Demo Abstract: RF Soil Moisture Sensing via Radar Backscatter Tags

Colleen Josephson
Stanford University
cajoseph@stanford.edu

Bradley Barnhart
Stanford University
bbarnhart@stanford.edu

Sachin Katti
Stanford University
skatti@cs.stanford.edu

Keith Winstein
Stanford University
keithw@cs.stanford.edu

Ranveer Chandra
Microsoft
ranveer@microsoft.com

ABSTRACT

We present a sensing system that determines soil moisture via RF using backscatter tags paired with a commodity ultra-wideband RF transceiver. Despite decades of research confirming the benefits, soil moisture sensors are still not widely adopted on working farms for three key reasons: the high cost of sensors, the difficulty of deploying and maintaining these sensors, and the lack of reliable internet access in rural areas. We seek to address some of these obstacles by designing a low-cost soil moisture sensing system that uses a hybrid approach of pairing completely wireless backscatter tags with a mobile reader.

We designed and built a backscatter tag prototype and tested our system both in laboratory and *in situ* at an organic farm field. Our backscatter tag has a projected battery lifetime of up to 15 years on 4×AA batteries, and can operate at a depth of at least 30cm and up to 75cm. It achieves an average accuracy within 0.01-0.03cm^3/cm^3 of the ground truth with a 90th percentile of $0.034cm^3/cm^3$, which is comparable to state-of-the-art commercial soil sensors, at an order of magnitude lower cost.

1 INTRODUCTION

Agriculture is the single largest pressure on the world's sources of fresh water— 69% of the global fresh water supply is used for agriculture [1]. Paired with the fact that the global population is projected to exceed 9 billion by 2050 [5] with most of that growth coming from developing nations in Africa and Asia, conservation of fresh water and sufficient food production are key concerns that need to be addressed for future generations. Soil moisture is the most important measurement for ensuring the maximization of crop yield without water waste. Yet fewer than 10% of irrigated crops in the United States use moisture sensors [3]. The lack of widespread adoption can be attributed to three key challenges: 1.) high sensor cost 2.) difficulty of deploying and maintaining the sensors and 3.) difficulty collecting and processing the sensor data.

The current model of sensor networks on farms is to install specific sensor devices that are connected to a power source and a data logger. The data logger often has a communication module that sends data either over a cellular network, or uses a locally-deployed communication network like LoRa [6] or TV whitespace networks [9]. The sensors often need to be removed and re-installed every growing season, since the wires interfere with farming equipment. Setting up and maintaining these networks is labor-intensive and expensive. Even for sparse deployments, benefits exceed the costs only a third of the time in the US [7]. Soil moisture sensing is even more infeasible for smallholder farmers in developing nations with the most food and water insecurity.

In contrast to the networked sensor model used on farms, geophysicists and remote sensing experts use a centralized approach. Ground penetrating radar (GPR) is used to measure soil moisture completely wirelessly, eliminating the need for deploying underground equipment. The signal strength and propagation speed of an RF wave is impacted by the media it travels though. RF travels 2-6 times more slowly in soil than air [4], and the speed and signal strength decrease as moisture content increases. Radars allow us to very accurately measure these changes to RF waves. The drawback is that the radars used in these studies are either deployed in satellites [2] whose data do not provide the necessary resolution, or use bulky terrestrial radars that require contact (or very close proximity) with the ground [8] and have limited depth and accuracy compared to wired sensors.

Taking inspiration from both the sensor network and remote sensing approaches, we propose a hybrid technique. Instead of using radar alone, we pair the radar with completely wireless underground backscatter tags. Unlike traditional backscatter tags, these tags do not have any additional sensors attached to them whose measurements need to be communicated. Instead they provide a known reference point in the ground and increase the strength of the signal returning to the radar. This allows us to measure soil moisture with RF using a significantly cheaper and more portable radar than traditional terrestrial GPRs. In the future this radar reader could even be integrated with farm equipment, drone or mobile phone.

2 BACKSCATTER TAG

There are no off-the-shelf backscatter tags designed for radar, so we built our own prototype (see Fig. 1a). UWB radars have a wide bandwidth to facilitate accurate ToF measurements, but they are required to transmit at low power to avoid causing interference. This means the incoming RF is far too quiet for power harvesting with a passive tag. Instead, we implemented a semi-passive tag with a very simple design consisting of a UWB Vivaldi antenna, an RF switch and an 80 Hz oscillator. The tag lasts 15 years on 4×AA batteries. A waterproof case creates an air pocket around the antenna, which acts as a radome and ensures proper impedance matching, as direct contact with soil could cause a mismatch.

The advantage of using an oscillating backscatter tag instead of a simple static reflector (e.g., a piece of metal) is that it allows us

978-1-7281-5497-8/20/$31.00 ©2020 IEEE
DOI 10.1109/IPSN48710.2020.000-4

(a) Tag prototype has only three components **(b) Setup for laboratory experiments** **(c) Screenshot of demo software**

Figure 1: Equipment and software to be used in our soil moisture sensing demo

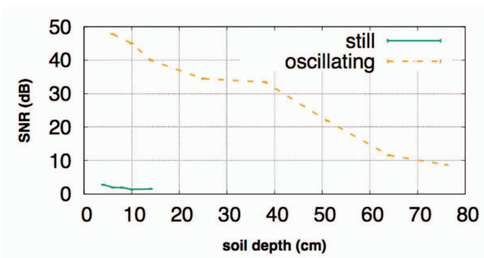

Figure 2: The significant SNR gain of oscillating tags over static

to very effectively eliminate clutter from the surrounding dirt. This allows us to operate at depths of at least 30cm and up to 75cm.

3 SIGNAL PROCESSING

Underground, the tag is one reflector among many, such as particles of dirt and rock. To isolate reflections that are coming from the tag, we use a clutter removal technique that treats only objects that are oscillating at specific frequencies as a target. All other reflections are considered clutter. The tag is extremely likely to be the only object oscillating at 80 Hz: roots grow and water seeps, but at slow speeds. This technique yields significant gain in SNR (see Fig. 2).

4 DEMO EXPERIENCE

To demonstrate our system, we will be doing live soil moisture measurements. The setup will be similar to Fig. 1b. On a screen we will display the MATLAB program (see Fig. 1c) that runs our measurement algorithm in real-time.

One challenge is that once dirt is wet, it takes a long time to dry. Therefore we plan to have multiple boxes of dirt pre-moistened to different levels. The demo audience then will move the radar over the various bins of dirt to see how the measurement changes.

Additionally, to simulate irrigation, we plan to do a periodic live demo where one of the authors pours water onto the dirt and the audience can see the measurement change on the screen. We will repeat this process approximately once every 30 minutes, making an announcement so people can come back to see the it if they wish. Spacing out the waterings is necessary to ensure that the soil doesn't become saturated with water before the end of the demo session.

REFERENCES

[1] Aquastat. 2014. Water withdrawal by sector. http://www.globalagriculture.org/fileadmin/files/weltagrarbericht/AquastatWithdrawal2014.pdf.

[2] Ali Fares, Marouane Temimi, Kelly Morgan, and Thijs J. Kelleners. 2013. In-Situ and Remote Soil Moisture Sensing Technologies for Vadose Zone Hydrology. *Vadose Zone Journal* 12, 2 (2013), 0. https://doi.org/10.2136/vzj2013.03.0058

[3] Aaron Hrozencik. 2019. Irrigation & Water Use. *United States Department of Agriculture Economic Research Service* (2019).

[4] Harry Jol. 2008. *Ground Penetrating Radar Theory and Applications*. Elsevier Science.

[5] United Nations Department of Economic and Social Affairs. 2017. World Population Prospects: The 2017 Revision, Key Findings and Advance Tables. https://population.un.org/wpp/Publications/Files/WPP2017_KeyFindings.pdf.

[6] Usman Raza, Parag Kulkarni, and Mahesh Sooriyabandara. 2016. Low Power Wide Area Networks: A Survey. *CoRR* abs/1606.07360 (2016). arXiv:1606.07360 http://arxiv.org/abs/1606.07360

[7] David Schimmelpfennig. 2016. Farm Profits and Adoption of Precision Agriculture. *Economic Research Service/USDA* (2016).

[8] Omer Shamir, Naftaly Goldshleger, Uri Basson, and Moshe Reshef. 2018. Laboratory Measurements of Subsurface Spatial Moisture Content by Ground-Penetrating Radar (GPR) Diffraction and Reflection Imaging of Agricultural Soils. *Remote Sensing* 10, 10 (oct 2018), 1667. https://doi.org/10.3390/rs10101667

[9] Deepak Vasisht, Zerina Kapetanovic, Jong-ho Won, Xinxin Jin, Ranveer Chandra, Ashish Kapoor, Sudipta N. Sinha, Madhusudhan Sudarshan, and Sean Stratman. 2017. Farmbeats: An IoT Platform for Data-driven Agriculture. In *Proceedings of the 14th USENIX Conference on Networked Systems Design and Implementation (NSDI'17)*. USENIX Association, Berkeley, CA, USA, 515–528. http://dl.acm.org/citation.cfm?id=3154630.3154673