Camera-Free Human Sensing with Wi-Fi: Presence and Position Detection on ESP32-S3

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THE PROBLEM

Monitoring at home fails exactly where it is needed most. Cameras raise privacy concerns, are not accepted in bedrooms, and stop working in the dark — when falls and emergencies happen. Wearables must be worn, charged, and remembered; elderly people and patients are the ones who take them off. By 2030, 1 in 6 people worldwide will be 60 or older [1].

works in the dark | **nothing on the body** | **runs continuously**

HOW IT WORKS

The body is mostly water → it reflects Wi-Fi signals → **channel state information (CSI)** records the change — per subcarrier, per packet.

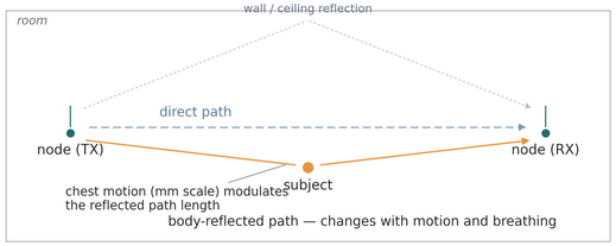


Fig. 1 — A person reshapes the paths Wi-Fi takes through a room; CSI records it.

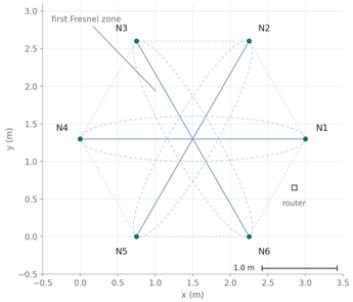
No image exists. The data records how the room treated a radio signal — never what the room looks like.

THE QUESTION

How much sensing capability survives when the hardware is the cheapest available and the room is an ordinary, uncontrolled space?

Six $5 ESP32-S3 boards in a hexagon, an open-plan office, transparent statistics — **no camera, no wearable, no trained model.**

METHODS



6 × ESP32-S3 ($5 each), RuView esp32-csi-node firmware [6], power-bank powered.

Isolated 2.4 GHz WPA2, channel 5, HT20; no third-party traffic, no data leaves the room.

50 pings/s per node to the router generate CSI; raw I/Q of all 128 subcarriers streams over UDP to a wired PC.

Fig. 2 — Six sensors, three sensing lines: opposite pairs (1–4, 2–5, 3–6) cross at the centre. Drawn to scale from tape-measured coordinates.

DETECTION METRIC — TRANSPARENT BY DESIGN

Per-subcarrier z-scores against an empty-room reference. A frame's score = fraction of the 52 active subcarriers with z > 3; detection = ratio of the occupied score to the mean of **repeated empty phases** — a single baseline cannot separate detection from drift. **Noise floor validated: theory 0.27%, measured 0.31%.**

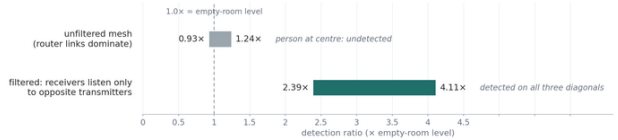


Fig. 3 — A mesh is blind at its own centre until its links are engineered (reported ranges).

12 CLAIMS VERDICTS FROM RAW RECORDINGS

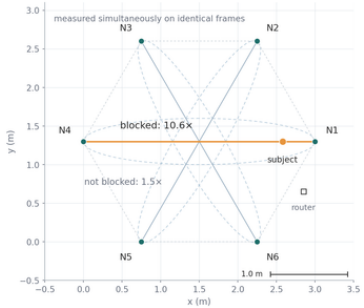
Still person detectable from CSI	CONFIRMED	5.5×, 3 cycles, no class overlap
Detection resets after subject leaves	CONFIRMED	3 empty phases return to baseline
Motion outscores static presence	CONFIRMED	13.2× vs 9.0× on the same node
Response falls with distance	CONFIRMED	2.20× (0 m) → 1.13× (3.0 m)
Position readable from link geometry	CONFIRMED	7:1 crossed vs uncrossed, simultaneous
Node–node links usable unfiltered	REFUTED	centre missed: 0.93–1.24×
Breathing recoverable here	NOT DEMONSTRATED	3 attempts, 2 quantities, all negative
Four positions distinguishable	PARTIAL	2 of 3 correct; closing control failed
Node placement limited the results	REFUTED	hexagon at GDOP floor, 99.97% of ideal
Tail statistic beats shipped variance	CONFIRMED	10.6× vs 1.26×, identical frames
Built-in presence output informative	REFUTED	"present" 100% of ticks — empty included
Link phase stable enough to baseline	REFUTED	>30° drift in a static empty room

RESULTS

5.5×
still person vs empty room — zero overlap across 3 cycles

7 : 1
the line you stand on vs a distant line, simultaneously

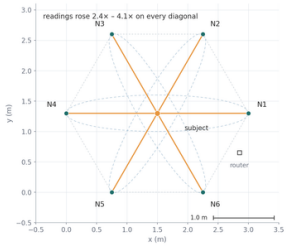
10.6× vs 1.26×
our transparent statistic vs the framework's variance feature



Where you stand is written in which line reacts. Subject beside node 1: the crossed diagonal rose to 10.57× baseline while the farthest line sat at 1.48× — a 7:1 contrast on identical frames, from geometry alone.

Motion outscores stillness (13.2× vs 9.0×), and response fades with distance: 2.20× at 0 m → 1.13× at 3.0 m.

Fig. 4 — Standing beside one sensor: the blocked line announces the position.



Blind until engineered. Unfiltered, the mesh missed a person at its own centre (0.93–1.24×): every node's CSI was dominated by its router link. Filtering receivers to opposite transmitters recovered the centre on all 3 diagonals (2.39–4.11×).

Breathing: not recovered — cause measured. No amplitude peak (chest motion shifts timing, not strength); phase shows a ~7.5 BPM artifact even in an empty room. Measured: link phase drifts >30° with nobody present — larger than breathing's shift. 3 attempts, reported in full.

Fig. 5 — Standing in the centre touches all three sensing lines at once.

TWO DESIGN REQUIREMENTS

1. A mesh senses only the links it is deliberately configured to form — router traffic masks the node-to-node paths until receivers are filtered to their opposite transmitters.

2. The uncorrected link phase is too unstable for vital signs — correcting >30° idle drift must come before any breathing attempt.

Future Work

Phase correction first — then repeat the four-position test with an intact closing control, validate across subjects, days, and rooms, and record all links simultaneously by adding the transmitter's identity to the frame format.

REFERENCES

[1] WHO, "Ageing and health," 2024. [2] L.-H. Shen et al., "Time-Selective RNN for Device-Free Multiroom Human Presence Detection Using WiFi CSI," IEEE Trans. Instrum. Meas., vol. 73, 2024. [3] Wi-Fi Alliance, "Wi-Fi momentum in 2025," 2025.
[4] Y. Ma, G. Zhou, S. Wang, "WiFi Sensing with Channel State Information," ACM Computing Surveys 52(3), 2019. [5] Espressif, "ESP-CSI," github.com/espressif/esp-csi, 2023. [6] ruvnet, "RuView," github.com/ruvnet/RuView, 2025.