Wi-Fi SENSING · HUMAN PRESENCE DETECTION

Human Presence Detection
via Wi-Fi on Commodity Laptops

No external hardware. No camera. No calibration.

intel®

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MULTIX 6G SENSES

MOTIVATION

Why Human Presence Detection Matters

A feature expected in every modern laptop — still not solved without trade-offs

Wake-on-Approach

Laptop wakes up before you sit down — seamless UX, zero button presses

Secure Lock-on-Leave

Screen locks automatically when user walks away — privacy without friction

Adaptive Power Mgmt

CPU throttles, display dims when no one is near — extends battery life

Existing Approaches Have Fundamental Limitations

Dedicated ToF / IR Sensors

- ✗ Extra HW cost — only in premium laptops
- ✗ Limited field of view, added power draw

Camera-Based Systems

- ✗ Privacy concerns — always-on video
- ✗ Fails in low light or when camera is covered

OUR APPROACH

One Laptop
Built-in Wi-Fi
Zero Extra Hardware

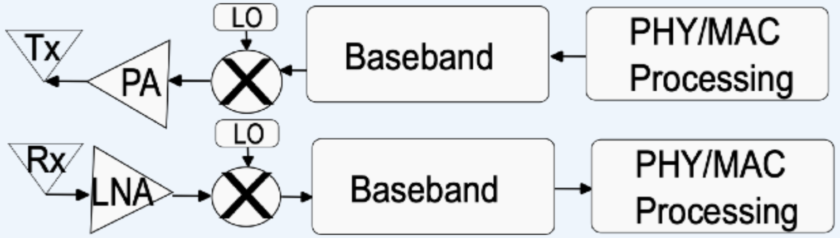
Monostatic radar — same device transmits and receives.
No router. No AP. No calibration
.

✓ OURS — MONOSTATIC

Shared Tx/Rx chain — single LO

✓ Fully self-contained in laptop - no external AP or router
✓ Works in any environment
✓ Range information – locate user and filter background motion

✗ TRADITIONAL BISTATIC



Separate Tx/Rx chains — two LOs

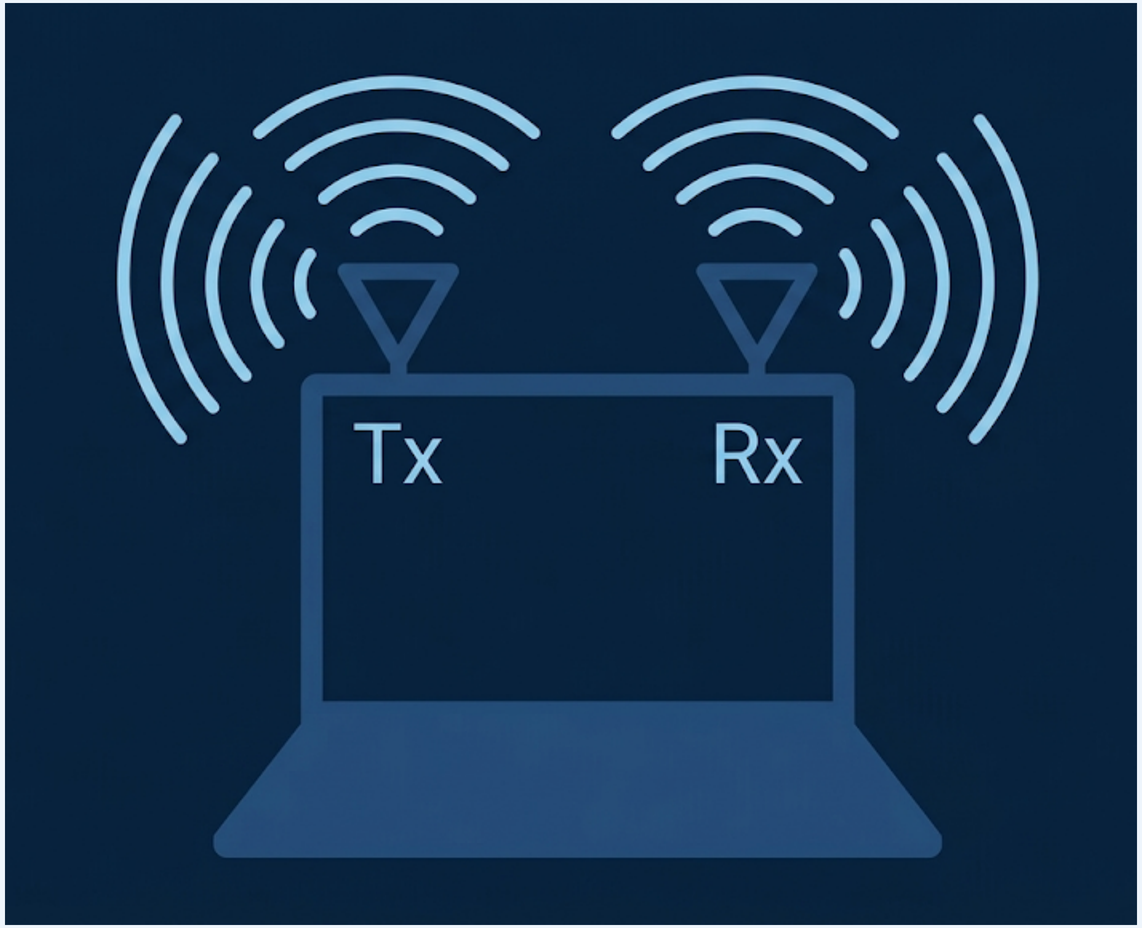
✗ Requires external router / AP
✗ Environment-dependent
✗ No range data — can't isolate background

First standalone Wi-Fi HPD system on a commercial laptop — no external devices required — Wi-Fi 6E & Wi-Fi 7

OUR APPROACH

Enabling Monostatic Radar on Commercial Wi-Fi

To transform a communication-focused Wi-Fi NIC into a radar, we must overcome hardware limitations designed purely for data exchange. This requires a shift to Coherent Full-Duplex operation.



Full-Duplex Coherency: Operating one antenna as Tx and another as Rx simultaneously on the same device.

Controlled Frame Rate: Injecting standard LTF frames at a precise, high-stability rate (up to 100Hz) to ensure high unambiguous velocity estimation (Vmax = 1.19 m/s).

Dedicated Resource Allocation: Reserving one Tx and one Rx chain specifically for sensing tasks during the sensing window to maintain signal integrity.

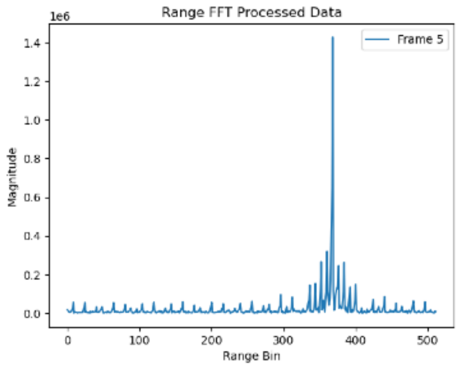
Tx Power Reduction: Transmit power is deliberately reduced to prevent LNA saturation from Tx/Rx self-coupling on co-located antennas.

Advanced Synchronization: Hardware clock offsets and phase drift are compensated in software via delay estimation and coherent phase alignment.

How to Overcome Hardware Imperfections? Range/ Doppler estimation

1 Reference Calibration

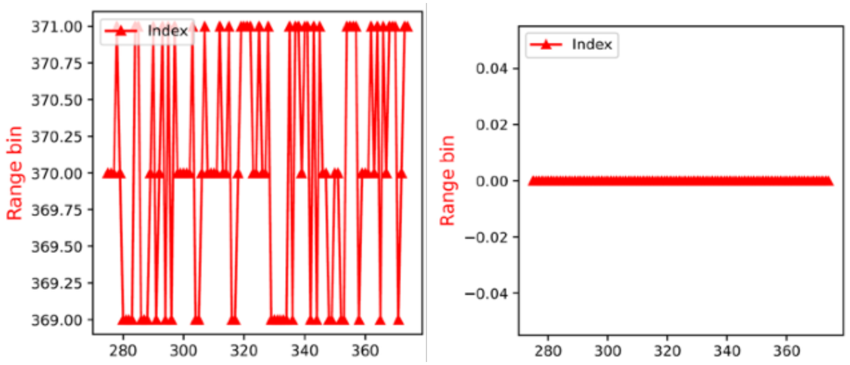
- Tx signal leaks directly into the Rx chain via Tx/ Rx coupling (>10× stronger than the reflected signal)
- Tx/Rx coupling acts as a known reference (zero distance and shares the same local oscillator frequency)



2 Time/Delay Synchronization

- Coarse estimation by Cross-correlation between the received signal and the known LTF reference sequence (LTF) to find the Tx/Rx peak
- Fine sync via Up sampling

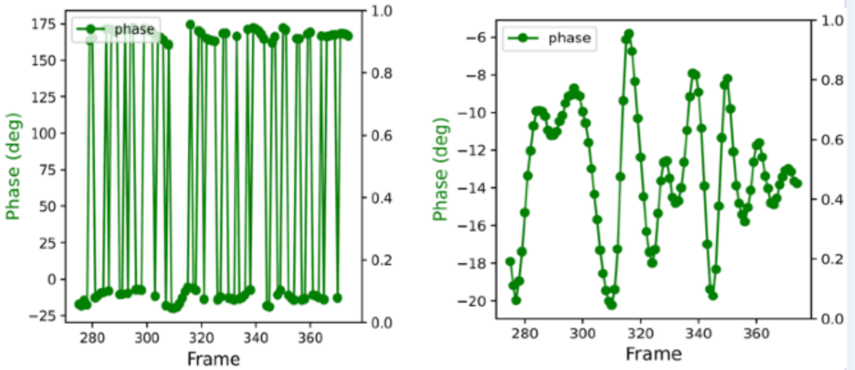
Before → After



3 Frequency/Phase Synchronization

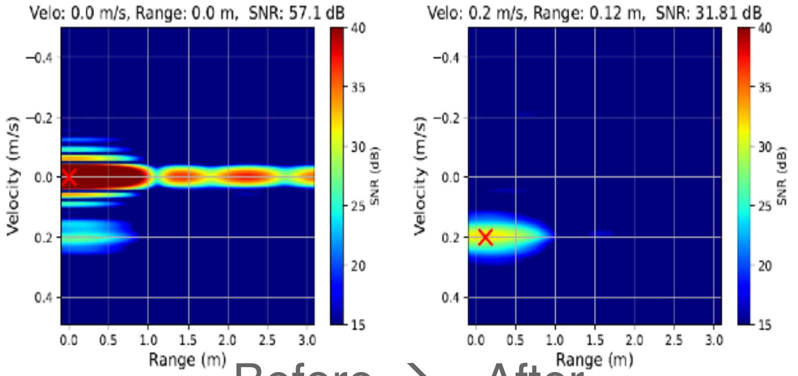
- Phase average computed across the last L frames for all peaks → coherent alignment applied

Before → After



4 Self-interference Cancelation

- After using the Tx/Rx coupling to calibrate the signal we cancel this signal.
- This can be done using DC cancellation, etc.
- Once hardware imperfections are canceled, range and Doppler parameters can be estimated via standard 2D-FFT/DFT



Before → After

Range-Filtered Doppler Spectrum (RF-DS)

Standard Radar 2D-FFT processing is too computationally expensive for "always-on" laptop. To solve that, we introduce RF-DS to focus processing only on the task-relevant spatial zones

Phase-Compensated Matched Filtering:

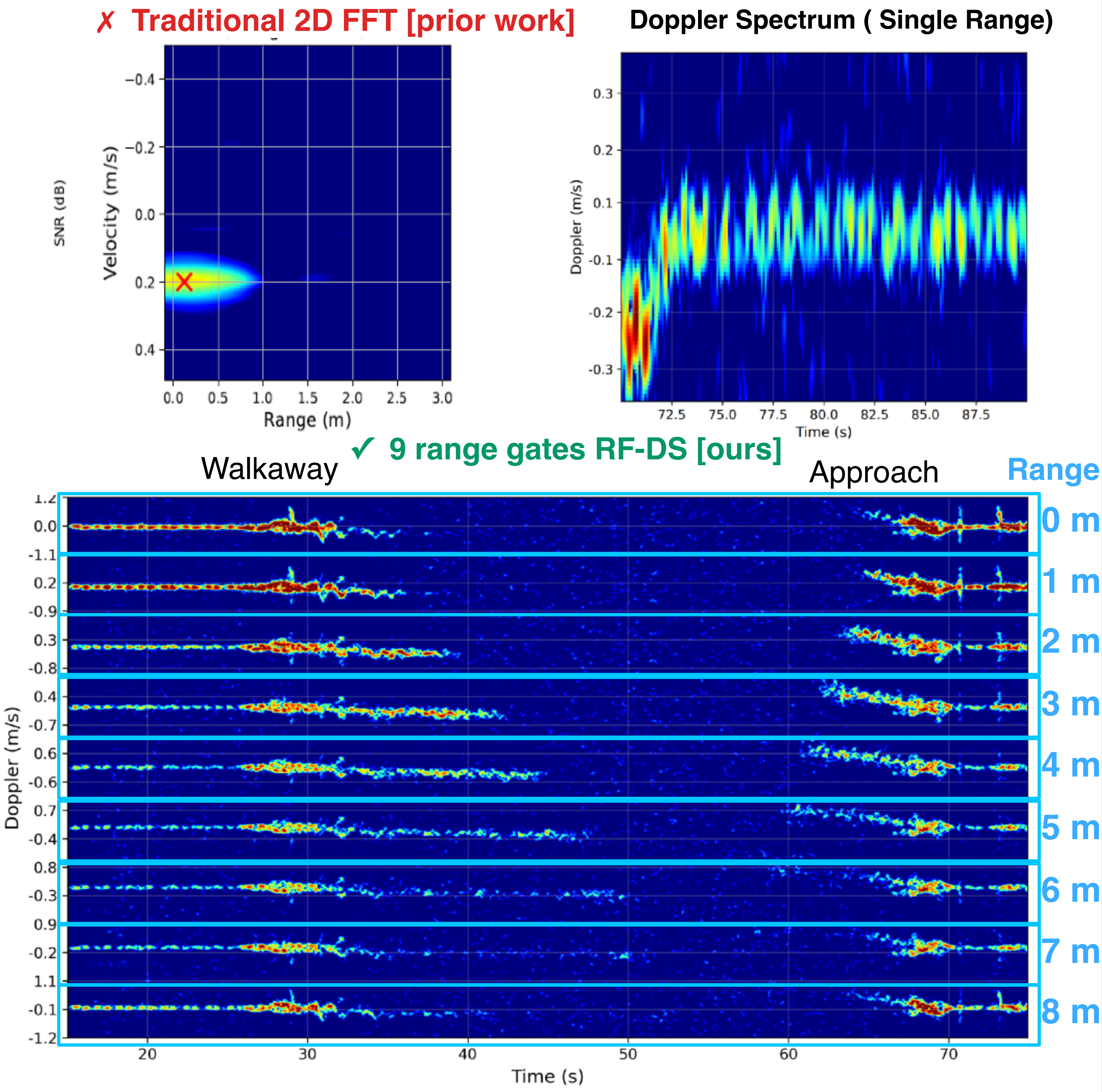
- Instead of a full 2D FFT, a phase shift is applied to subcarriers to 'tune' the receiver to a specific range. Reflections from that range add coherently; all others cancel. Equivalent to a single-point DFT per gate.

Spatial Targeting

- Only Rg=9 range gates covering 0–8 m are processed. Reflections from other distances are ignored — eliminating wasted CPU cycles on irrelevant zones

Temporal Stability & Decision Logic

- 1D Doppler slices are accumulated into a sliding Time-Doppler map. This temporal context distinguishes real human motion from transient noise.



* To improve accuracy we apply quadratic interpolation to the range gate index

Enhanced SI Cancellation for Micro-Motion

✗ DC Cancellation [prior work]

- Removes mean value from CSI — suppresses static self-coupling
- But breathing shifts are only 5–10 mm/s (≈ 0.08 m/s Doppler)
- These micro-motions fall inside the DC suppression band
- Cannot reliably detect stationary users at 2+ m range

✗ Traditional Time-Domain High-Pass Filters:

- FIR Filters: Require long sequences and high memory buffers to provide fine Doppler cancellation
- IIR Filters: While memory-efficient, they lack a linear phase response and can propagate errors across continuous frames

✓ Range Domain FIR Filter [ours]

- 64-tap bandpass FIR filter applied on range domain
- Applied only to 9 range gates → significantly reduce the system's memory
- Precise zero-Doppler rejection, isolating subtle micro-motions (respiration) as slow as 0.10 m/s
- Enables breathing detection at +2 m on commodity Wi-Fi hardware

* To improve accuracy we apply quadratic interpolation to the range gate index

Adaptive Multi-Rate Framework

Power efficiency designed for always-on laptop operation - Balances the need for rapid "Wake-on-Approach" (sub-second response) with the constraints of always-on battery operation.

IDLE MODE · 10 Hz

- Ultra-low power — minimal CPU usage
- Vel. resolution: 0.004 m/s · vmax ± 0.12 m/s
- Monitors for any motion event

DETECTION MODE · 100 Hz

- Activated on single motion trigger
- Vel. resolution: 0.074 m/s · vmax ±1.19 m/s
- Returns to Idle after 10 negative detections

Three Detection Zones

Zone	Range	Description
NEAR ZONE	0 – 2 m	User at desk — Presence
APPROACH ZONE	2 – 5 m	Moving toward / away
FAR ZONE	> 5 m	No presence detected

BW: 160 MHz · Range res: 0.94 m · SNR threshold: 12 dB · Majority vote: 3 frames

Validation Setup

Tested on Real Commercial Hardware — No Lab Modifications

HP EliteBook

Primary platform

Modified Intel driver · LTF capture ·**Wi-Fi 7**

Lenovo ThinkPad

Cross-platform test

Modified Intel driver · LTF capture · **Wi-Fi 6E**

Three Test Scenarios

1. **Breathing Detection**

   User stationary at 3 m, breathing normally · micro-Doppler sensitivity (5–10 mm/s)

2. **Approach & Leave**

   User walks 0.5 m → 8 m → returns · Evaluates continuous range + velocity tracking

3. **Cross-Platform Test**

   Full approach–leave on both devices

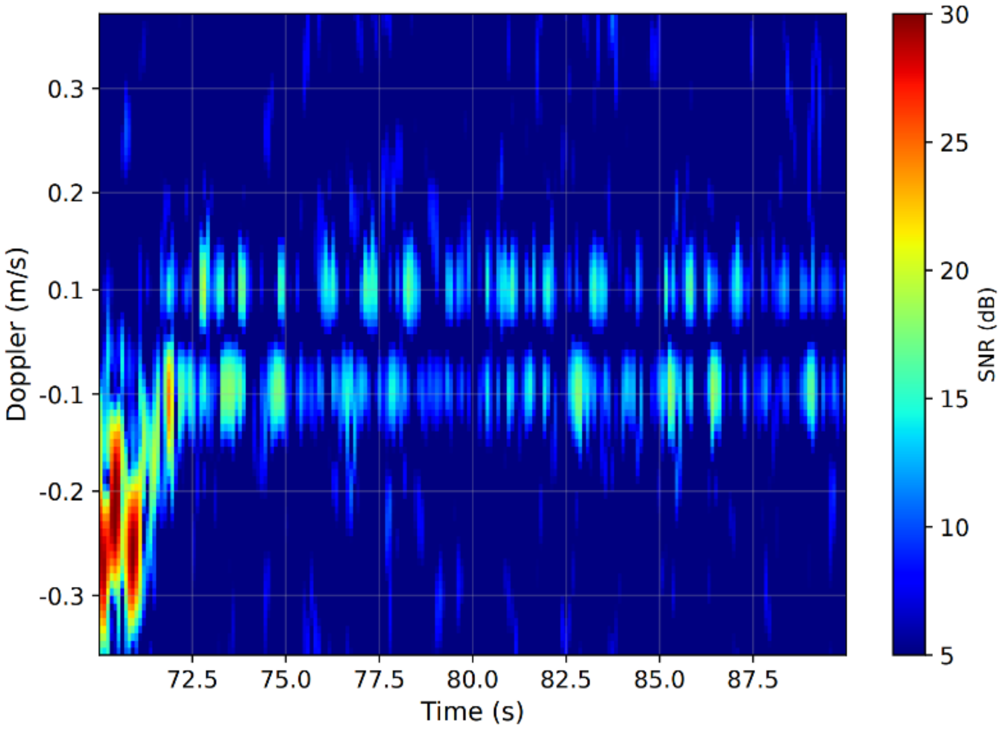
Parameter	Symbol	Unit	Idle	Detection
Frame Rate	fframe	Hz	10	100
Number of Frames	M	--	32	32
Bandwidth	B	MHz	160	160
Carrier Frequency	fc	GHz	5.8	5.8
Range Resolution	Δr	m	0.94	0.94
Number of Range Gates	Rg	--	9	9
Velocity Resolution	Δv	m/s	0.004	0.074
Unambiguous Velocity	vmax	m/s	±0.12	±1.19
SNR Window	MW	frames	20	20
Detection Window	Wdet	frames	3	3
Detection Threshold	TSNR	dB	12	12
Presence State Window	[illegible]	frames	[illegible]	[illegible]

RESULTS

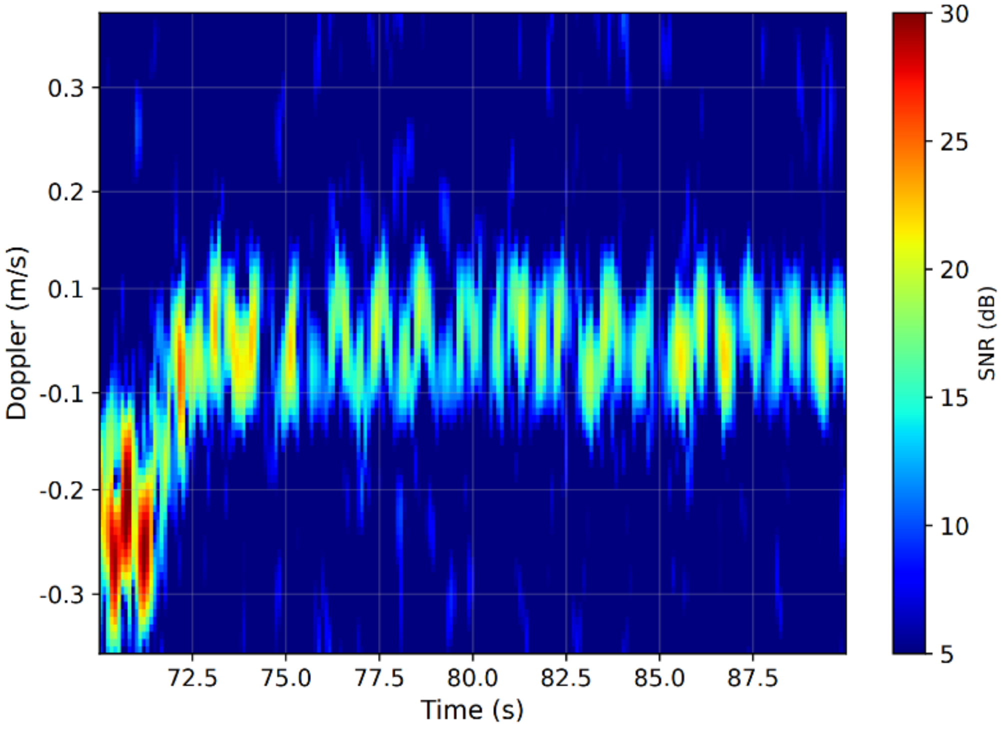
Breathing Detection at 3 m

Challenge: Breathing produces Doppler shifts of only 0.05–0.10 m/s — easily masked by static Tx/Rx coupling reflections

(a) DC Cancellation [prior work]



(b) MTI FIR Filter [ours]



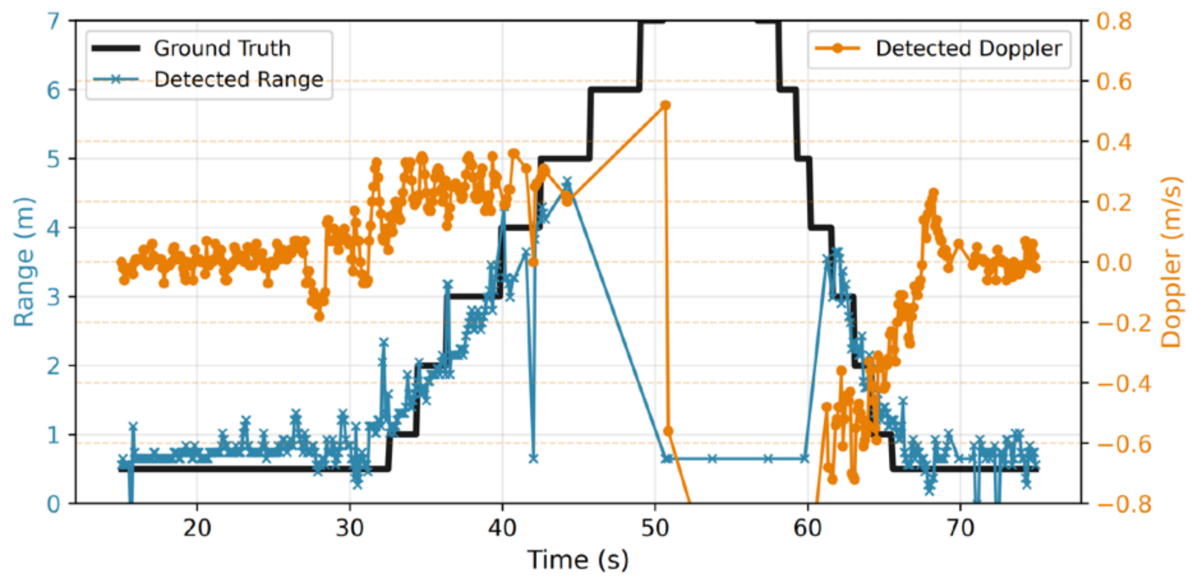
DC Cancellation: breathing signature buried in Tx/Rx leakage noise — can suppress slow motions (0.08 m/s)

MTI FIR Filter: clean micro-Doppler — breathing at 3 m clearly resolved, enabling stationary user detection

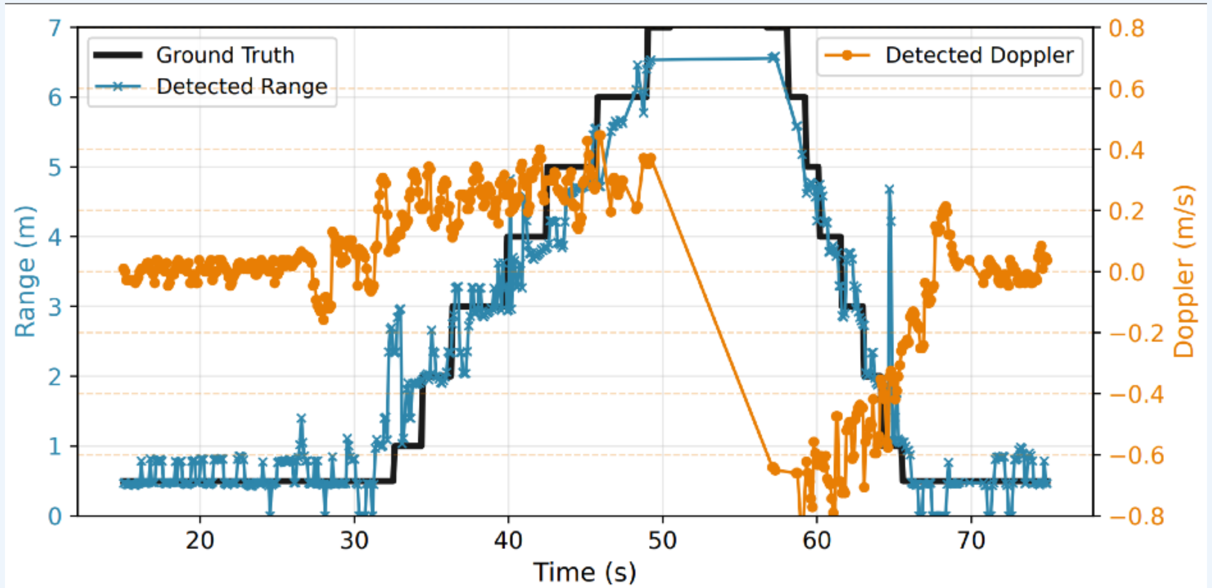
Approach & Leave Tracking

Continuous range and velocity estimation over 6+ meters

2D FFT Range-Doppler Map



RF-DS Output [ours]



Metric	2D FFT	RF-DS
Range tracking	Noisy low-speed	**Smooth / stable**
CPU load	All N subcarr.	**Rg=9 gates**
Operation per second	3.99M	**522.9k(100 Hz), 52.3k (10Hz)**
Far-range detect	6 m	**8 m**
Calibration	None	**None**
complexity	O(N·M·(Mfir + log N + log M))	**O(Rg·M·(N + Mfir + log M))**

RF-DS delivers smoother tracking in the workspace zone — which matters more than cm-level range accuracy for HPD.

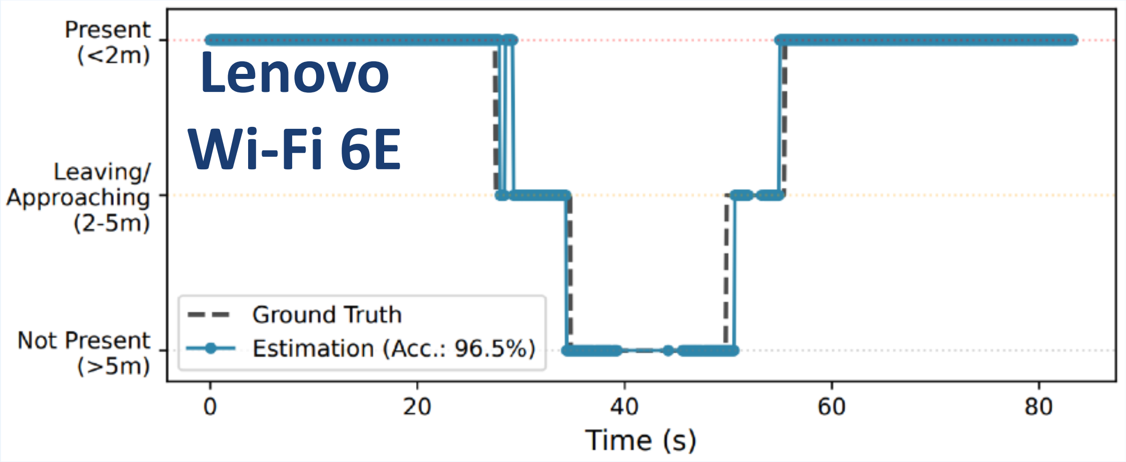
*N = number of subcarriers **M** = number of OFDM symbols / frames **M_fir** = number of FIR filter taps **R_g** = number of range gates of the Doppler spectrum

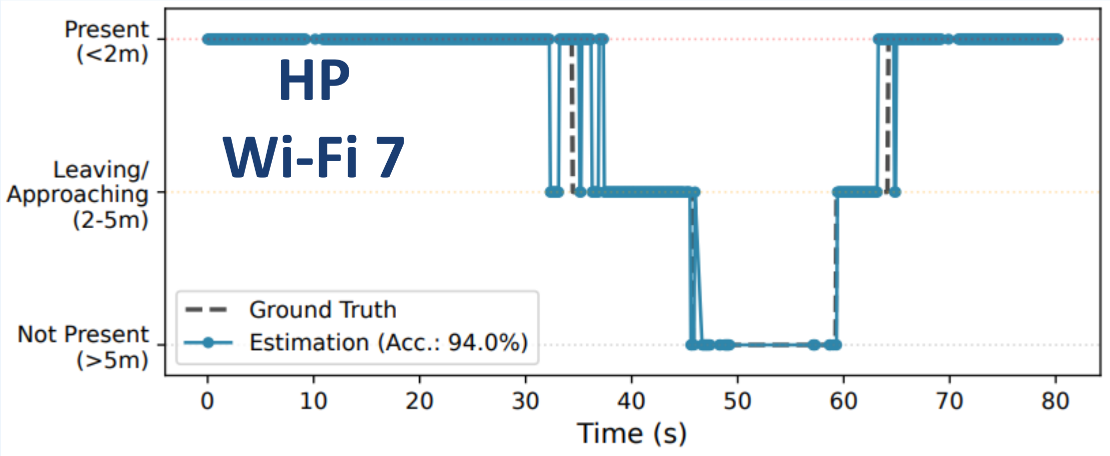
RESULTS

Cross-Platform Performance

Same algorithm. Different hardware. Consistent results.

PRESENT	APPROACHING	LEAVING	NOT PRESENT
User at desk, within 2 m	User walking toward laptop, 2–5 m	User moving away, 2–5 m	No detectable motion beyond 5 m





96.5%	94.0%	0.48s	0.89s
Accuracy	**Accuracy**	**Avg Latency**	**Max Latency**
Lenovo Wi-Fi 6E	*HP Wi-Fi 7*	*motion → state*	*worst case*

What We've Delivered

- First standalone monostatic Wi-Fi HPD on a commodity laptop — no external infrastructure
- RF-DS: low-complexity range-selective Doppler — detects breathing, approach, and departure
- Adaptive 10/100 Hz dual-mode framework — always-on with minimal battery impact
- >94% accuracy on both Wi-Fi 6E and Wi-Fi 7 devices — generalizes without calibration
- Sub-second latency (0.48s avg) — system ready before user sits down

Future Work

- Human vs. pet vs. object distinction via Doppler profiles
- Multi-user detection & localization
- Integration with OS power management APIs
- Expanded device & environment testing