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Technical Perspective
Is Your WiFi a Sensor?

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THE TITANIC DISASTER in 1912 prompted the first patent in echo-location, where sound waves would be sent under water to detect the presence of objects. Through the next decade, the technology matured into what was called SONAR in 1930, an acronym for SOund Navigation And Ranging. At the peak of World War II in 1940, in-air technologies matured fully into what the U.S. Navy called RADAR, or RAdio Direction And Ranging. The core principle in all of them is intuitive—detecting the presence and movement of objects by transmitting a signal toward them and analyzing their reflections.

Of course, these "objects" evolved through the course of history, starting from icebergs, submarines, and airplanes, to clouds, tornados, and weather conditions, to today's images of the urban environment from self-driving cars. In this evolving timeline, the next "object" is likely to be humans; and the next RADAR-capable device may already be in your home: your WiFi base station.

A number of research groups in academia and industry are exploring the possibility of sensing humans through WiFi signals. The core vision was seeded by a challenge paper in ACM MobiCom,[5] where authors envisioned device-free localization. Said differently, could the WiFi base station transmit a carefully designed signal, gather the various signal components that bounce off the surroundings (including humans), and infer the location of one or many users? Since humans impact the attenuation and reflections of these signals—called multipath—the challenge was essentially around careful multipath disentanglement.

Clusters of ideas emerged. Patwari et. al.[4] and others instrumented the environment with multiple transmitters and receivers and constructed a 3D lattice of wireless links, somewhat similar to criss-cross laser beams. As humans moved through this wireless environment, they "cut through" different subsets of links, revealing their locations. Progress accelerated and, with multiple antennas attached to a single device, projects like WiSee[3] and WiTrack[1] began presenting credible solutions. WiSee was able to send signals from outside a room and track simple movements of a human; WiTrack demonstrated how human hand gestures can be decoded from signal perturbations. With greater push, the techniques were becoming amenable to practical off-the-shelf devices.

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One may wonder why RADAR technologies are not directly applied to this problem. The challenges were threefold: (1) RADAR had mostly catered to open-space outdoor applications; indoor multipath, on the other hand, is significantly more complex, especially when it came to "localizing" the object. (2) The large size of metal planes, tornadoes, and buildings produced strong reflections, while their movements left discernible residues in Doppler Shifts. Human-sized objects, and their interaction with 2.4GHz signal wavelengths, called for new approaches. (3) Finally, the antennas in many RADAR solutions were large, often offering the ability to rotate. With indoor WiFi systems, the limited antenna array needed different solutions as well.

At this time, a non-trivial jump emerged when Adib et. al. showed the feasibility of measuring a baby's breathing and average heartrate.[2] At a high level, the movement of the chest during the act of breathing alters the reflections enough that it could be sensed and (heart-rate) counted with consistency. Other movements in the environment would obviously pollute such sensing, however, the rhythmic frequency of breathing is amenable to signal isolation. Moreover, since the breathing rate is related to the average heart rate, it was becoming possible to approximate an ECG device.

The natural next step was to count the heartrate precisely. It is against this backdrop that the following paper made another leap in the ability to zoom into human micro-motions. Adib et. al. shows that not only can the heartrate be counted with accuracy comparable to ECG devices, but the variabilities of the heart signals—in each pulse—can be recognized as well. The implications are exciting—various emotions, such as happiness, excitement, sadness, manifest themselves into heartbeat patterns that in turn become visible in the ECG output. This paper reveals how these minute patterns of the heart, buried in the breathing action of the individual, and further buried in all the environmental dynamism, can be extracted consistently, such that a simple classifier can predict the user's emotion. Yes, you read it right; tomorrow's smart-home may indeed turn down the lights and play a soft country song when you are back home, because your WiFi base station may automatically sense that you are tired and glum. Let me stand no more in your way to reading this paper.

References

1. Adib, F., Kabelac, Z., Katabi, D. and Miller, R.C. 3D tracking via body radio reflections. In *11th USENIX Symp. Networked Syst. Design and Implement.* (2014), 317–329.
2. Adib, F., Mao, H., Kabelac, Z., Katabi, D. and Miller, R.C. Smart homes that monitor breathing and heart rate. *CHI* (2015).
3. Pu, Q., Gupta, S., Gollakota, S. and Patel, S. Whole-home gesture recognition using wireless signals. In *Proceedings of the 19th Annual Intern. Conf. Mobile Comput. & Netwk.* (2013), ACM, 27–38.
4. Wilson, J. and Patwari, N. Demo abstract: Radio tomographic imaging. MobiCom (2008).
5. Youssef, M., Mah, M. and Agrawala, A. Challenges: Device-free passive localization for wireless environments. MobiCom (2007).

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