TH3C-6

# High-Accuracy Cardiac Activity Extraction Using RLMD-Based Frequency Envelogram in FMCW Radar Systems

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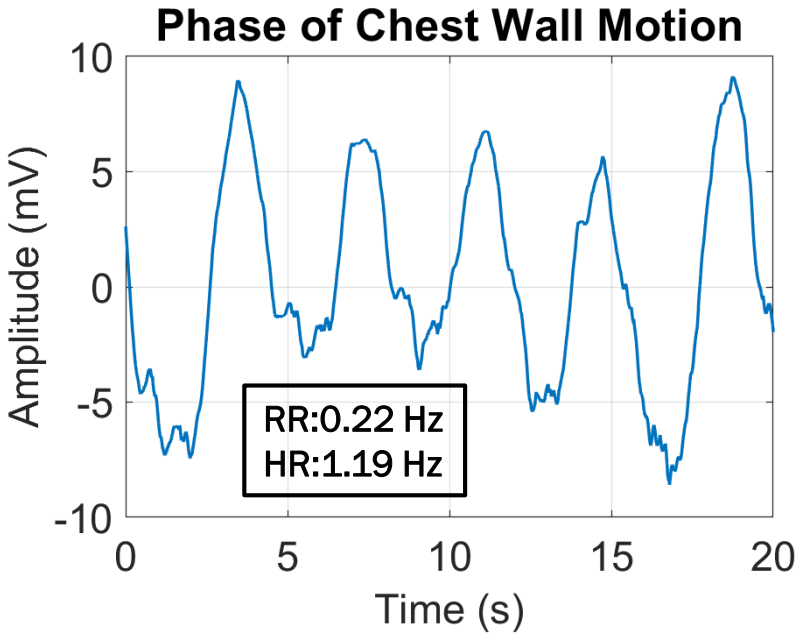
# Outline

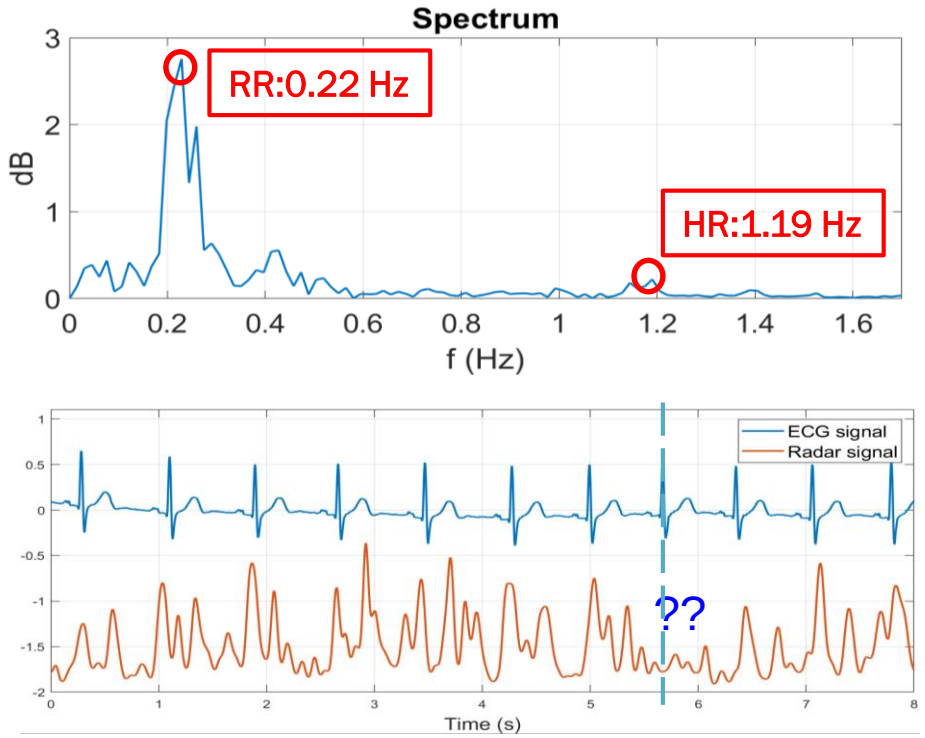
- Introduction
- Motivation
- Proposed Method
  - RLMD-Based Frequency Envelogram
- Experiment Setup
- Measurement Results
- Conclusion

# Introduction



- Heart rate variability (HRV) features reflect changes in time intervals between two consecutive heartbeats, the so called beat-to-beat intervals (BBIs).
- The most common devices used to measure BBIs are ECG, PPG, and Doppler radar. Among them, only Doppler radar is suitable for long-distance and long-term use.
- Radar technology is one of the most promising methods for non-contact BBIs measurement.



# Motivation



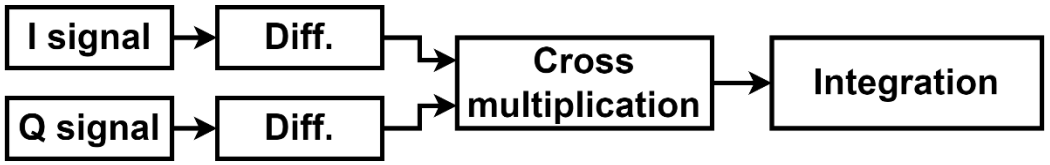
- Time-frequency representation (TFR) is a commonly used method for HRV analysis, but TFR suffers from limit of time-frequency resolution.
- Almost all literatures analyzing HRV use CW radar with high sensitivity, but CW radar cannot obtain distance information and its anti-interference ability is not as good as FMCW radar.
- Solution:
  - Robust local mean decomposition (RLMD)-based TFR [1] is not affected by time-frequency resolution because the signal is decomposed in time domain.
  - Preprocessing procedure for the demodulation method must have strong anti-interference ability and enhance signals.

[1] Liu, Zhiliang, et al. "Time-frequency representation based on robust local mean decomposition for multicomponent AM-FM signal analysis," *Mechanical Systems and Signal Processing*, 2017

# Signal Preprocessing



- **Modified DACM [2]**




$$x[\mathrm{n}] = \sum_{k=2}^{n} I[k-1]Q[k] - I[k]Q[k-1] \qquad (1)$$

- **The calibrated items and arctangent demodulation can be omitted :**
  - ➢ Less susceptible to I/Q imbalance.
  - ➢ Demodulation linearity and stability greatly improved.

[2] W. Xu, C. Gu and J. -F. Mao, "Noncontact High-Linear Motion Sensing Based on A Modified Differentiate and Cross-Multiply Algorithm," *2020 IEEE/MTT-S IMS*, 2020.

- **Differential Enhancement [3]**

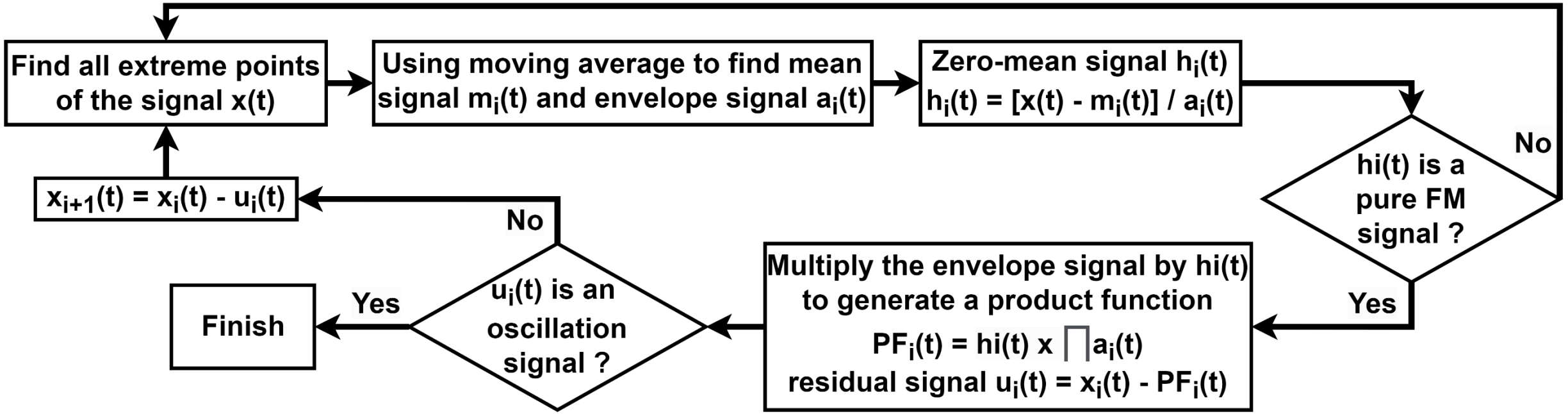
$$x_0' = \frac{5(x_1 - x_{-1}) + 4(x_2 - x_{-2}) + x_3 - x_{-3}}{32\Delta t} \qquad (2)$$

- **Frequency band setting of differentiator**
  - – Suppress low-frequency respiration and enhance the relative high-frequency heartbeat component.
- **The short filter length**
  - – Short window can track cardiac motion sensitively to ensure that the signal is not distorted.

[3] Y. Xiong, Z. Peng, C. Gu, S. Li, D. Wang and W. Zhang, "Differential Enhancement Method for Robust and Accurate Heart Rate Monitoring via Microwave Vital Sign Sensing," *IEEE Trans. Instrument. & Meas.*, 2020.

# Local Mean Decomposition

- Local mean decomposition (LMD) [4] method is specially designed to solve multicomponent AM-FM signals.
- However, LMD is difficult to verify whether the pole is selected for the real pole, leading to the end effect and mode mixing problems.




[4] J.S. Smith, "The local mean decomposition and its application to EEG perception data," *J. R. Soc. Interface*, 2005.

# RLMD Based Frequency Envelogram



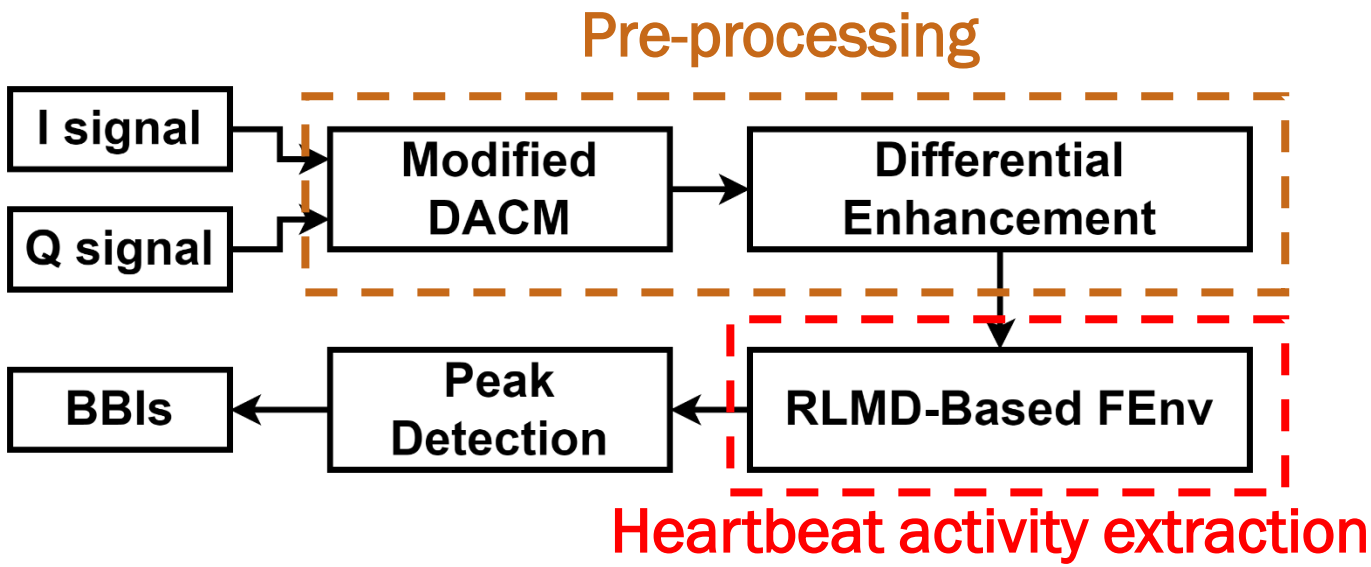
- Robust-LMD (RLMD) [5] was proposed to improves the performance of LMD by simultaneously solving problems such as :
  - Boundary conditions
  - Envelope estimation
  - Sifting stopping criterion
- The AM signals from RLMD processing are the energy of the instantaneous frequency at each time point that called frequency envelogram (FEnv).
- Since not every AM signal contains heartbeat components, the heartbeat signal is screened by autocorrelation to generate a higher-resolution FEnv.
- The proposed method is obtained through the time domain, which greatly improves the time-frequency resolution of STFT.

[5] Z.L. Liu, Y.Q. Jin, M.J. Zuo, Z.P. Feng, “Time-frequency representation based on robust local mean decomposition for multicomponent AM-FM signal analysis,” *Mechanical systems and signal processing*, 2017.

# Proposed Method



- Proposed algorithm consists of two main parts :
  - Pre-processing
    - Modified differentiate and cross-multiply (MDACM) [2]
    - Differential enhancement [3]
  - Heartbeat activity extraction
    - RLMD-based FEnv

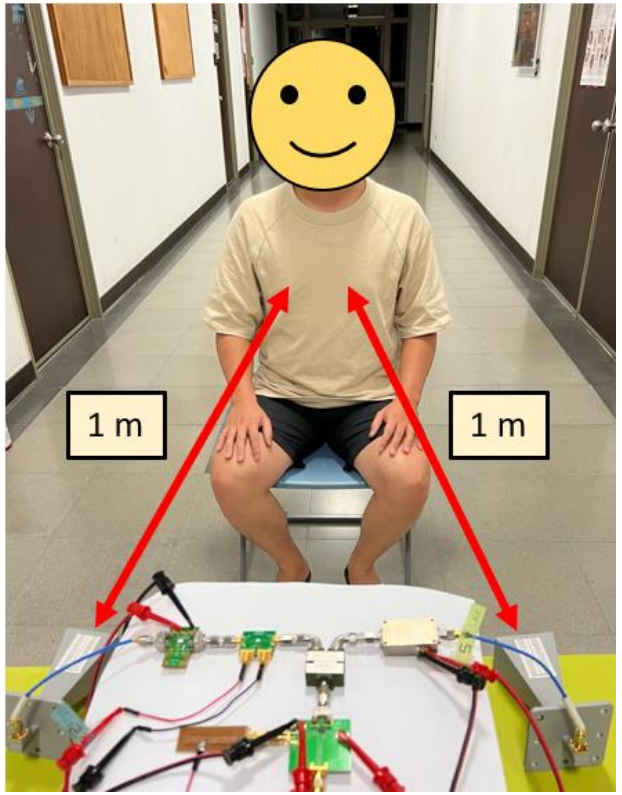


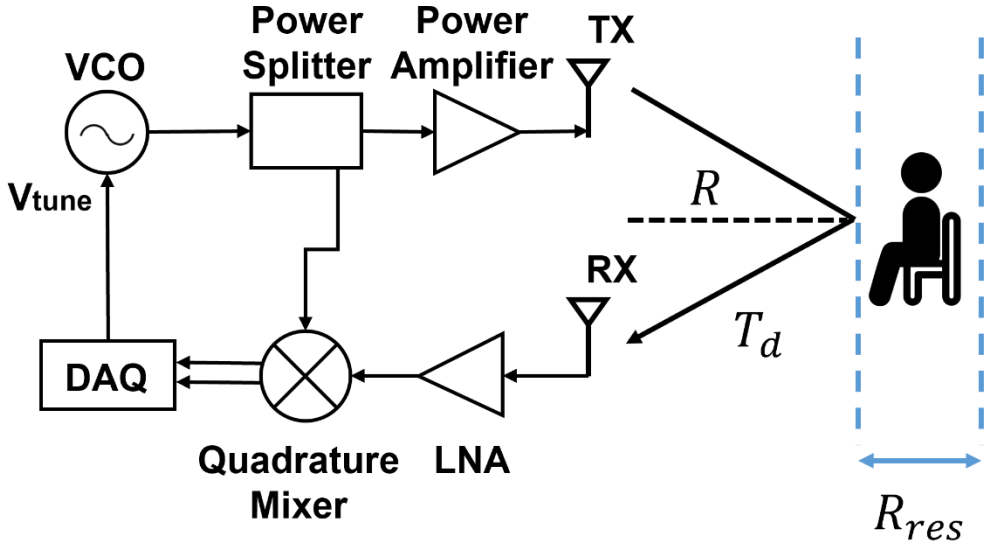

[2] W. Xu, C. Gu and J. -F. Mao, "Noncontact High-Linear Motion Sensing Based on A Modified Differentiate and Cross-Multiply Algorithm," *IEEE IMS*, 2020.
[3] Y. Xiong, Z. Peng, C. Gu, S. Li, D. Wang and W. Zhang, "Differential Enhancement Method for Robust and Accurate Heart Rate Monitoring via Microwave Vital Sign Sensing," *IEEE Trans. Instrument. and Meas.*, 2020.

# Experiment Setup



- Measurement Scenarios

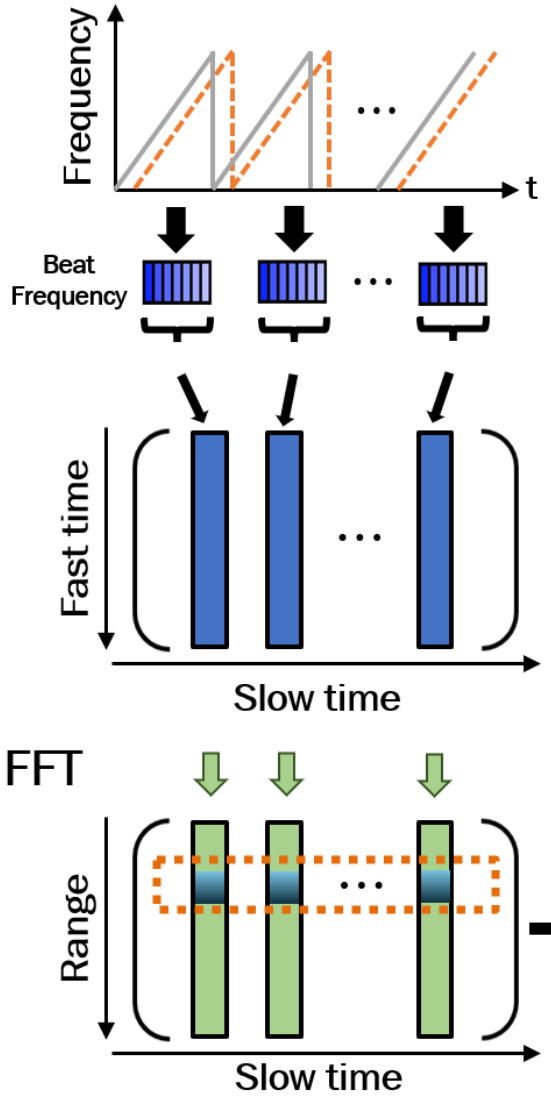


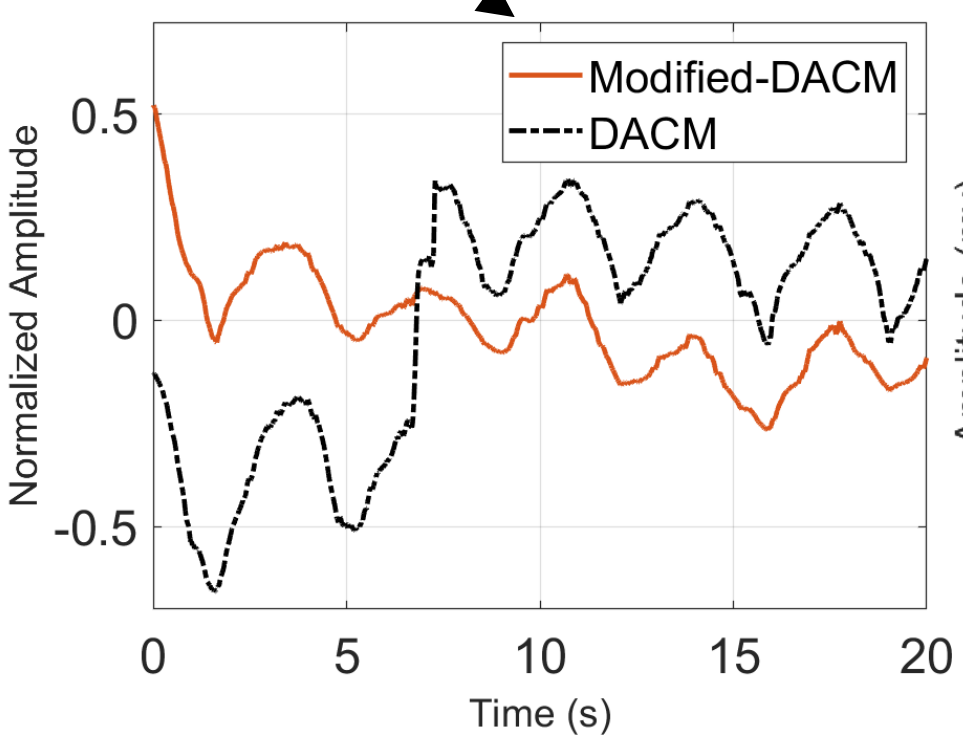

| Parameter | Value |
|---|---|
| Central Modulation Frequency | 24 GHz |
| Modulation Bandwidth | 160 MHz |
| Pulse Repetition Interval | 2 ms |
| Range Resolution | 0.9375 m |
| Measurement Period | 60 sec |

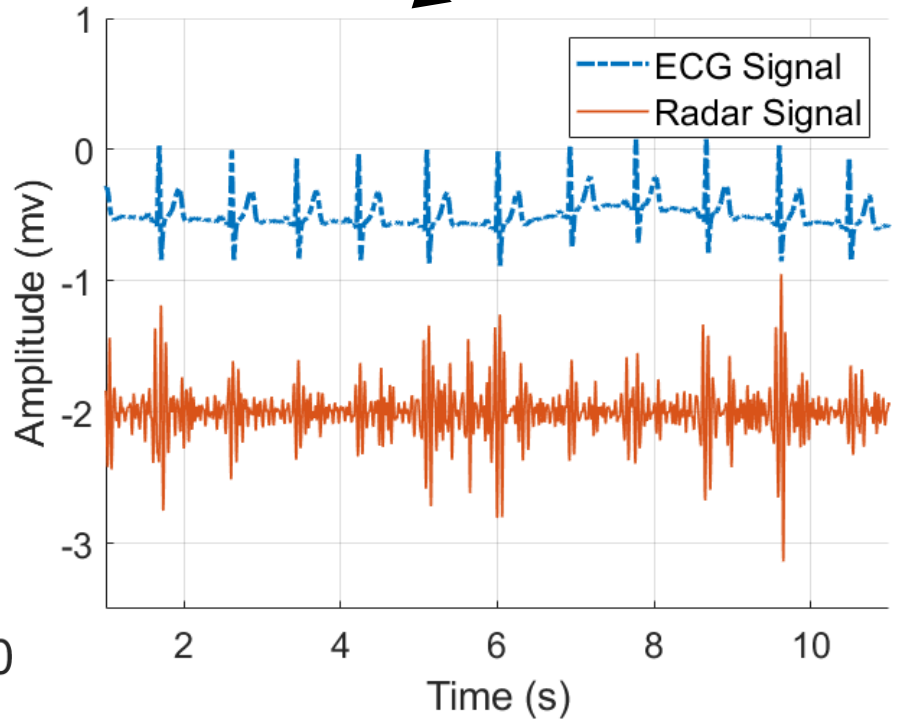
# Measurement Results (1)






Modified DACM → Differential Enhancement → RLMD-Based FEnv

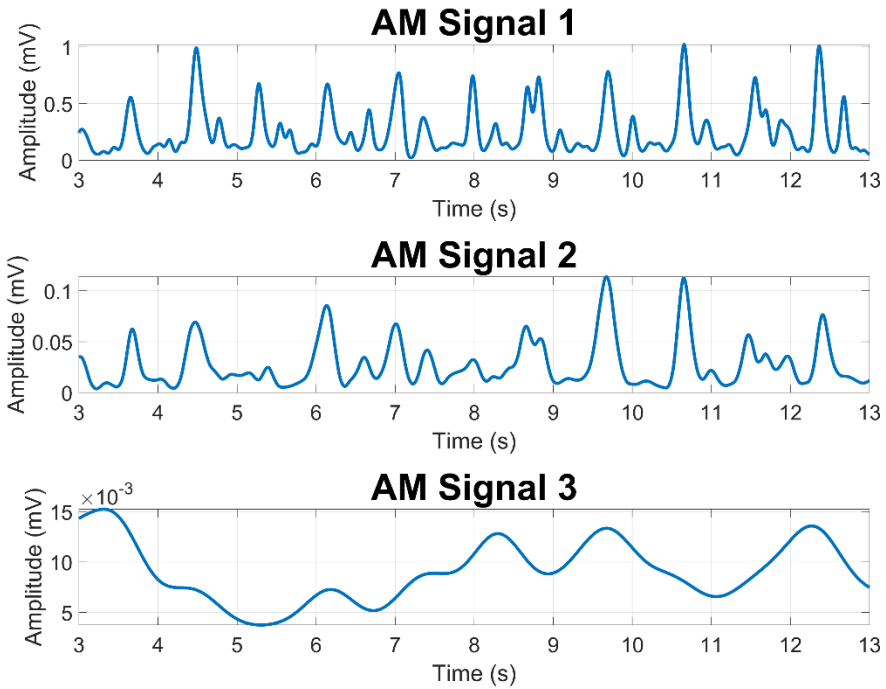


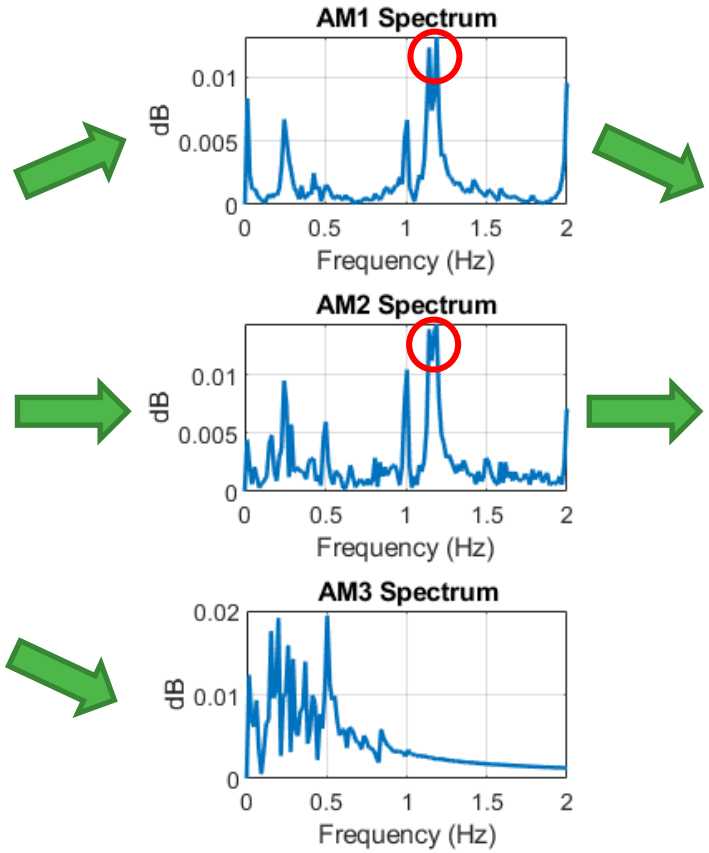



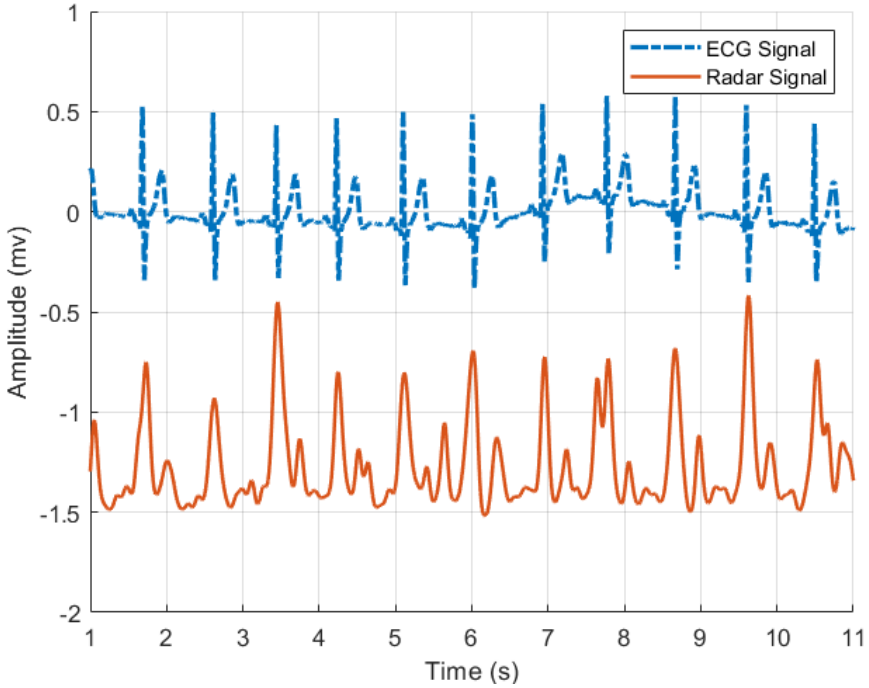
# Measurement Results (2)



**RLMD-Based FEnv** → **Autocorrelation** → **FFT & Find the highest peak in heart beat range** → **Combining signals with heartbeat components**



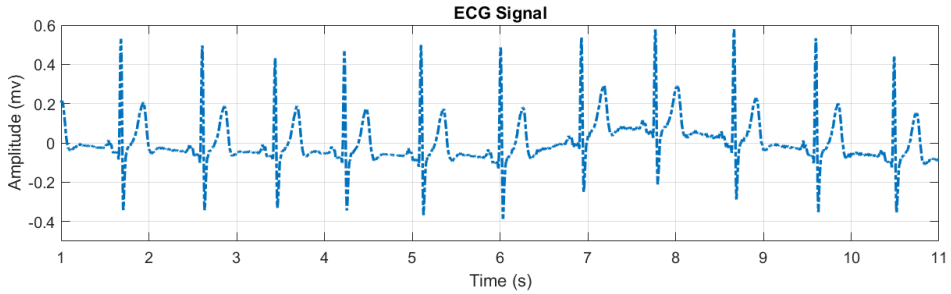



# Measurement Results (3)

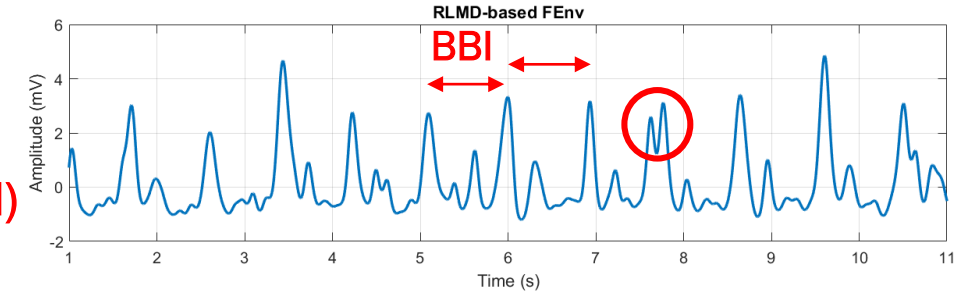


- The result of the extracted heartbeat

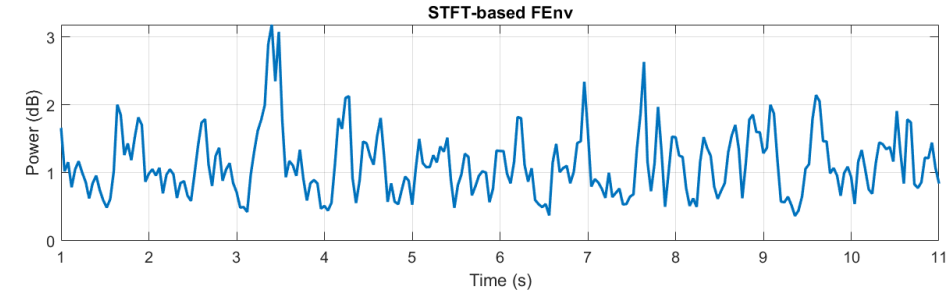
ECG



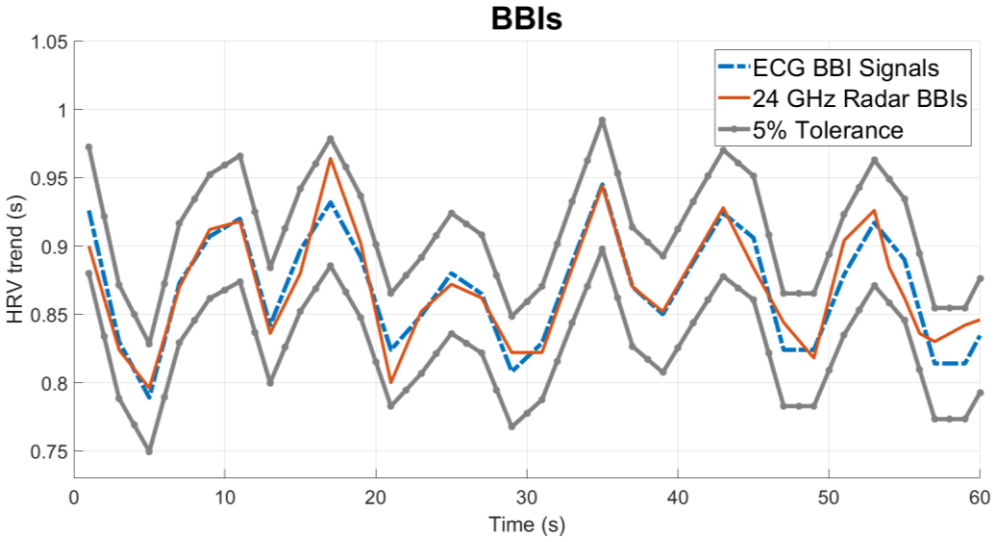

RLMD FEnv (Proposed)




STFT FEnv




- The error rate in every second




$$\mathrm{MRE} = \frac{1}{N_{\mathrm{BBI}}} \sum_{i=1}^{N_{\mathrm{BBI}}} \frac{|\mathrm{BBI}_{\mathrm{radar}}(i) - \mathrm{BBI}_{\mathrm{ECG}}(i)|}{\mathrm{BBI}_{\mathrm{ECG}}(i)}$$

MRE : 1.84 %

# Comparison



| Ref. | System | Method | Error |
|---|---|---|---|
| [4] | 24 GHz CW Radar @ 0.8m | IZA-SLMS with TWV | < 5 % |
| [5] | 24 GHz CW Radar @ 0.8m | Spectral Viterbi with RNN-based deep clustering | < 7 % |
| [6] | 24 GHz CW Radar @ 0.5m | STFT-based FEnv with HSMM | < 2 % |
| This work | 24 GHz FMCW Radar @ 1m | Differential Enhancement with RLMD-based FEnv | < 2 % |

[4] C. Ye, K. Toyoda and T. Ohtsuki, “A Stochastic Gradient Approach for Robust Heartbeat Detection with Doppler Radar Using Time-Window-Variation Technique,” IEEE Trans on Biomed. Engr., 2019.
[5] C. Ye and T. Ohtsuki, “Spectral Viterbi Algorithm for Contactless Wide-Range Heart Rate Estimation with Deep Clustering,” *IEEE TMTT*, May 2021.
[6] W. Xia, Y. Li and S. Dong, "Radar-Based High-Accuracy Cardiac Activity Sensing," in IEEE Trans. Instrument. and Meas. , 2021

# Conclusion



- A novel method is proposed to accurately extract HRV in the FMCW radar system including the distance information of the target.
- The FEnv generated by the RLMD improves the time-frequency resolution, and the addition of a filtering mechanism can greatly improve the resolution of FEnv.
- The average HRV trend error of this method is 1.84 %, which has the same accuracy as other methods in CW radar system.

# Thanks for your attention!

# Questions?

Feel free to contact me:
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