WANTED

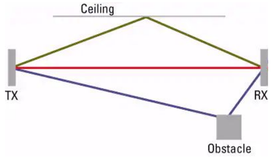
Practical, efficient sensor systems to solve real-world problems

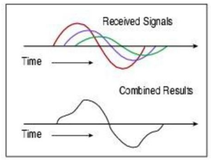
Practical sensor systems are:

- Accurate
- Accessible and affordable
- Usable and maintainable

Wireless sensing is challenging!

- Indoors: multipath, interference
- Outdoors: rugged environments and limited infrastructure





Multipath interference, which is common indoors, leads to signal distortion at the receiver.
image courtesy of Cisco Inc.

Saving power with RF backscatter

RF backscatter is the scattering of radiation or particles back towards the source. *Examples:*

- Radar/lidar
- WiFi-based [1]
- RFID

➢ Modulating backscatter is a form of *passive communication.*

Avantages:

- Orders of magnitude power savings over active radios (WiFi, etc.)
- Cheap to implement

Disadvantages:

- Low signal strength, limited range

The backscatter transmitter emits an excitation signal, the backscatter tag reflects it and modulates data.

Sensing with RF

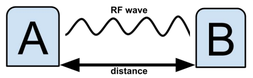
RF for communicating pairs sensors w/ wireless comm chip

- Wireless camera, e.g. BackCam [2]
- Environmental sensing, e.g. Permamote [3]

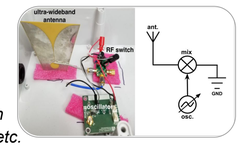
In contrast, **RF sensing** uses phase and amplitude of wireless signals

- Localization (e.g. GPS)
- Respiration monitoring [4]
- Soil moisture and EC [5,6]

In RF sensing, backscatter tags are a middle-ground between active radios and device-free sensing.



Time of Flight (ToF): *RF propagation time between two points. Used to infer range, dielectric permittivity, etc.*



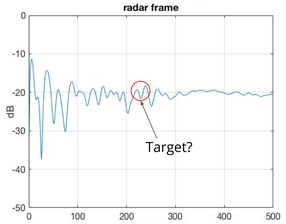
A simple backscatter tag (right) is easy to prototype and cheap to mass produce.

Design

Key idea: pair backscatter tags with UWB radios (e.g. radar)

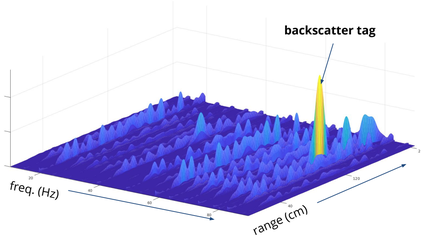
Target detection is identifying the target correctly, despite clutter.

Target identification is the ability to label a target correctly when multiple targets are in the environment

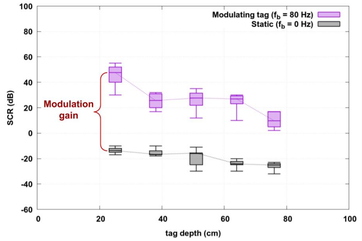


Clutter causes the target (located in bin 230) to be effectively invisible.

Combating clutter with modulation:
Simplest modulation toggles tag ant. between max and min impedance.
Varying modulation parameters can help uniquely identify the tag target.



Range-Doppler plot of FFT'd radar capture. If the tag is oscillating at a constant rate, we see a bright peak corresponding to the fundamental frequency.

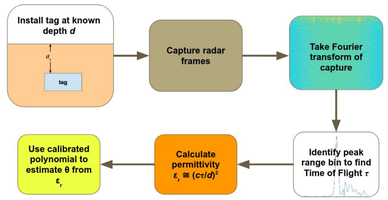


An oscillating tag has orders of magnitude gain compared to a non-oscillating target

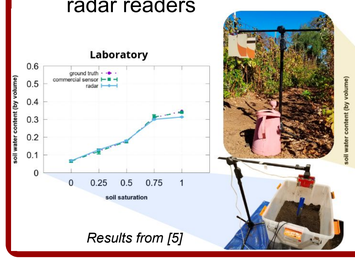
Applications

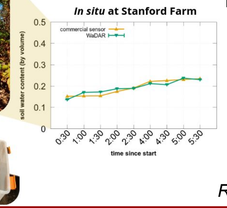
Measuring soil moisture: RF travels slower in wet soil; ToF strongly correlated w/ moisture.

- Completely wireless
- High accuracy (within 1.4% of ground truth, vs 1.3% for commercial sensor)
- Scale using one (or a few) mobile radar readers



Overview of our algorithm to measure soil moisture with high accuracy.

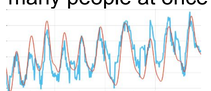




Results from [5]

Further applications:

- Localization
- Monitoring vitals of many people at once

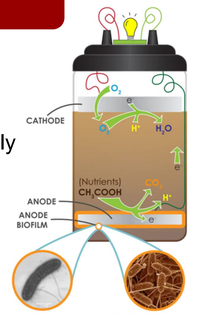


Respiration rate proof-of-concept

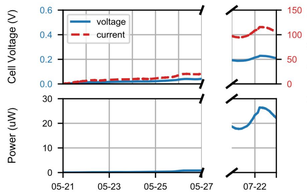
Current and future work

Harnessing the power of dirt

- Microbial fuel cells (MFCs) harvest power from electrogenic microbes naturally occuring in soil
- Well-known in civil engineering and biology, but relatively unstudied in EE and sensing communities.
- Our preliminary study suggests it would be possible to power a revised backscatter tag design with MFCs
- Leading a cross-institutional collaboration to deploy 16 fuel cells for long-term study across multiple locations



Courtesy of MFC Guy (2010)



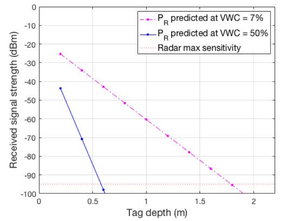
Early results showing that our MFC harvested up to 25uW [7].

Sensor fusion

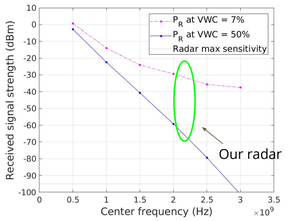
- Microbial power output reacts to conditions like soil moisture, nutrient levels and temperature.
- Modify backscatter modulation to also convey battery stats
- Can we infer more complex properties (e.g nitrate levels) from combined data?

Discussion and conclusions

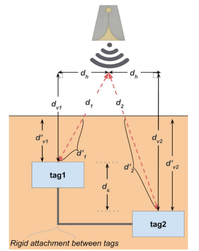
Link Budgets can help other researchers re-use our design with other equipment or environments.



Signal strength as tag depth varies, radar height fixed at 1m.



Signal strength as center frequency varies. Our radar has f_c = 2 Ghz.



Example of using relative ToF for soil moisture

- In some circumstances, relative ToF between two tags may be more useful.
- Ideas presented here won't work for all scenarios; networks are too heterogeneous. Instead, they should be added to our growing toolbox.
- Results are promising, but long-term follow-up studies needed for specific applications (e.g. moisture sensing reliability and scaling).

Sources

[1] Zhang, P.; **Josephson, C.**; Bharadia, D. & Katti, S. Freerider: Backscatter Communication Using Commodity Radios. Proceedings of the 13th International Conference on Emerging Networking EXperiments and Technologies, ACM, 2017, 389-401

[2] **Josephson, C.**; Yang, L.; Zhang, P. & Katti, S. Wireless computer vision using commodity radios.Proceedings of the 18th International Conference on Information Processing in Sensor Networks, ACM, 2019

[3] Jackson, N.; Adkins, J.; Dutta, P.; Capacity over capacitance for reliable energy harvesting sensors. In Proceedings of the 18th International Conference on Information Processing in Sensor Networks (IPSN '19). Association for Computing Machinery.

[4] Adib, F.; Mao, H.; Kabelac, Z.; Katabi, D. & Miller, R. C. Smart Homes that Monitor Breathing and Heart Rate. Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI '15,

[5] **Josephson, C.**; Barnhart, B.; Katti, S.; Winstein, K; Chandra, R. Time-of-flight soil moisture estimation using RF backscatter tags. IEEE International Geoscience and Remote Sensing Symposium (2020)

[6] Ding, J.; Chandra, R.; Towards Low Cost Soil Sensing Using Wi-Fi. The 25th Annual International Conference on Mobile Computing and Networking - MobiCom '19, ACM Press, 2019

[7] **Josephson, C.**; Jackson, N., Panutto, P.; Farming Electrons: Galvanic vs. Microbial Energy in Soil Batteries. Submitted '20

Acknowledgements: *I thank Alex Konings (Stanford Earth), Scott Fendorf (Stanford Earth), the staff of the Stanford Educational Farm, Kenny Green (Packard Building Manager), as well as George Wells (Northwestern University) and Kristian Lukas Dubrowski (University of BC).*