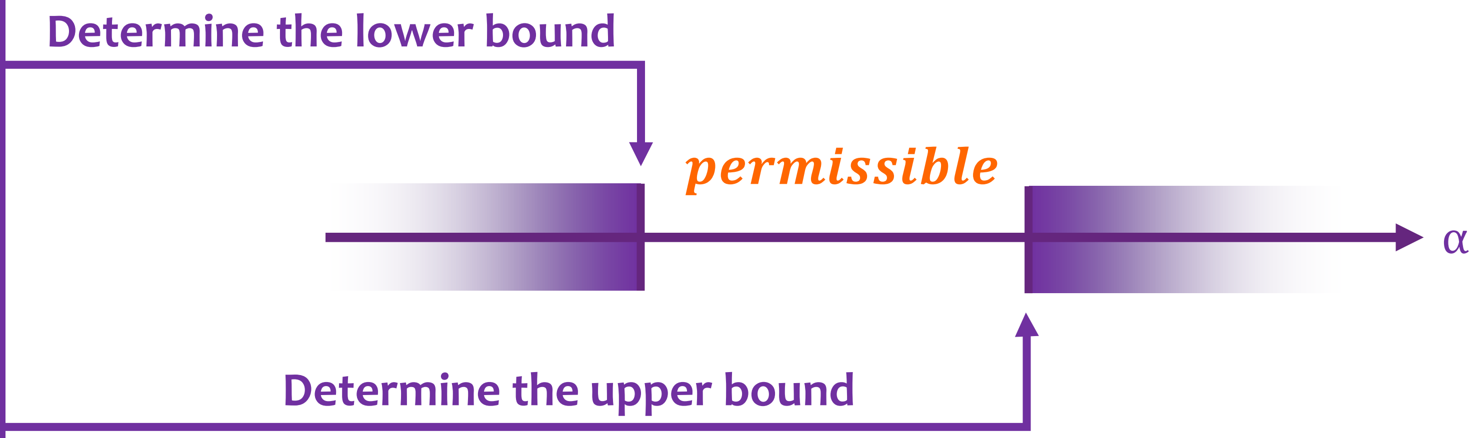
VMD Algorithm

Adaptive

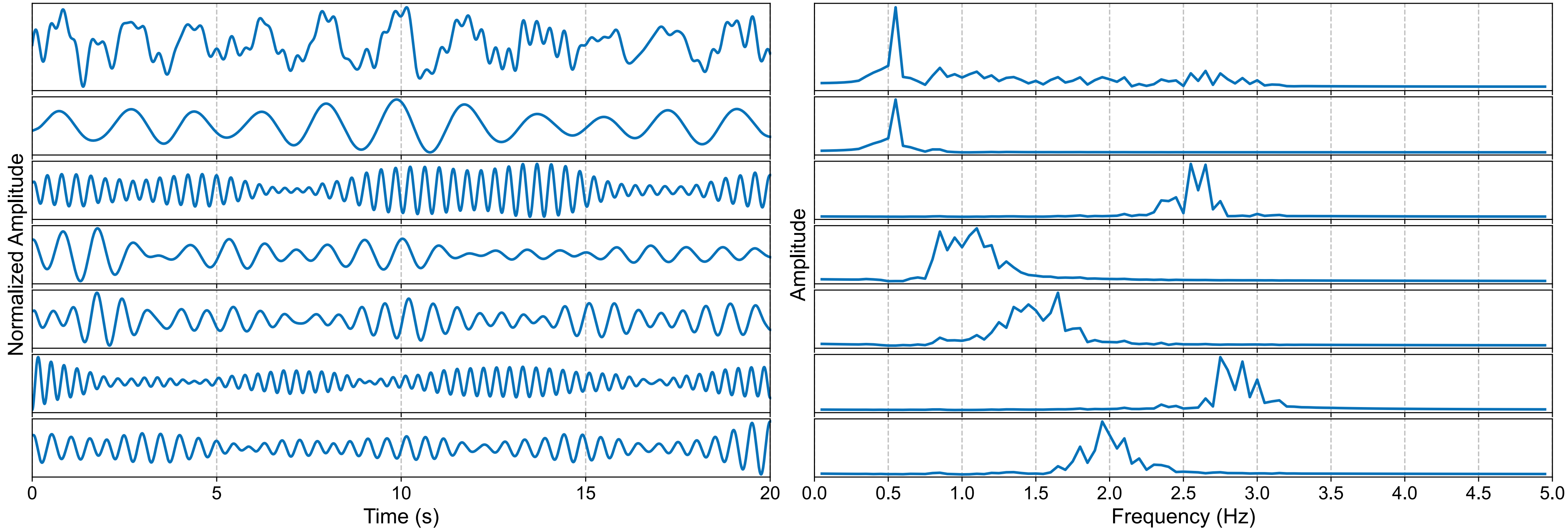
Selection of parameter α

- A smaller value can lead to mode aliasing.
- A larger value can cause over-decomposition.

Select any value within the range by **binary search**.



Heartbeat Mode Selection



Original Signal

Respiratory Signal

Heartbeat Signal

2nd Respiratory Harmonic

3rd Respiratory Harmonic

5th Respiratory Harmonic

4th Respiratory Harmonic

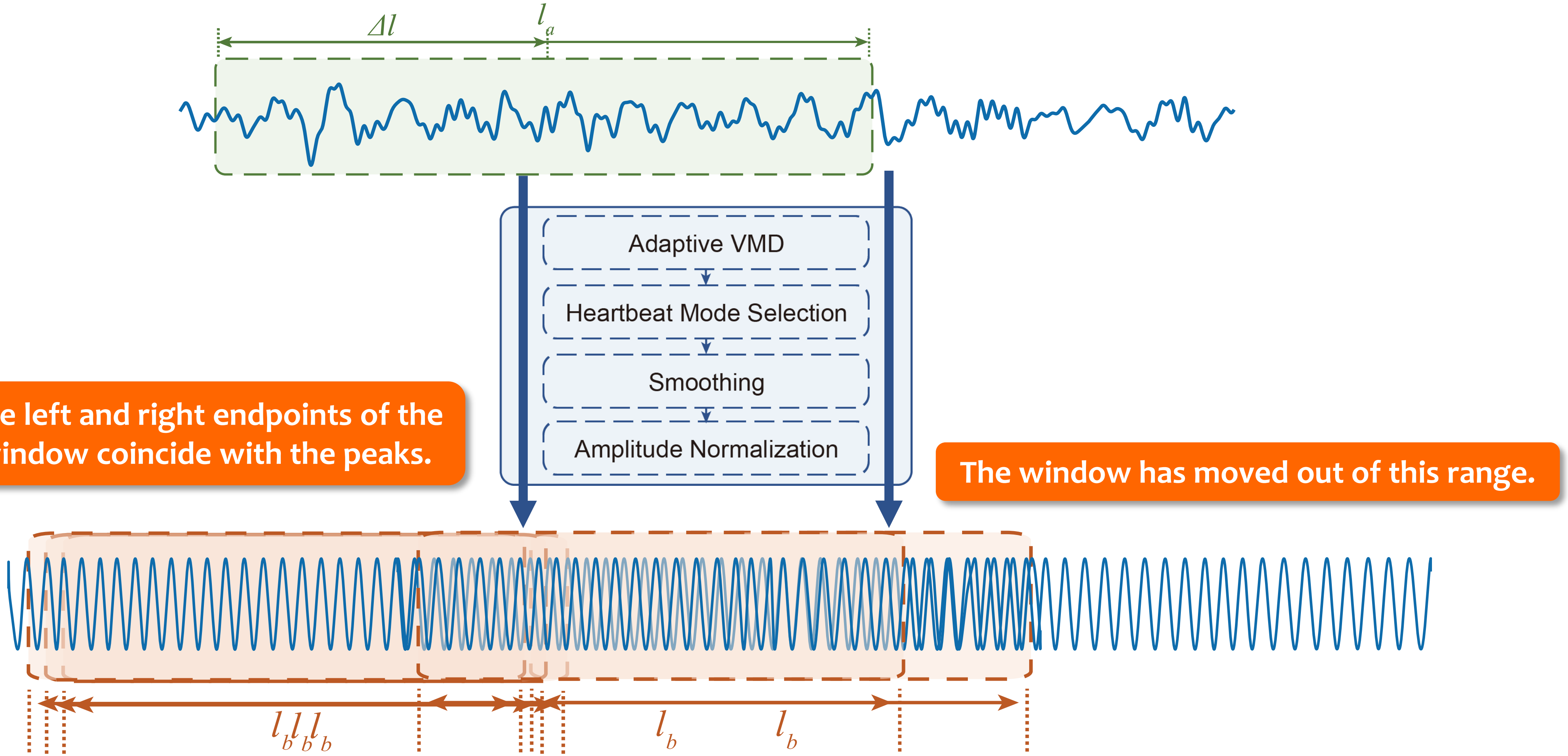
Heart Rate Estimation

Original Signal

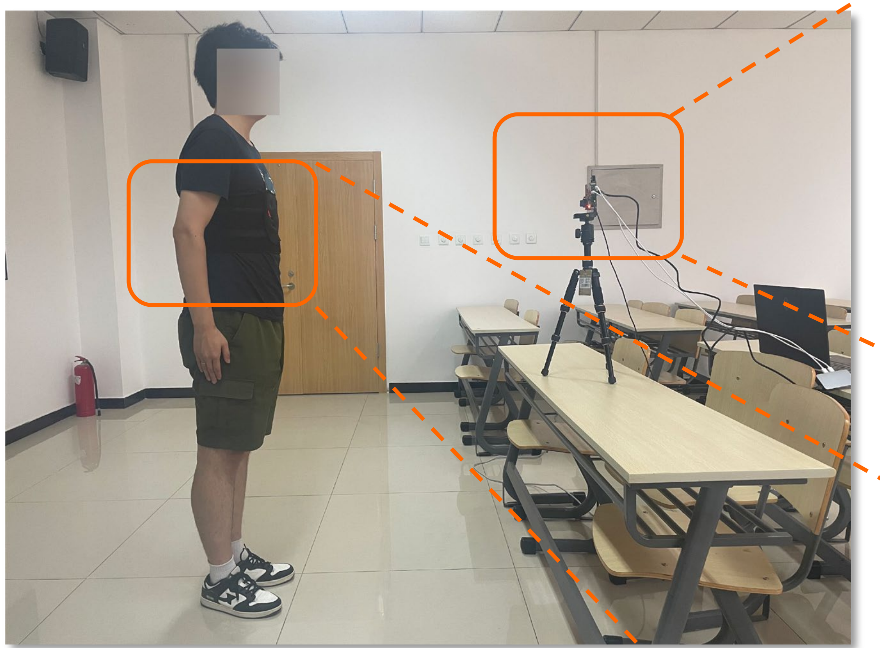
$t = t + 1$

$$HR = \frac{n_{peaks}}{l_b}$$

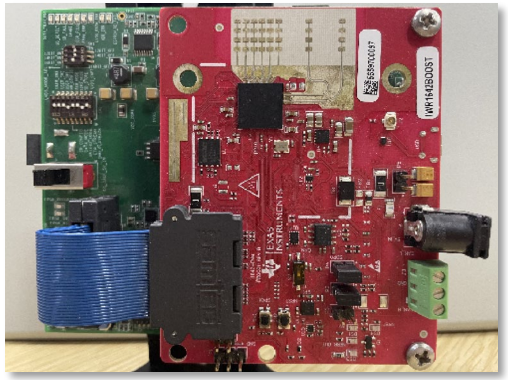
Normalized Heartbeat Signal



Implementation



TI IWR1642BOOST mmWave Radar

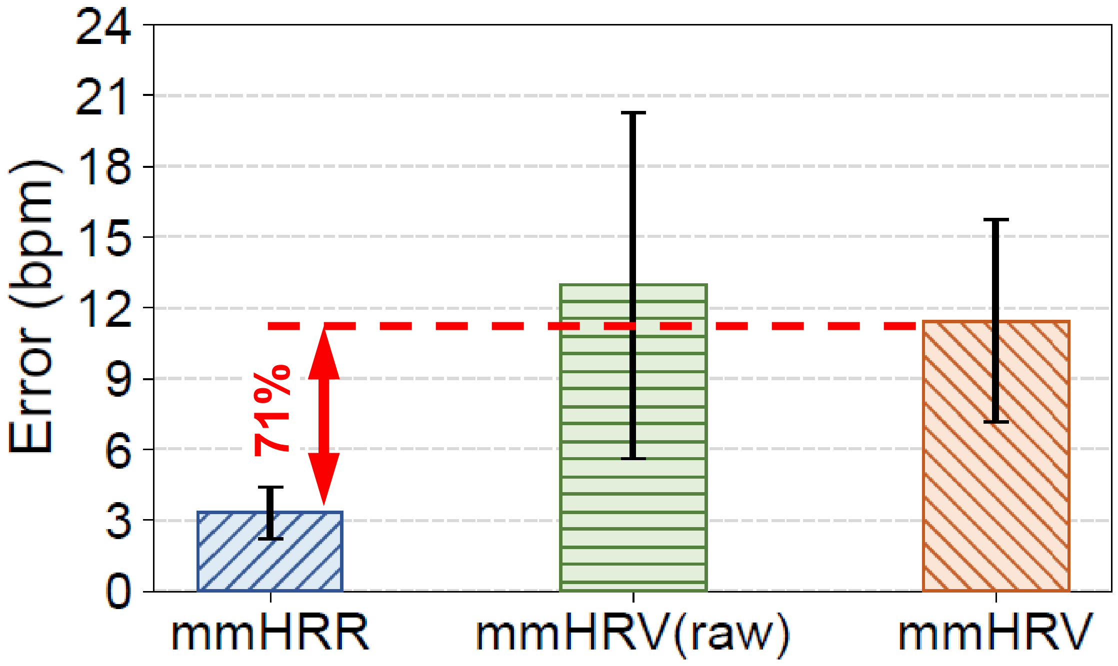


- 77-81 GHz 1Tx 4Rx used
- 200 samples/s
- Data captured by TI DCA1000EVM

Polar H10 Heart Rate Sensor

- 130 samples/s ECG waveform
- Synchronization of data timestamps via PC

Evaluation – Overall Performance



Error = |Measured HR – Ground Truth HR|

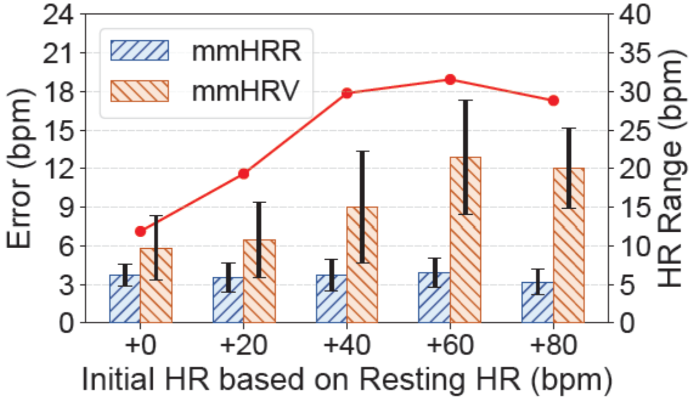
mmHRV: VMD-like algorithm for HRV estimation. mmHRV(raw) overlooks the interference from the respiratory harmonics, therefore sometimes misidentifies the heartbeat signal.
The performance with this part of data removed is marked as mmHRV.

The performance of mmHRV is mainly limited by the lack of signal preprocessing and a suboptimal selection of VMD parameters.

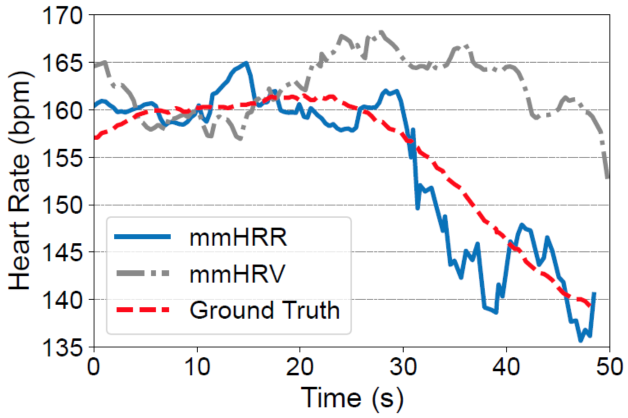
[mmHRV]: F. Wang, X. Zeng, C. Wu, B. Wang and K. J. R. Liu, "mmHRV: Contactless Heart Rate Variability Monitoring Using Millimeter-Wave Radio," in IEEE Internet of Things Journal

Evaluation

Error vs. initial HR



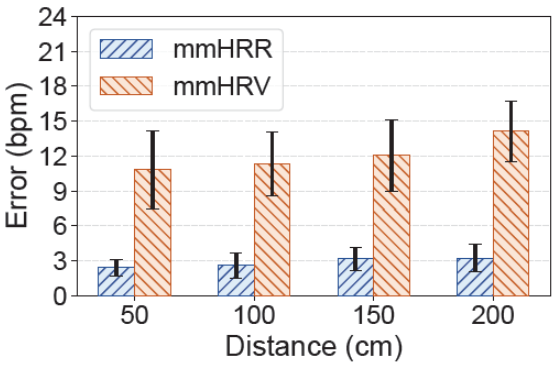
Error vs. HR variations



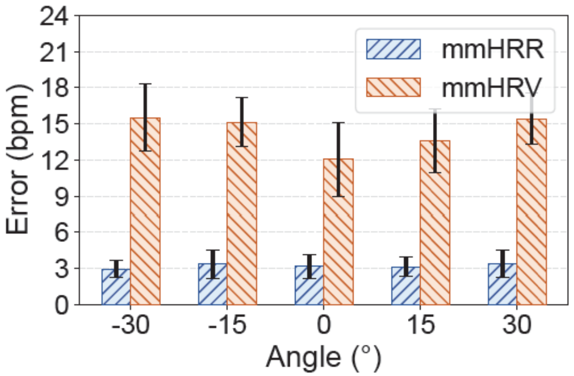
mmHRR can accurately track the rapid changes in HR.

Evaluation

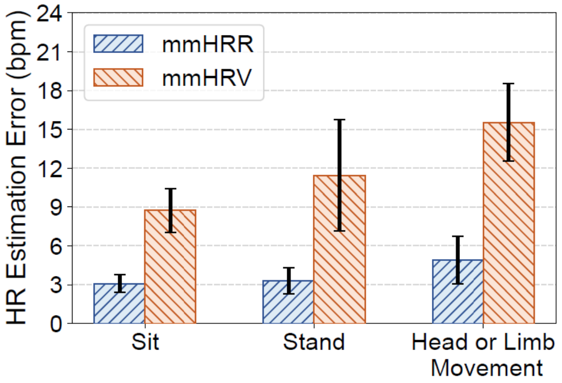
Error vs. distance



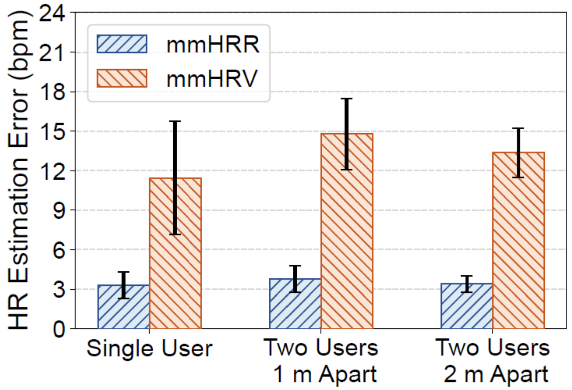
Error vs. angle



Error vs. postures



Error vs. multiple users



mmHRR exhibits good robustness under different experimental conditions.

Conclusion

- We propose mmHRR, a contactless technique for monitoring HRR based on mmWave radar.
- We introduce customized preprocessing techniques and an adaptive VMD method for extracting the heartbeat signal.
- We estimate the HR from the non-stationary heartbeat signal using a novel peak counting algorithm.
- Our experiment results show that mmHRR achieves accurate and robust estimation of HR across diverse environmental conditions.

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