# (SD2025-068) Low-Cost, Scalable Passive Sensors: a battery-free wireless general sensor interface platform

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## ABSTRACT

Researchers from UC San Diego present a fully-passive, miniaturized, flexible form factor sensor interface titled ZenseTag that uses minimal electronics to read and communicate analog sensor data, directly at radio frequencies (RF). The technology exploits the fundamental principle of resonance, where a sensor's terminal impedance becomes most sensitive to the measured stimulus at its resonant frequency. This enables ZenseTag to read out the sensor variation using only energy harvested from wireless signals.

UCSD inventors further demonstrate its implementation with a 15x10mm flexible PCB that connects sensors to a printed antenna and passive RFID ICs, enabling near real-time readout through a performant GUI-enabled software. They showcase ZenseTag's versatility by interfacing commercial force, soil moisture and photodiode sensors.



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## OTHER INFORMATION


### KEYWORDS

Sensors and actuators, Sensor devices and platforms, Wireless devices, Sensor applications and deployments

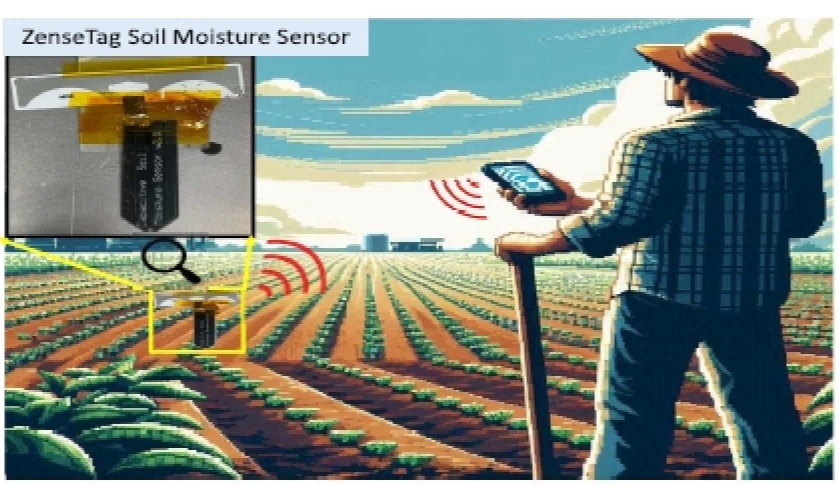

### CATEGORIZED AS

- **Communications**
  - Wireless
- **Sensors & Instrumentation**
  - Environmental Sensors
  - Other

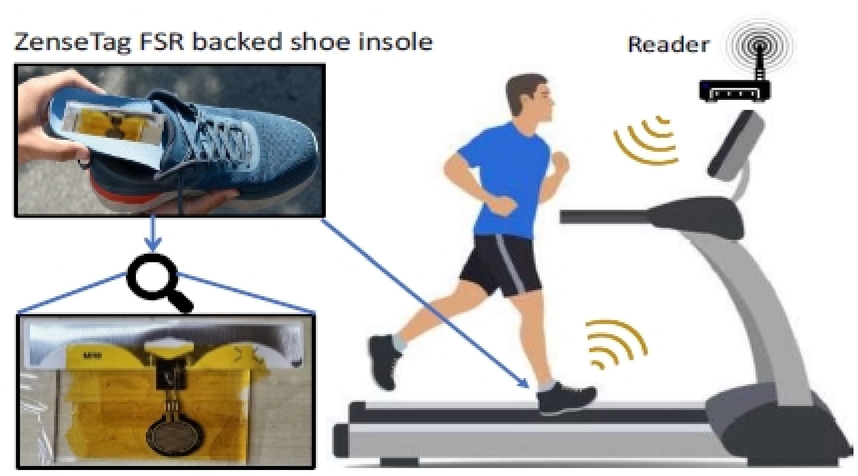
### RELATED CASES

2021-Z08-1

## TECHNOLOGY DESCRIPTION



(a) Battery-free Soil moisture sensing in Farms (AI-generated image)



(b) Battery-free wearable shoe-insole based force sensing.

Sensors enable us to digitally capture stimuli like moisture, light, and force. Despite their low cost, reliability, and scalability, the lack of widespread adoption ofIoT has hindered the realization of true ubiquitous sensing. A likely reason is that the current sensor platforms are bulky due to the batteries and complex electronics needed to interface sensors communication systems.

This patent-pending invention teaches how to interface any commercial sensor with RFID reader to enable passive sensing, while also addressing the problem of signal corruption by channel multipath. The inventors validated the hypothesis of true differential sensing using the twin-tag single antenna architecture in a small form factor; also validating the ability of their sensing platform to interface readily with any commercial two-terminal sensor that shows an impedance response at radio-frequencies.

The researchers successfully tested their sensing platforms with commercially sourced capacitive soil moisture sensor, force sensitive resistor, and photodiode. They demonstrated that this method of passive wireless sensing can be deployed in the presence of dynamic environments and can be used to obtain sensor readings in near-real time.

**APPLICATIONS**

**ADVANTAGES**

Improved Analog readout for COTS sensors: We methodically profile the impedance of commercial 2-terminal COTS sensors at RF (902-928 MHz used by RFID systems), accounting for parasitic effects to enable Direct-to-RF Interfacing of COTS Sensors. Furthermore this interfacing technique can be extended to any other RF wireless technology.

More importantly, ZenseTag utilizes the novel concept of impedance-resonance effect exhibited by two-terminal commercial sensors modeled as R-L-C circuits at particular frequencies where they maximally couple the stimulus to the backscatter signal. We demonstrate for the first time, how generic sensors that were hitherto posed as a challenge to work with at RF can be made responsive at the appropriate frequencies using simple passive components.

• Generality of Sensing: We demonstrated that ZenseTag works with three commercial sensors, enabling various applications. This technique can also be applied to any sensor with terminal impedance variation.

• Robust analog sensing with a Miniaturized, Flexible, COTS compatible PCB: ZenseTag interfaces the frequency tuned sensor with two RFID tags using a Twin-Tag SingleAntenna Sensor Interface, such that one tag is modulated with the sensor stimuli, while other is isolated. This is done with just a 15mm x 10mm flexible PCB that connects these three components: sensor and the two RFID tags, to a single printed RFID antenna. The RFID reader then decodes the analog sensor data by comparing the relative channel measurements from the two tags.

• Low-latency RFID reader software: We read the tags using a COTS RFID reader (Impinj Speedway) and an opensource library, SLLURP that can be implemented on any general purpose computing platform. Using a PyQTdesigned GUI, we show near real-time sensor readout, as highlighted in our demo videos for force, soil moisture and light intensity sensing.

• Power Consumption: We highlight that the ZenseTag platform consumes no power beyond what the RFID tags use,

operating solely on RF harvesting from a reader without needing additional energy sources.

## STATE OF DEVELOPMENT

UCSD researchers have presented ZenseTag, a compact, battery-free, wireless sensing platform that can interface commercially available sensors to inexpensive, flexible commercial RFID stickers. Through innovative approaches such as direct-RF interface, sensor resonance tuning and twin-tag-single-antenna interface, ZenseTag achieves superior reliability and accuracy in differential analog sensing of stimuli such as soil moisture, light intensity and contact forces.

## INTELLECTUAL PROPERTY INFO

**The technology is patent pending. UCSD is offering to license rights to companies in a position to commercialize aspects of this technology.**

## RELATED MATERIALS

- Nagarjun Bhat, Agrim Gupta, Ishan Bansal, Harine Govindarajan, Dinesh Bharadia. 2024. ZenseTag: An RFID assisted Twin-Tag Single Antenna COTS Sensor Interface. In ACM Conference on Embedded Networked Sensor Systems (SenSys '24), November 4- 7, 2024, Hangzhou, China. ACM, New York, NY, USA, 15 pages. - 11/05/2024
- UCSD News Release: UC San Diego Researchers Develop Low-Cost, Scalable Passive Sensors (5-Nov-2024) - 11/05/2024

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