Vital Waves — Non-Contact Vital Signs Monitoring Using mmWave Radar

UNIVERSITY OF CALGARY | WAVES LAB | SCHULICH School of Engineering

Motivation

VitalWaves was motivated by the **limitations of current health and fitness devices.** The most popular devices, such as smart watches, need to be in contact with the user. People may find this **uncomfortable, intrusive, or impractical**, especially when they are sleeping. For some users, including children or individuals with sensory sensitivities, wearing these devices may not be feasible at all. Our mission is to make tracking important health and fitness indicators like **heart rate (HR), heart rate variability (HRV), and breathing rate (BR) more accessable.** Heart rate and breathing rate can provide insights into overall cardiovascular health, whilst HRV can provide insights into the physical strain on one's body.

Our Solution

VitalWaves addresses these limitations through **a contactless,** non-invasive monitoring system based on **millimeter-wave (mmWave) radar** and **digital signal processing (DSP)**. The system enables continuous **tracking of vital signs without requiring physical contact,** improving **comfort, accessibility, and usability.**

Research & Background

We reviewed 8 papers to guide our hardware and signal processing choices. Key findings:

- **77–81 GHz radar** gives the highest signal-to-noise ratio for HRV extraction.
- **MIMO antenna arrays** improve target selection accuracy.
- **Breathing motion** masks the weaker **heart-rate signal.**
- Advanced processing is needed to separate **respiratory and cardiac signals.**
- **Phase-based chest displacement** is key for biometric extraction with **FMCW radar.**

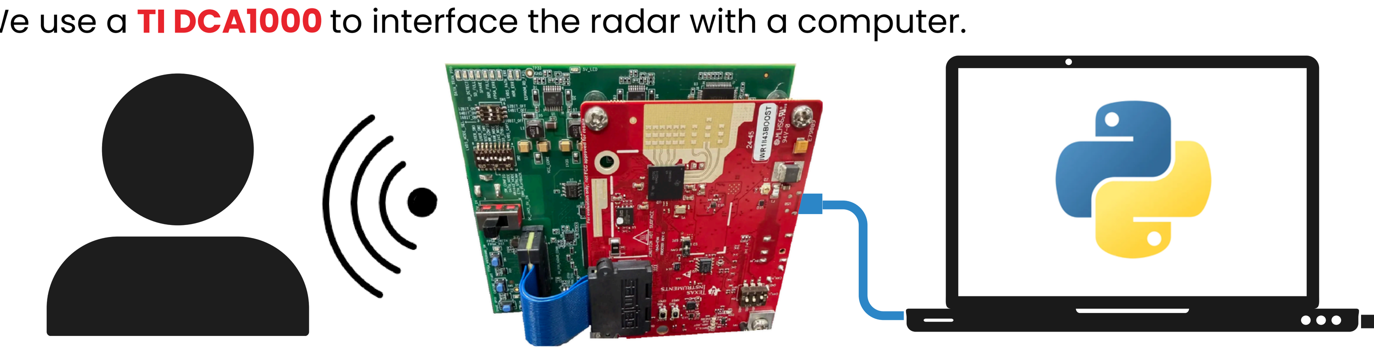
Hardware Selection

To verify our results, we selected **two ground truth devices**:

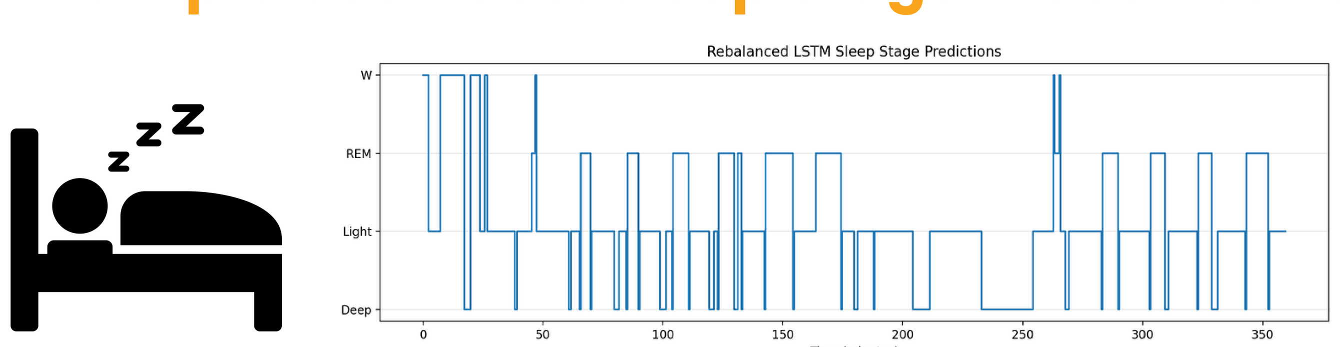
The radar that VitalWaves uses is a **TI IWR1843BOOST**. Key selection reasons include:

- It is a high frequency radar operating at **77-81 GHz** which allows us to **detect small changes.**
- It has **3 transceiver antennas (Tx)** and **4 receiver antennas (Rx),** allowing us to triangulate the position of the target's chest significantly better than a radar using a single input and output antenna.
- The IWR1843 is a frequency-modulated continuous-wave radar (**FMCW**). FMCW radars are designed to **measure distances via phase difference** of transmitted and received signals.

We use a **TI DCA1000** to interface the radar with a computer.

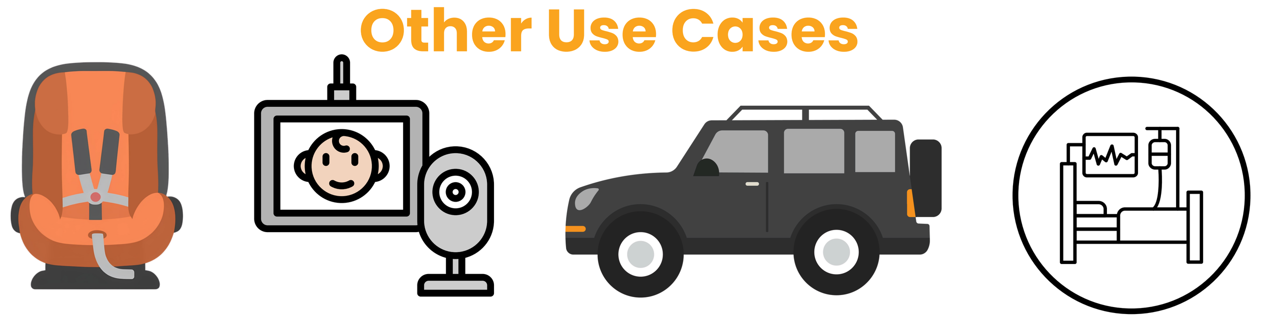


Example Use Case: Sleep Stage Classification



A notable use case for our pipeline is a **sleep stage classification algorithm using our extracted BR, HR, and HRV metrics.** We decided to use a **Long Short-Term Memory (LSTM) algorithm** to predict the users sleep stages. Right now, our LSTM can predict whether a user is in light, deep, REM, or awake sleep with about 50% accuracy. This suggests there is some potential to infer sleep stages from our results, though further work is needed to improve performance. At this stage, the goal was to demonstrate a proof of concept rather than develop a fully robust solution.

Other Use Cases



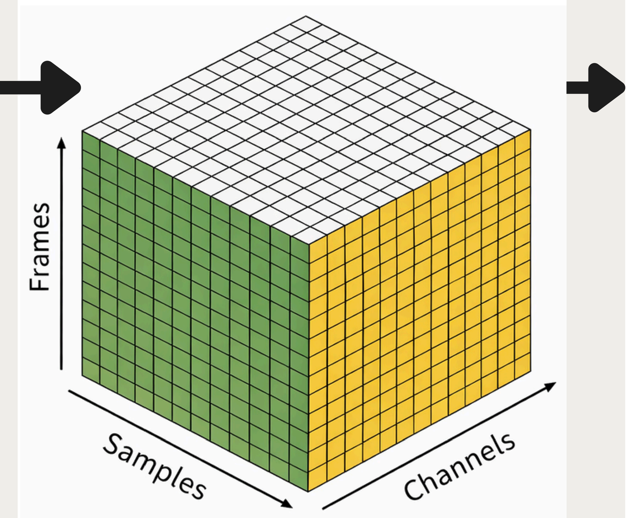
Conclusion

1. Vitalwaves demonstrates the potential of **noninvasive biometrics as an alternative** to wearable health and fitness technology.
2. Using The TI IWR1843 Radar, we can **reliably extract physiological metrics** such as: **Heart Rate, Breathing Rate,** and **Heart Rate variability** stats such as SDNN and RMSSD.
3. Using outputs from the radar, it is possible to derive further health and fitness applications, such as **sleep stage classification**.

VitalWaves Digital Signal Processing Pipeline

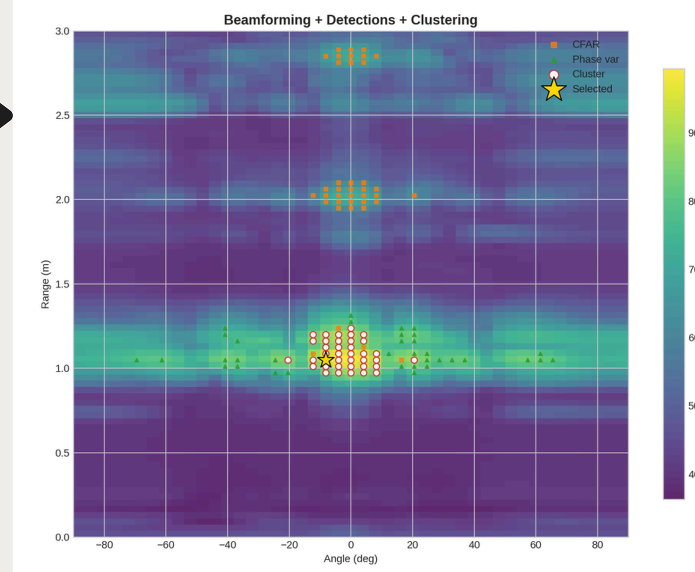
Data Acquisition

Configure the **IWR1843** radar and capture raw data with the **TI DCA1000** at a rate of **6.5 million samples** per second over a **4 GHz** bandwidth



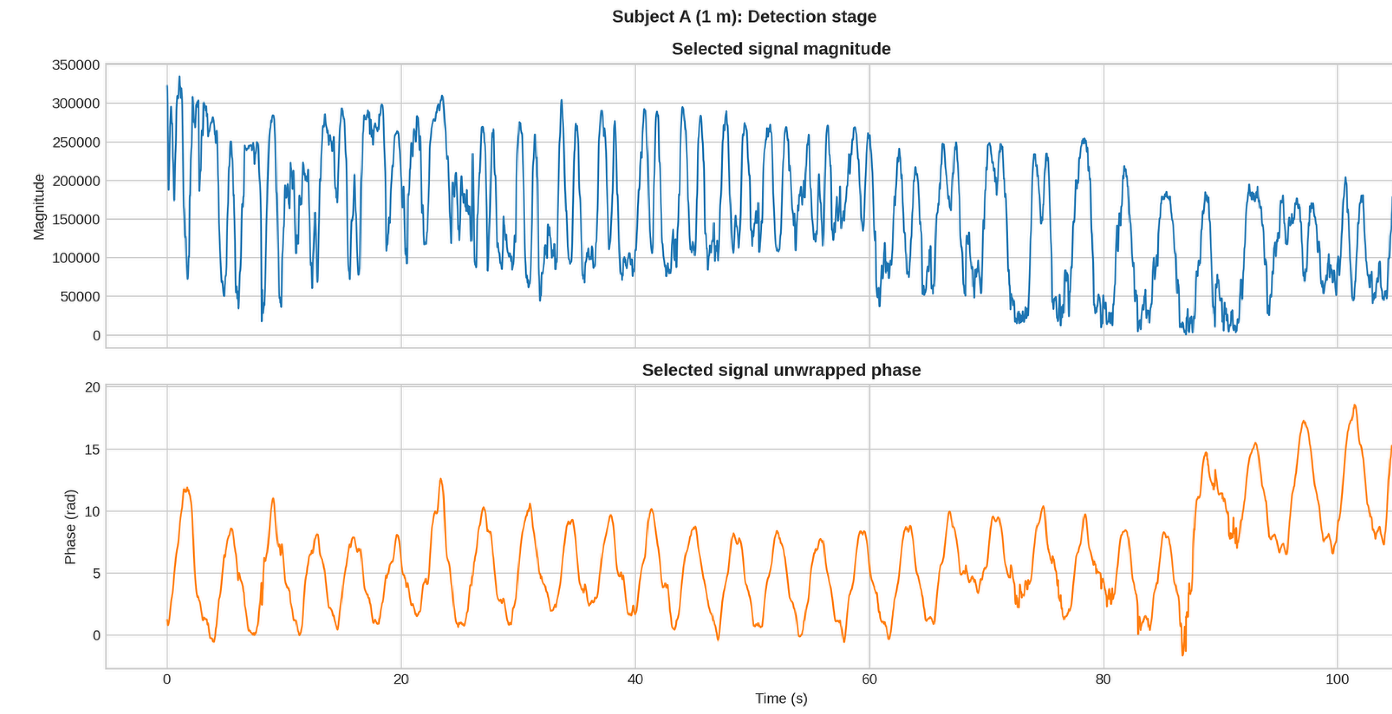
Preprocessing

Apply DSP techniques to refine raw 3D radar data: **EWMA** filtering removes static reflections, **Bartlett beamforming** combines RX signals, **CFAR** with phase variance isolates motion, and **DBSCAN** localizes the user.



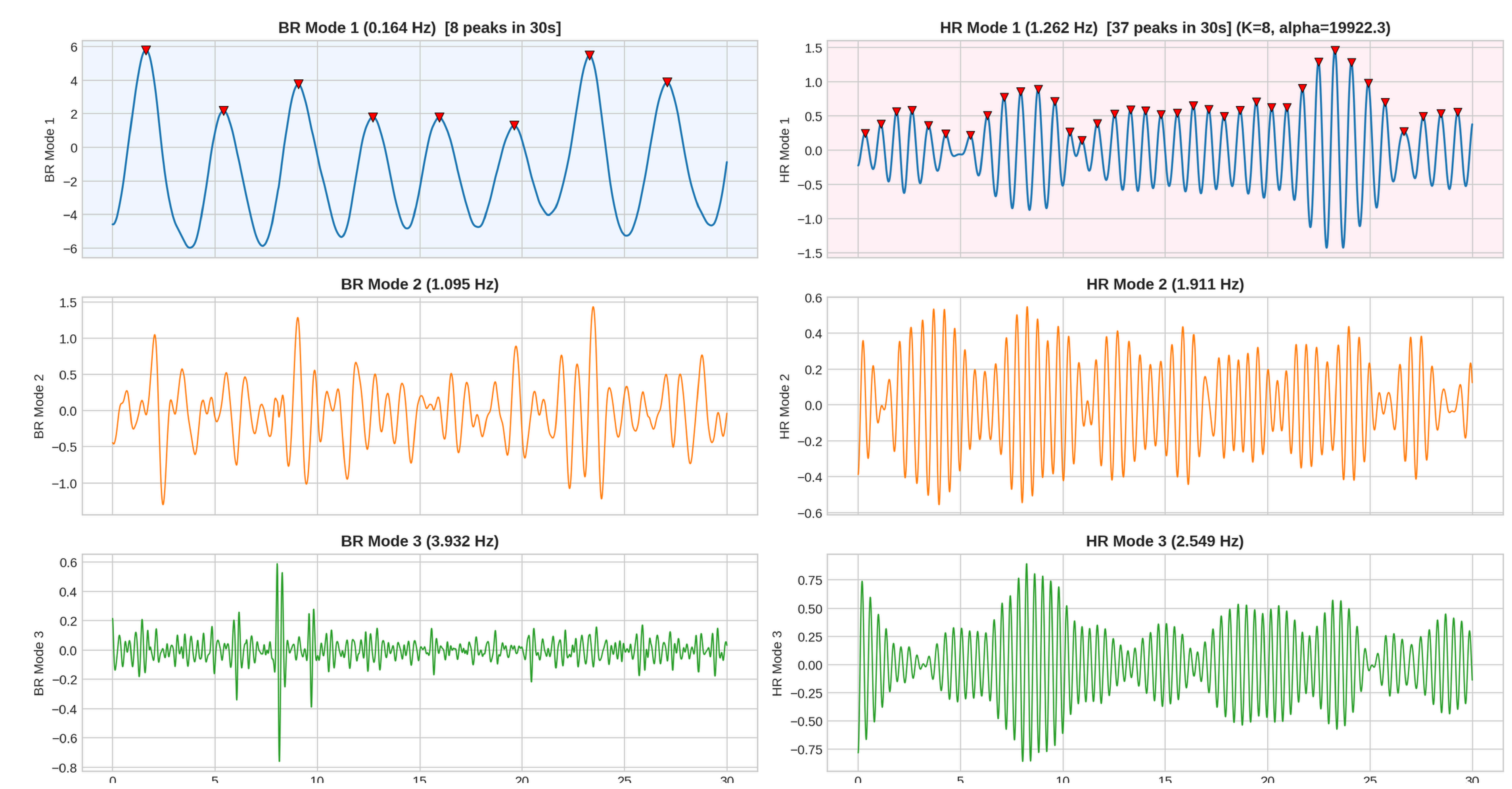
Chest Motion Extraction

- Transform the selected **slow-time signal into a chest displacement waveform**
- Apply **phase unwrapping** to fix 2π ambiguity
- Recover **sub-millimeter motion** from chest wall
- Preserve both **breathing and cardiac segments.**



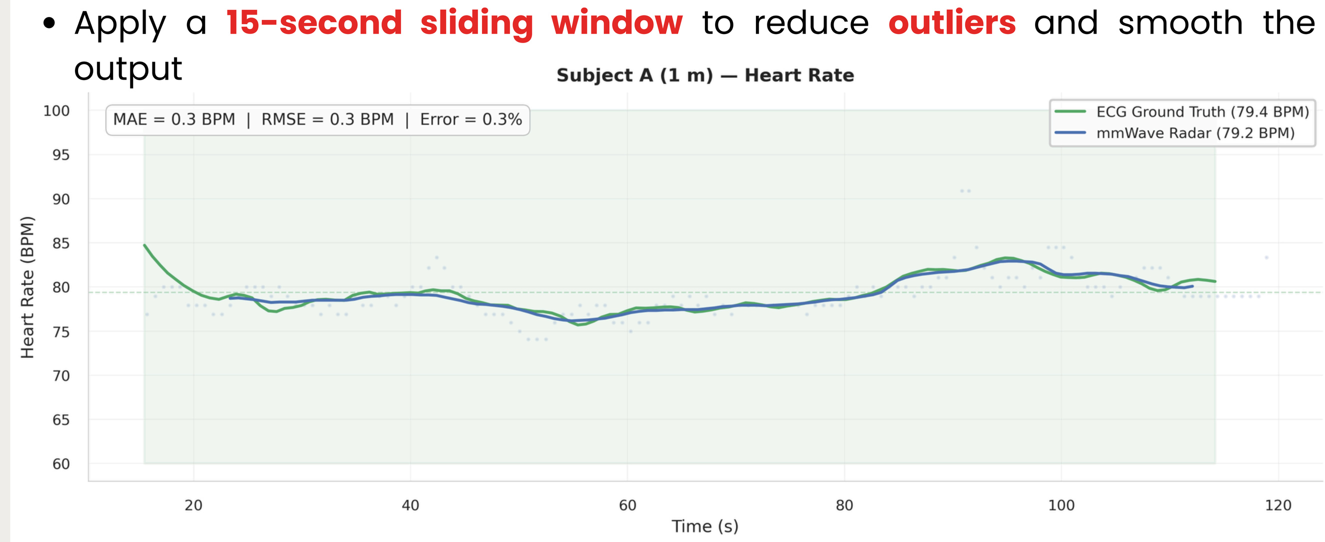
Wave Decomposition

- Apply **Variational Mode Decomposition (VMD)** to decompose the enhanced signal into band-limited modes
- Separate distinct **oscillatory components** adaptively
- Estimate each mode's center frequency for robust HR/BR extraction
- Sweep K with auto-tuned alpha,
- Use multi-feature scoring to select the cardiac and respiratory modes



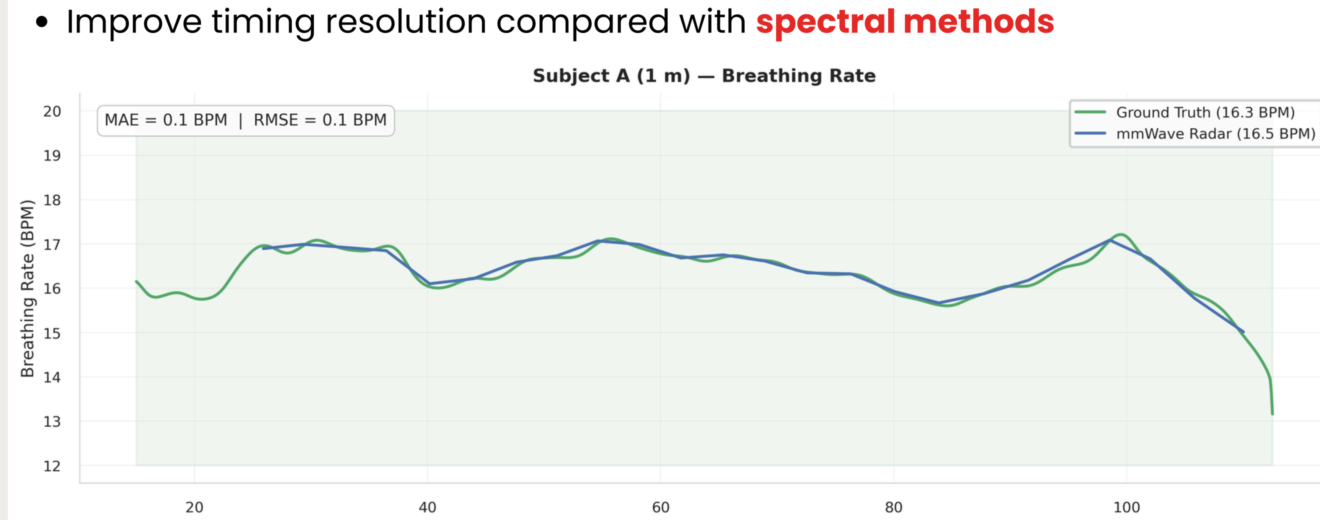
Heart-Rate Extraction

- Select the **heartbeat mode** from **VMD**
- Detect **heartbeats** and extract beat timing
- Convert **beat-to-beat intervals** into **heart rate**
- Apply a **15-second sliding window** to reduce **outliers** and smooth the output



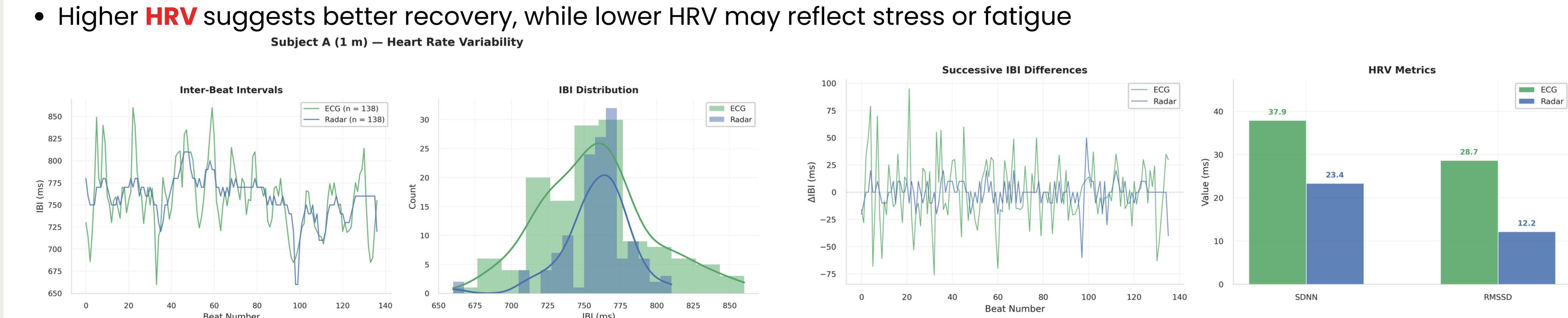
Breathing-Rate Extraction

- Detect **breathing cycles** from the isolated **respiration mode**
- Convert **peak-to-peak** intervals into **breathing rate (BPM)**
- Preserve **breath-by-breath timing**
- Improve timing resolution compared with **spectral methods**



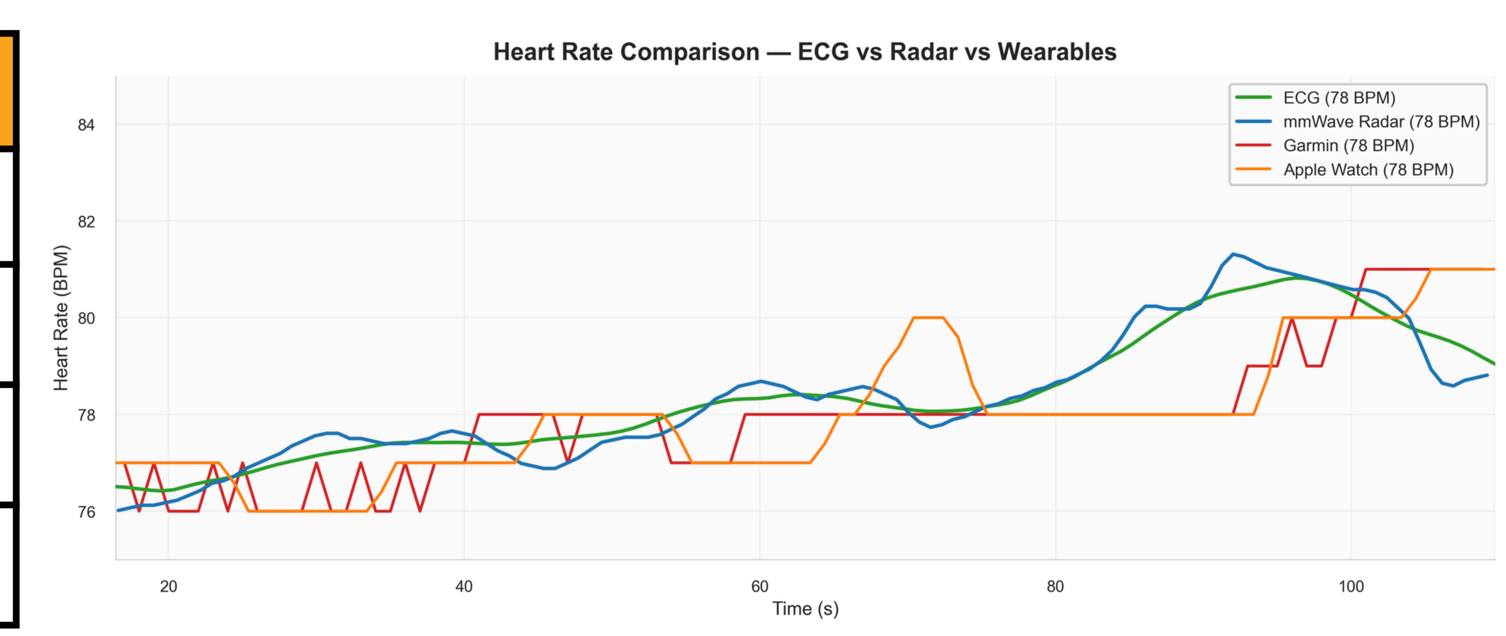
Heart-Rate Variability Extraction

- Compute **HRV** from beat-to-beat intervals before conversion to BPM
- Use **RMSSD** for short-term variability and **SDNN** for long-term variability
- Higher **HRV** suggests better recovery, while lower HRV may reflect stress or fatigue



Final Results

Biometric	Average Error	Best Case
Breathing Rate	1.59bpm	0.15bpm
Heart Rate	4.96bpm	0.36bpm
SDNN (HRV)	16.87ms	2.3ms
RMSSD (HRV)	22.11ms	0.1ms



Team Members: Maged El Habiby, Mazen El Habiby, Samir Sakr, Ben Zuidema, Marshal Kalynchuk
Sponsor (Waves Lab): Dr. Hatem Abou-Zeid, Dr. Gholamreza Bakhshi
Academic Advisor: Dr. Naser El-Sheimy
Teaching Assistant: Simon Wu

References

[1] mmHRV: Contactless Heart Rate Variability Monitoring Using Millimeter-Wave Radio, 2001
[2] mmHRR: Monitoring Heart Rate Recovery with Millimeter Wave Radar, 2025
[3] Detection of vital signs based on millimeter wave radar, 2025
[4] A high precision vital signs detection method based on millimeter wave radar, 2024.
[5] A Real-Time Evaluation Algorithm for Noncontact Heart Rate Variability Monitoring, 2023.
[6] mmWave-RM: A Respiration Monitoring and Pattern Classification System Based on mmWave Radar, 2024.
[7] mmRH: Noncontact Vital Sign Detection With an FMCW mm-Wave Radar, 2023.
[8] Pulse-Fi: A Low-Cost System for Accurate Heart Rate Monitoring Using Wi-Fi Channel State Information, 2025
[9] Canva, "Icons," [Online]. Available: https://www.canva.com/