

mmHRR: Monitoring Heart Rate Recovery with Millimeter Wave Radar

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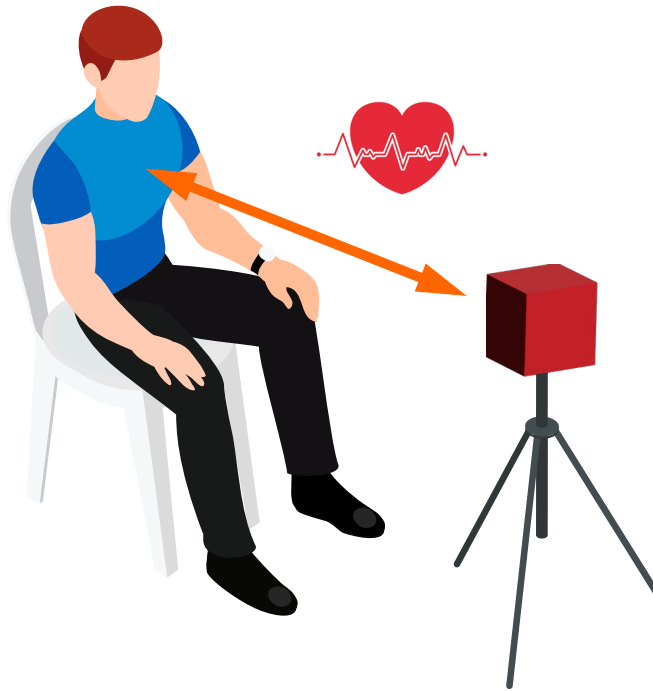
Background

- 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.



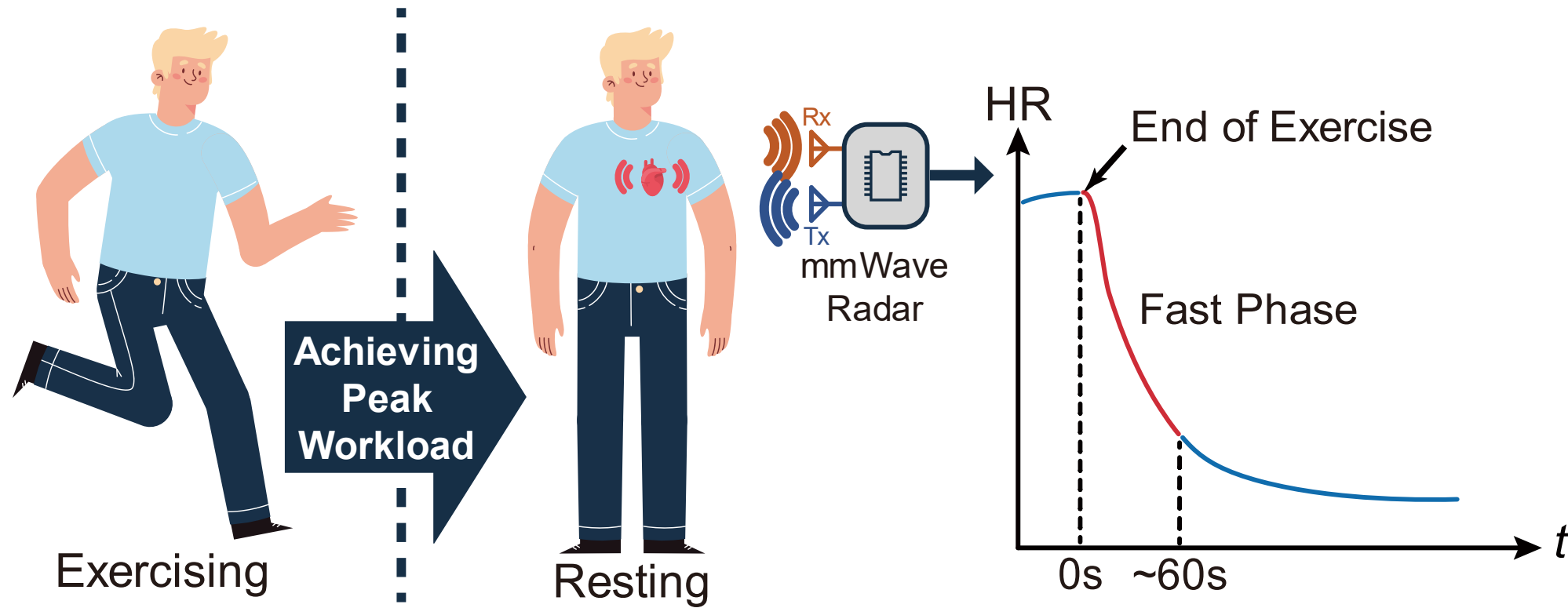
Limitations of Existing Work

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



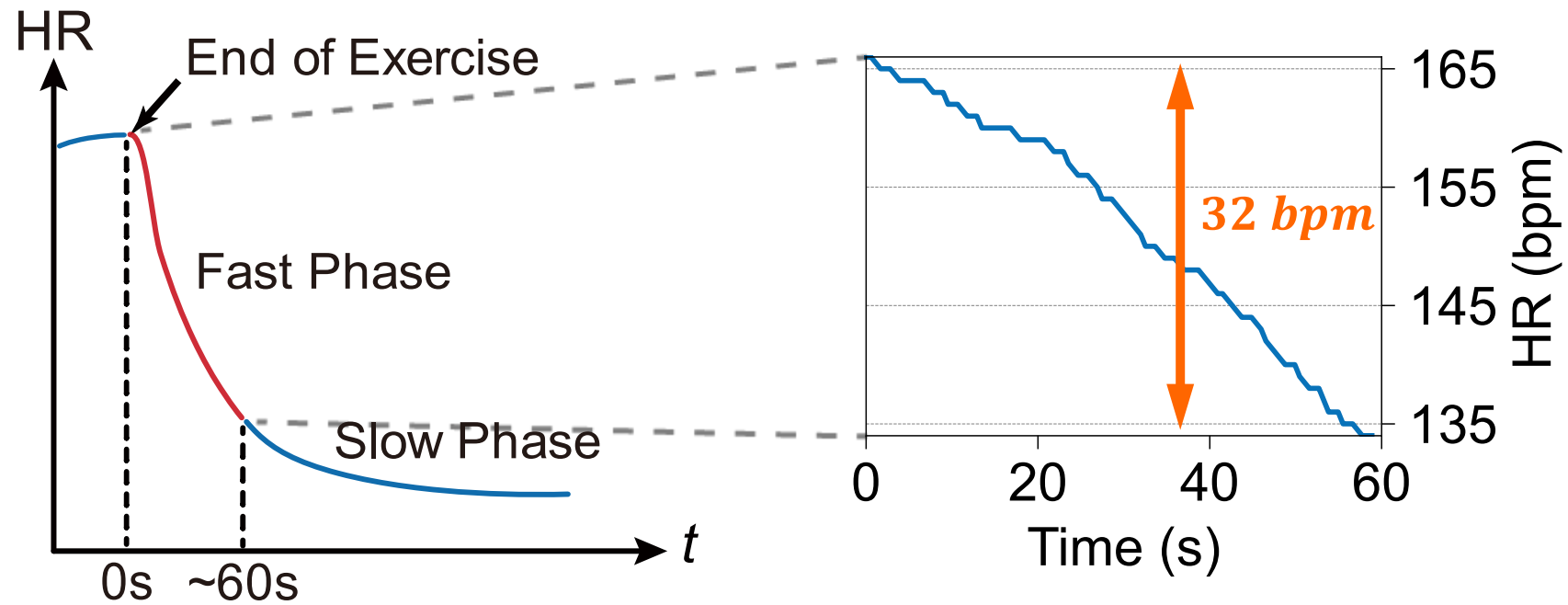
These characteristics are difficult to achieve in our scenario.

Monitoring HRR with mmWave Radar



Main Challenges

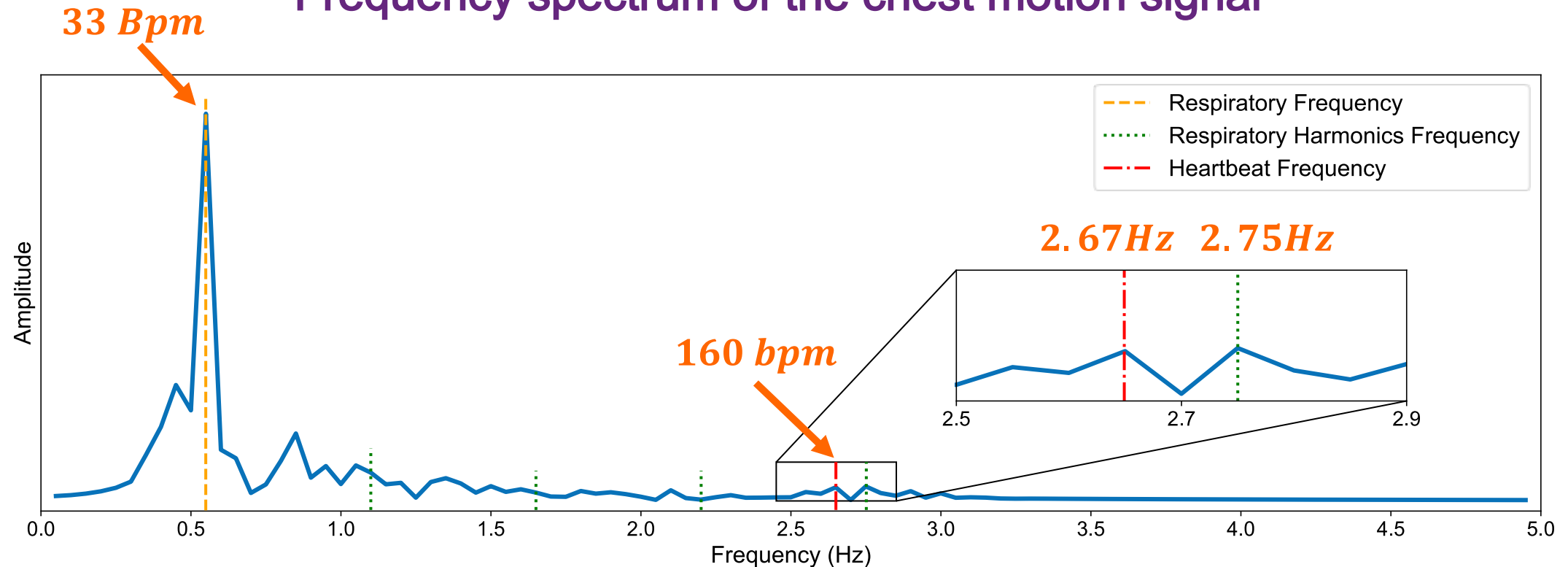
➤ Challenge 1: Non-stationary property of heartbeat signal



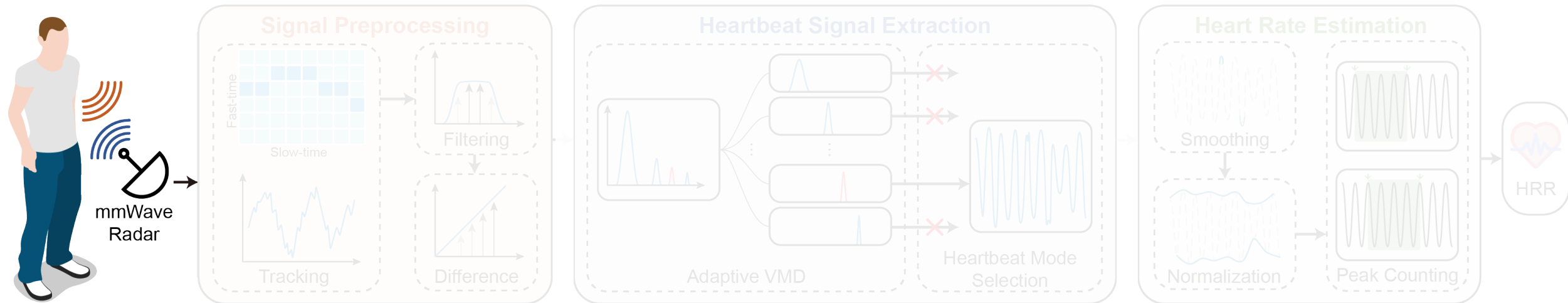
Main Challenges

- 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

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

Adaptive Algorithm

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**.

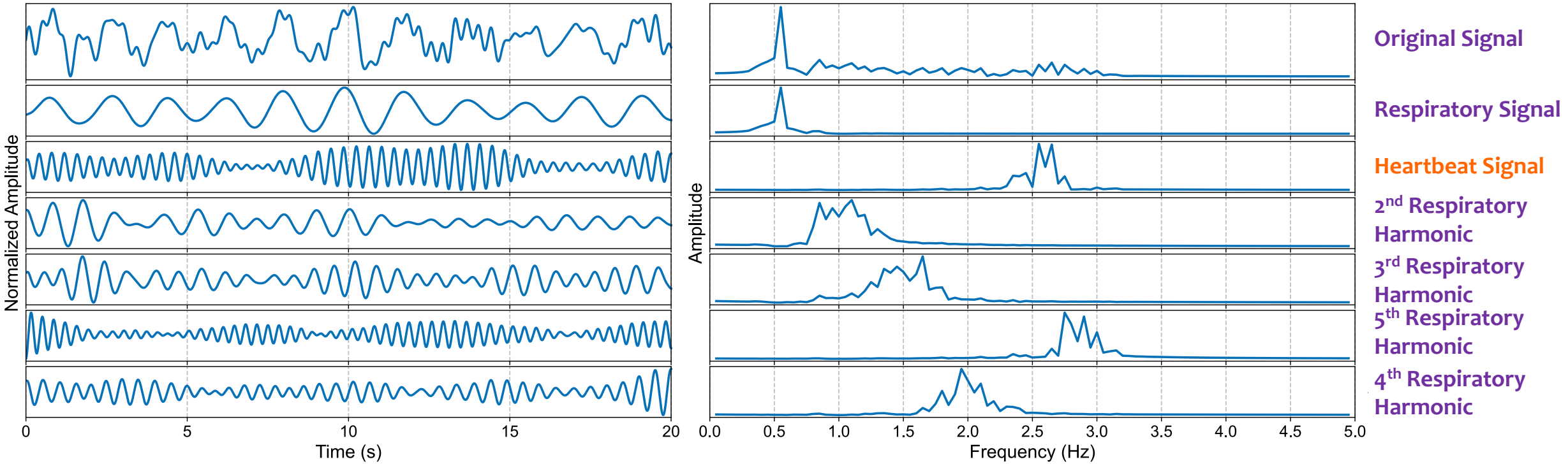
Determine the lower bound

permissible

Determine the upper bound

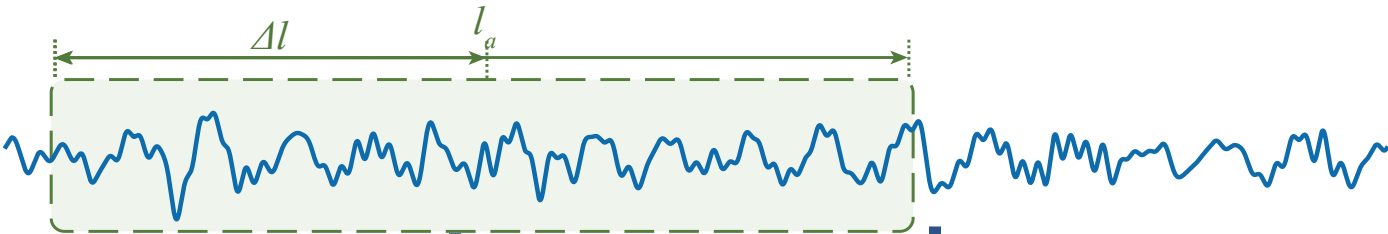
α

Heartbeat Mode Selection



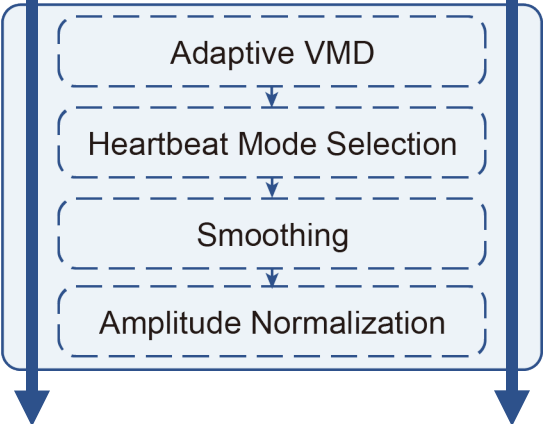
Heart Rate Estimation

Original Signal



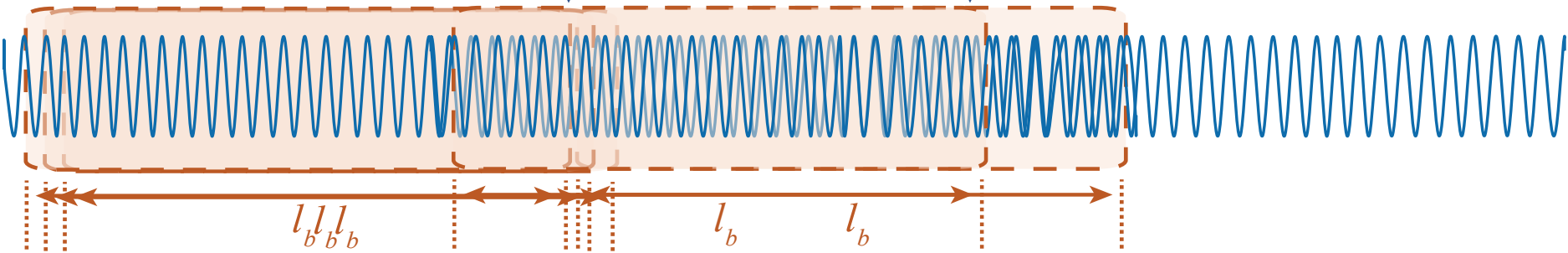
$$t = t + 1$$
$$HR = \frac{n_{peaks}}{l_b}$$

The left and right endpoints of the window coincide with the peaks.

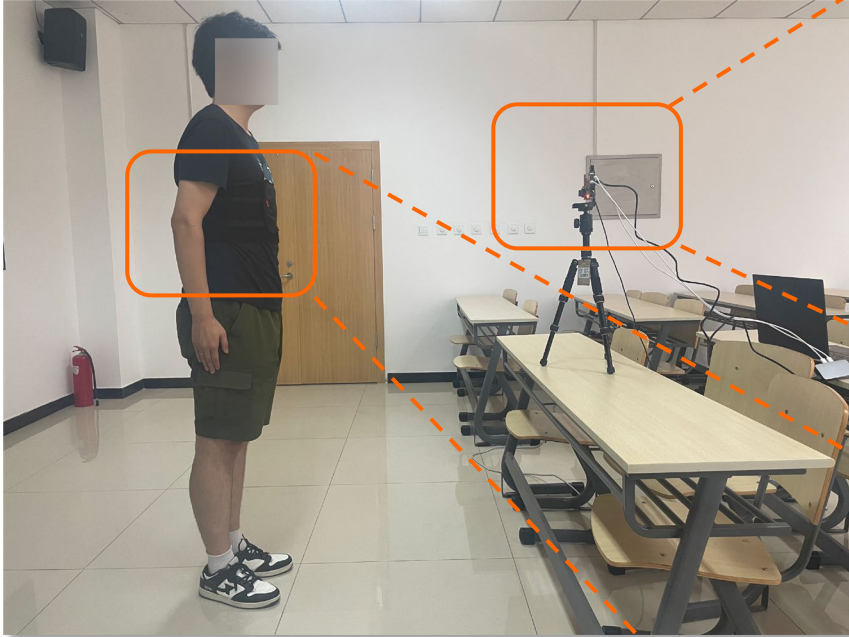


The window has moved out of this range.

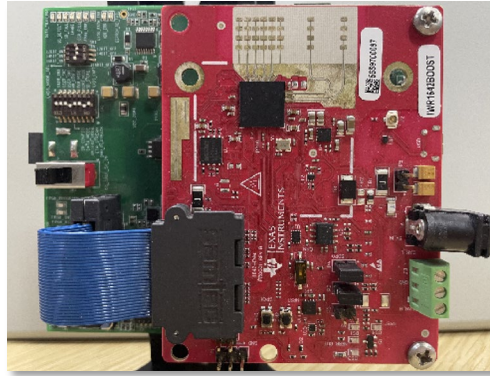
Normalized Heartbeat Signal



Implementation



TI IWR1642BOOST mmWave Radar



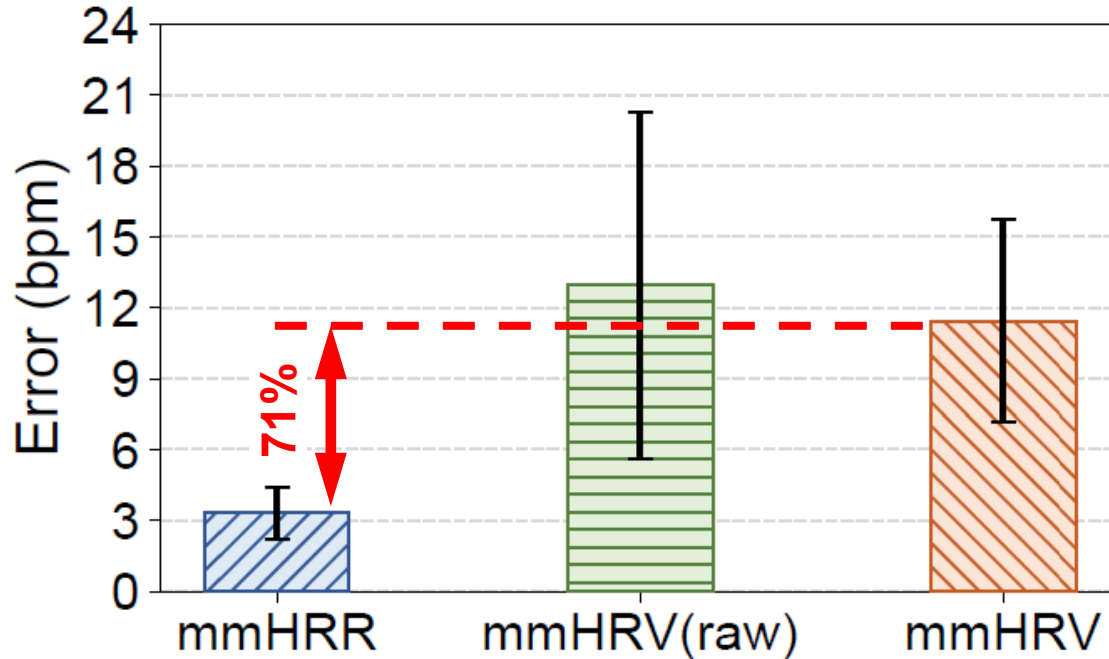
- 77-81 GHz 1Tx 4Rx used
- 200 samples/s
- Data captured by TI DCA1000EVM

Polar H10 Heart Rate Sensor



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

Evaluation – Overall Performance



$$\text{Error} = |\text{Measured HR} - \text{Ground Truth HR}|$$

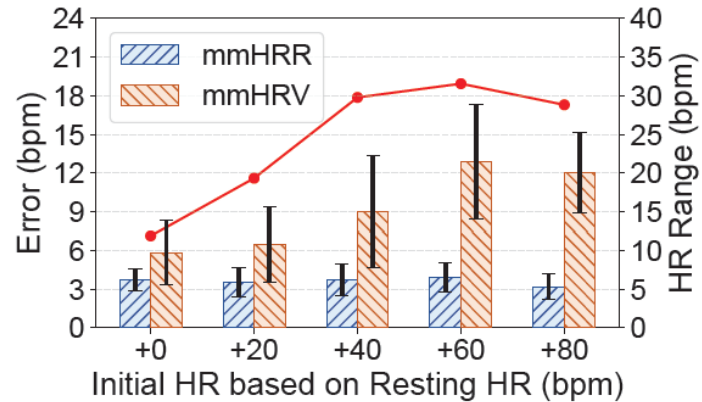
mmHRV: VMD-like algorithm for HRV estimation. **mmHRV(raw)** overlooks the interference from the respiratory harmonics, therefore sometimes misidentifies the heartbeat signal.

The performance with this part of data removed is marked as **mmHRV**

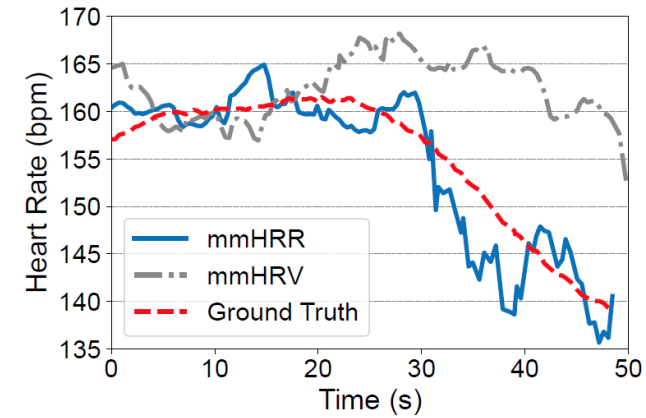
The performance of mmHRV is mainly limited by the lack of signal preprocessing and a suboptimal selection of VMD parameters.

Evaluation

Error vs. initial HR



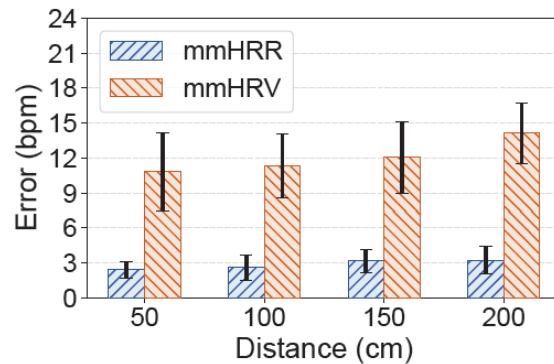
Error vs. HR variations



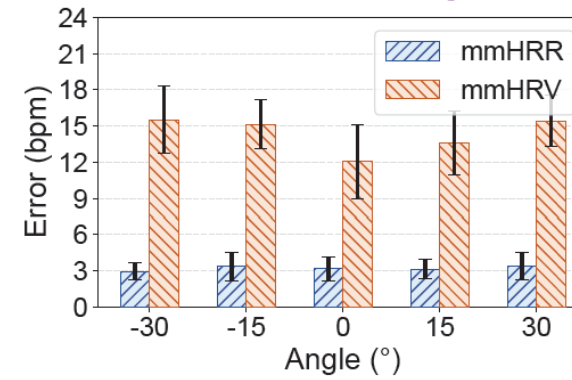
mmHRR can accurately track the rapid changes in HR.

Evaluation

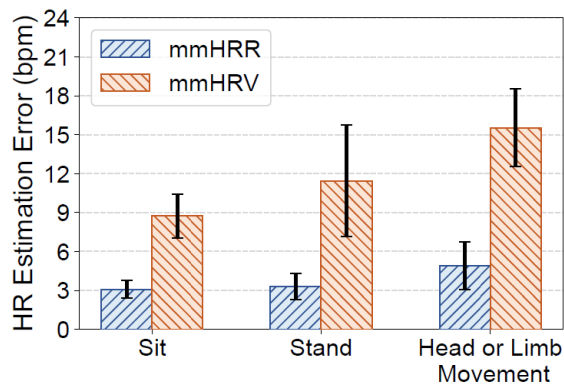
Error vs. distance



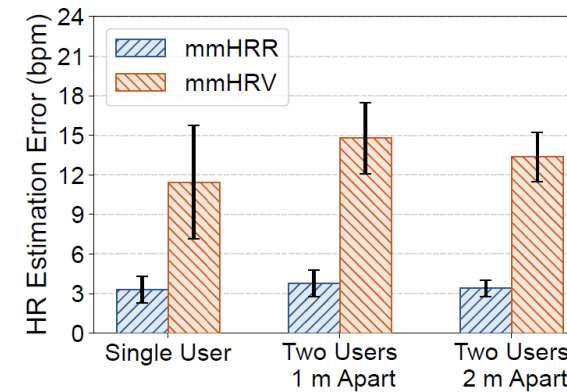
Error vs. angle



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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