ACM MobiSys 2020

Soil Moisture Sensing with RFID

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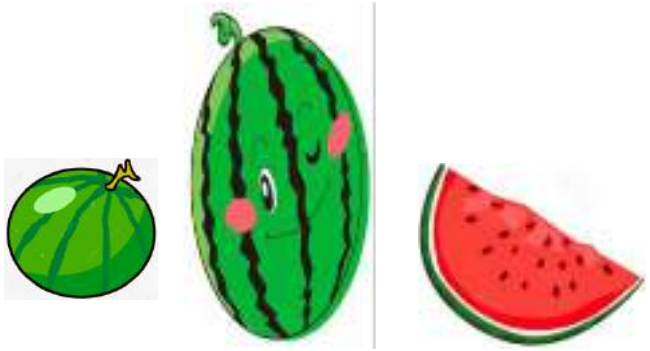
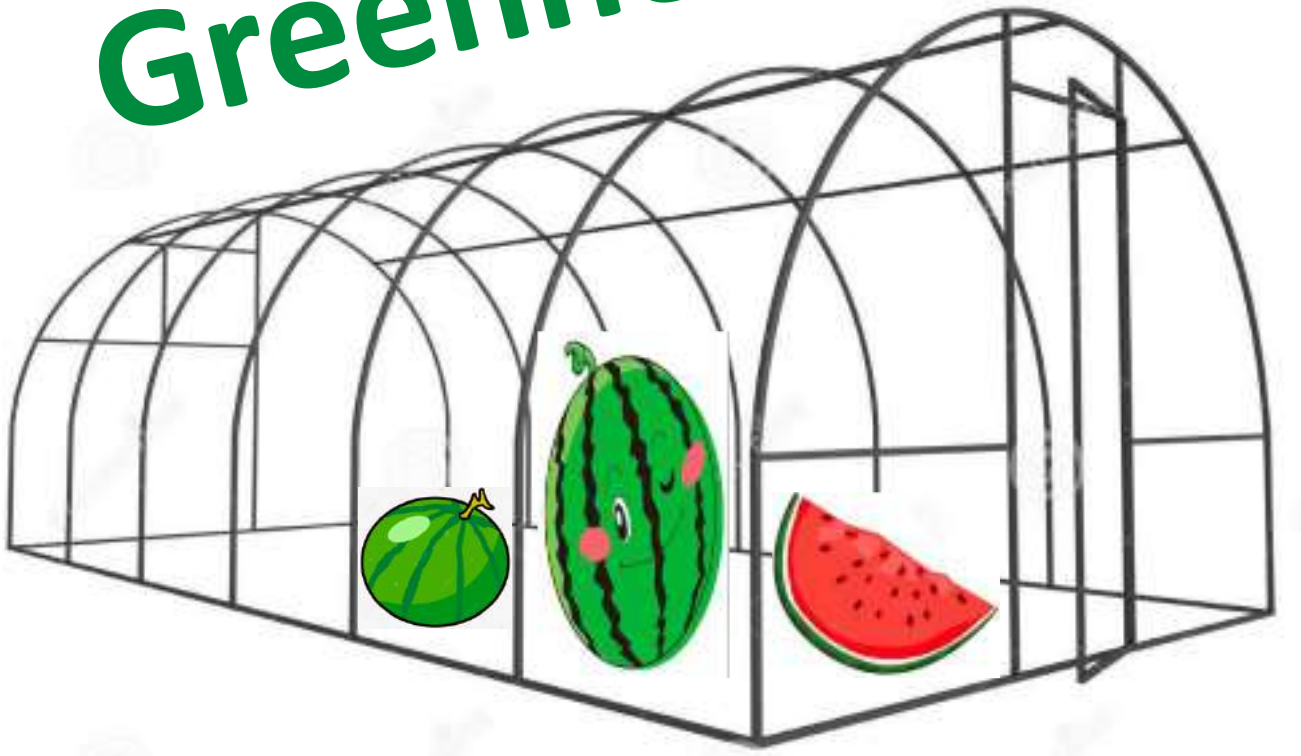
UNIVERSITY OF WATERLOO

ICONLAB.ca



Did you know why we can eat *watermelons* in *winter*?

Greenhouse !



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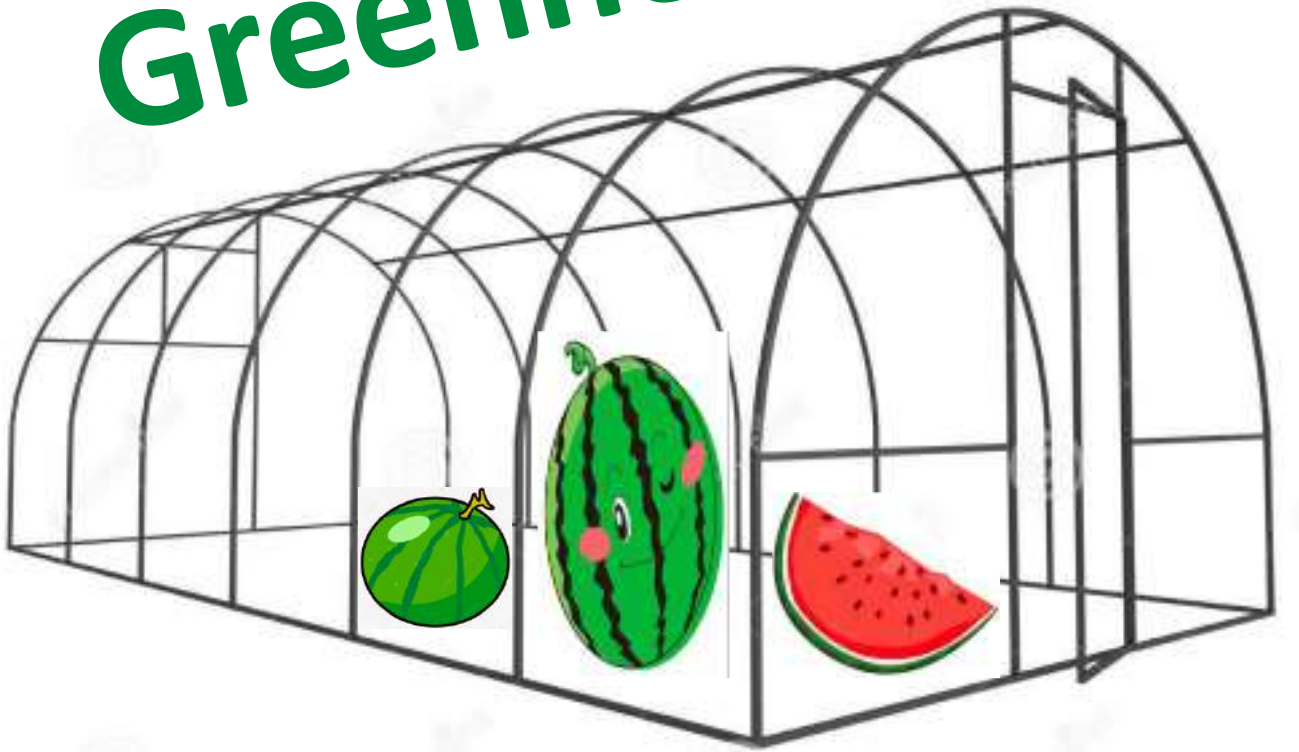

In 2022, the market value of greenhouses will be $1.5 Billion!

A Real-World Greenhouse

Plants grow in pots with soil

> 100K pots in a greenhouse

A Real-World Greenhouse

Sensing soil moisture is important

(keeping plants growing well and saving water)

A Real-World Greenhouse

Challenge: >100K pots, it’s impossible to measure moisture for every pot!

Existing Moisture Sensing Solutions

Estimating the weight of "water" inside a pot by hand

Inaccurate

Time consuming

Using a soil hygrometer

Expensive (>$400)

Time consuming

Using a soil sensor

Expensive (>$160)

Impossible to install it to every pot

Can we have a cheap and accurate soil moisture sensing system for greenhouses?

Our Solution: GreenTag

A low-cost and accurate RFID-based soil moisture sensing system

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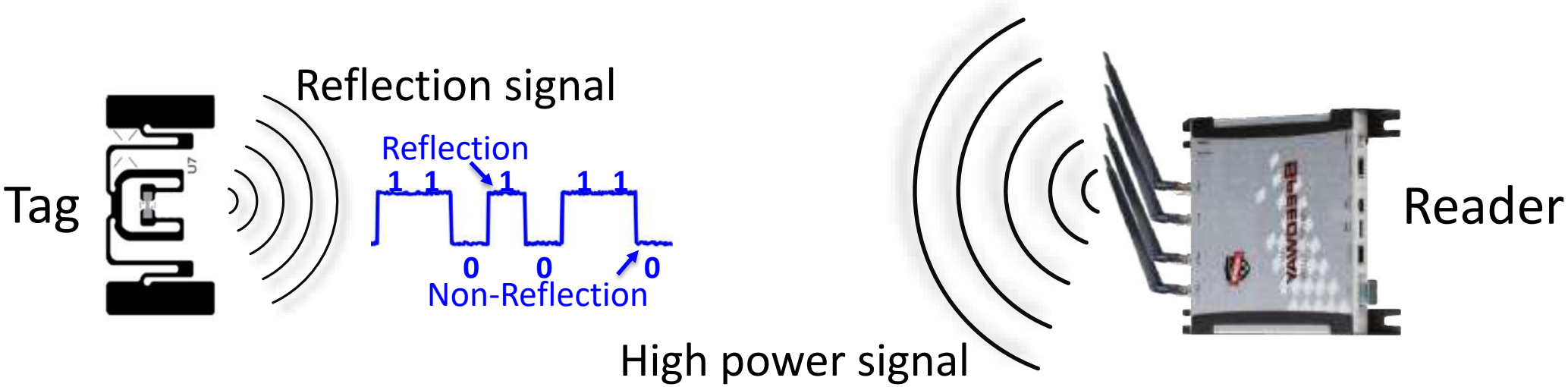
A low-cost and accurate RFID-based soil moisture sensing system

- ***Low cost, battery-free, wireless***:
  - Cheap commodity RFID tags
- ***High accuracy***:
  - Accuracy of GreenTag is comparable with dedicated sensors
- ***Reuse RFID systems***:
  - RFID tags have been used in greenhouses for tracking plants

What are RFIDs

RFID tag: cheap (5 cents), battery-free RF reflector with unique ID.



Received Signal Strength (RSS):

$$R(dB) = 10\log\left[\frac{C}{d^4}P_{tx}\lambda^4\right]$$

Phase:

$$\emptyset = \left(\frac{4\pi}{\lambda}d + C\right) \bmod 2\pi$$

d: tag-to-reader distance. C: related to RF environment and tag's antenna.

Minimum Response Threshold (MRT)

High power signal actives tags.

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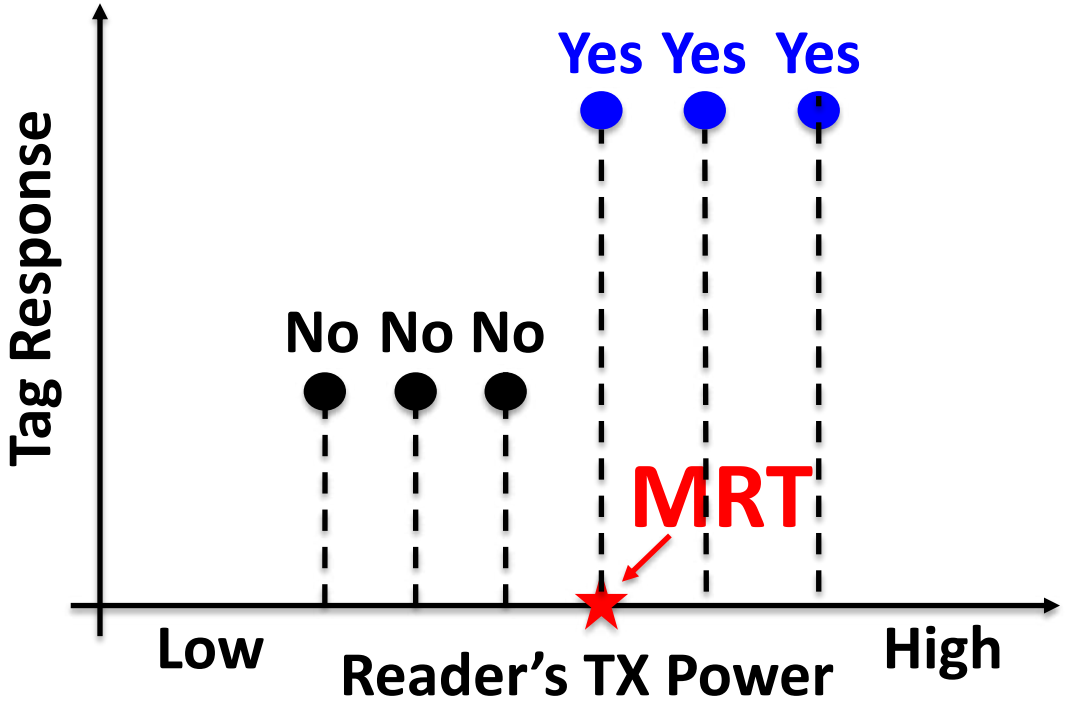


MRT: the required minimum TX power to activate a tag.

Can we use RSS, Phase and MRT of a tag for sensing soil moisture?

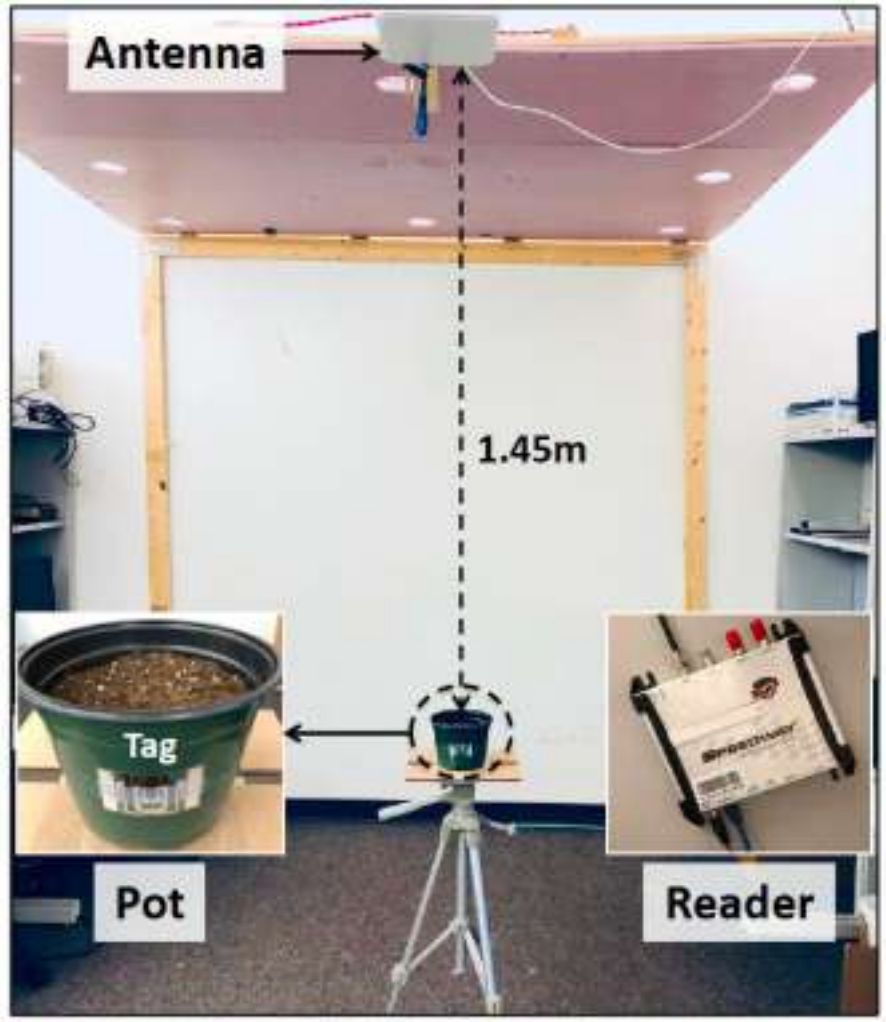
Basic Idea

Setup:

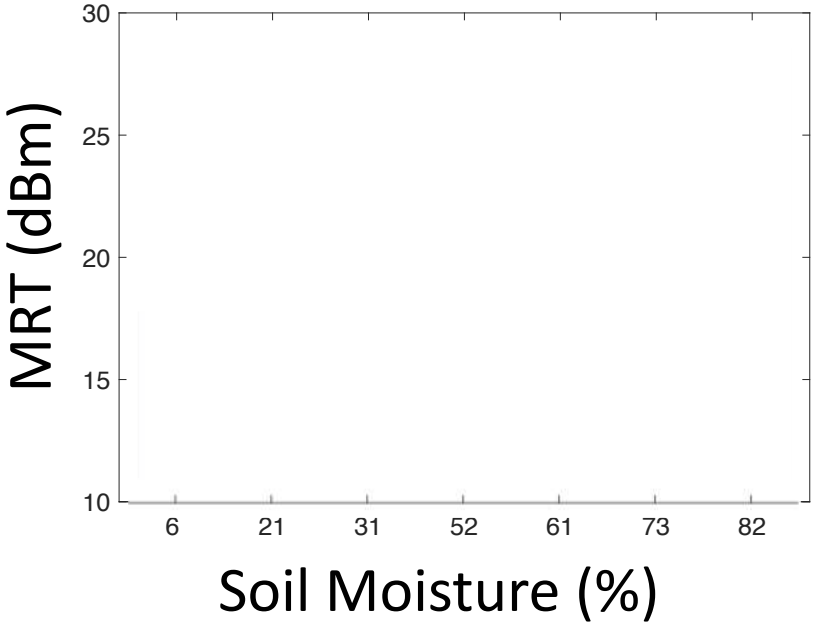
- One RFID tag is attached to the outside of a pot with soil.
- One reader antenna is deployed on the ceiling.

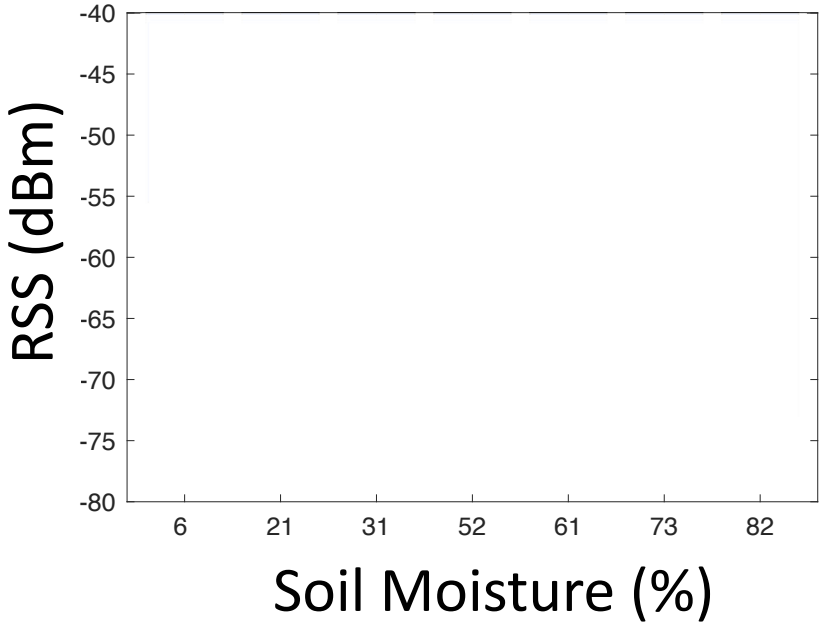
Measurement:

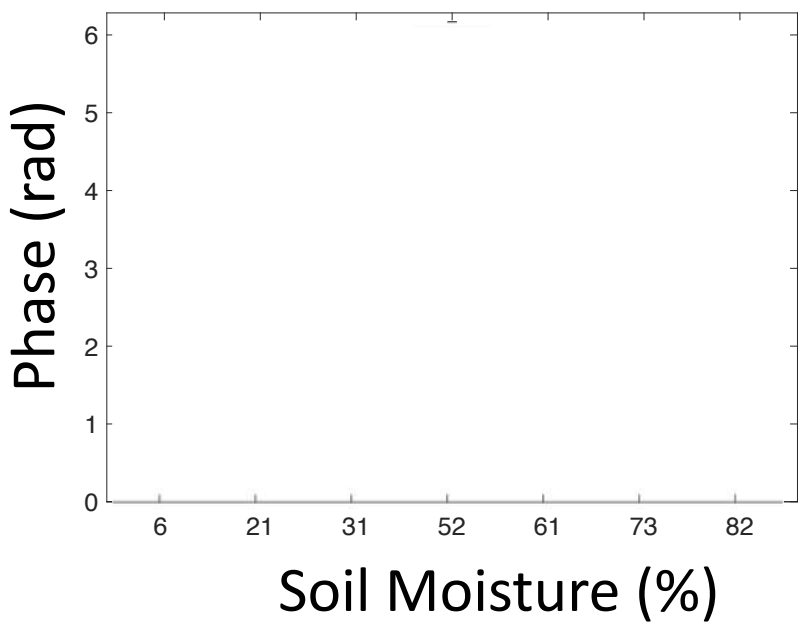
- Changing the soil moisture by adding water.
- Measuring MRT, RSS and phase for each soil moisture level.



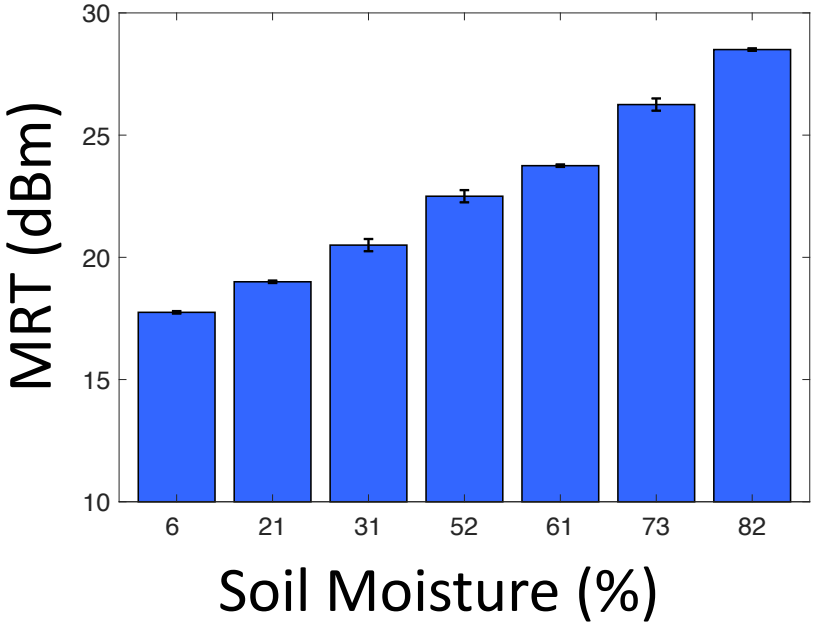
Basic Idea

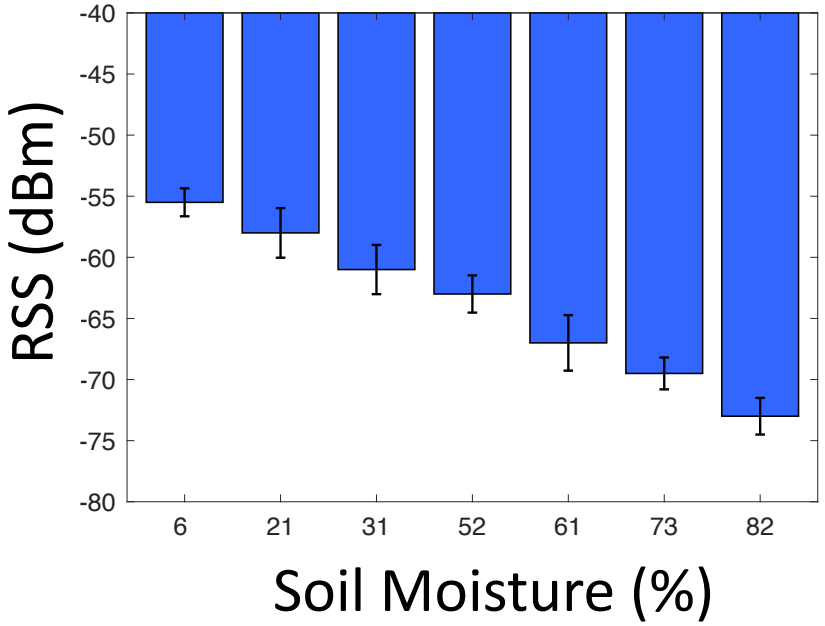

MRT (dBm)
30
25
20
15
10
6
21
31
52
61
73
82
Soil Moisture (%)

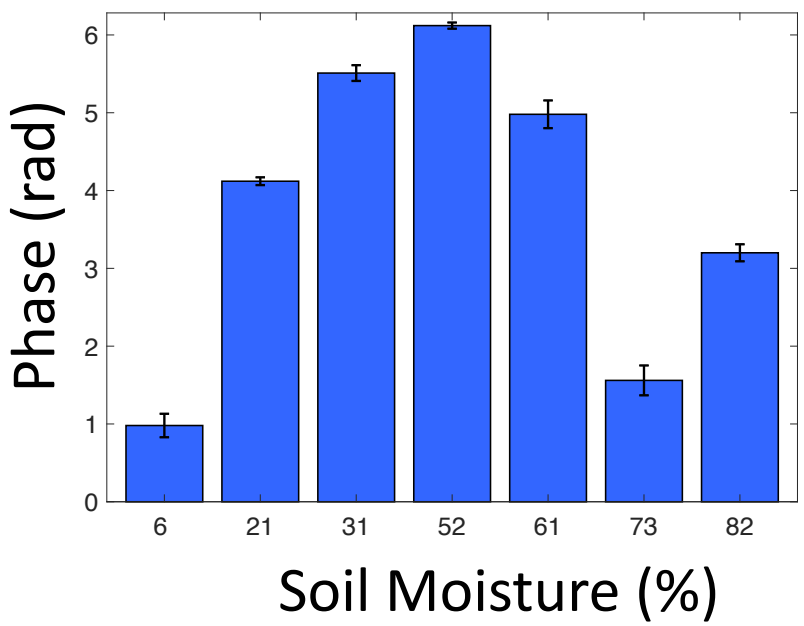

RSS (dBm)
-40
-45
-50
-55
-60
-65
-70
-75
-80
6
21
31
52
61
73
82
Soil Moisture (%)


Phase (rad)
6
5
4
3
2
1
0
6
21
31
52
61
73
82
Soil Moisture (%)

Basic Idea





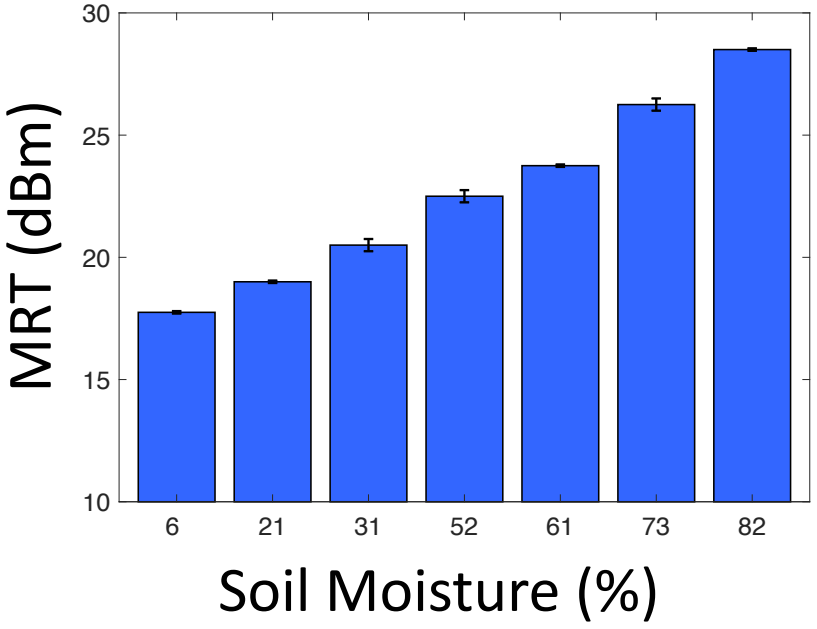


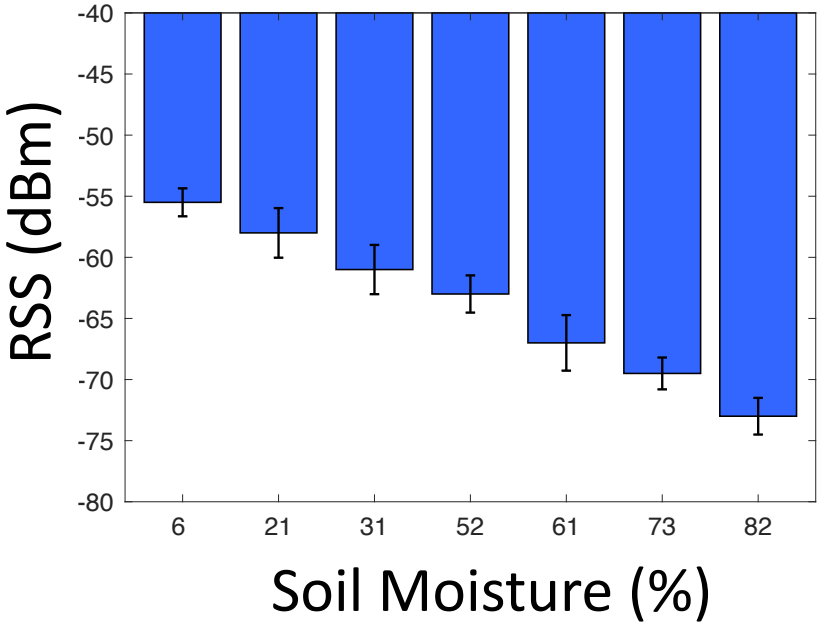
MRT, RSS and phase vary by soil moisture levels.

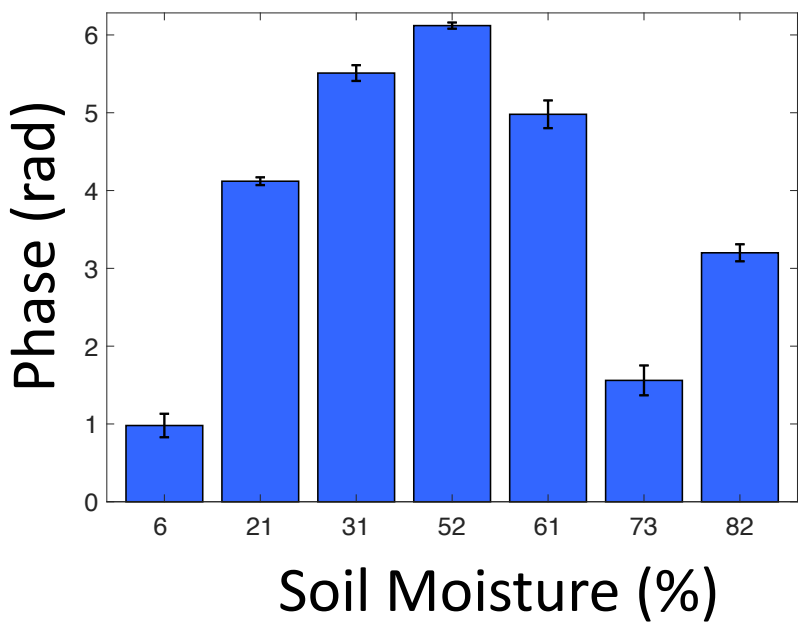
⬇

It's possible to use RFID for soil moisture sensing!

Basic Idea





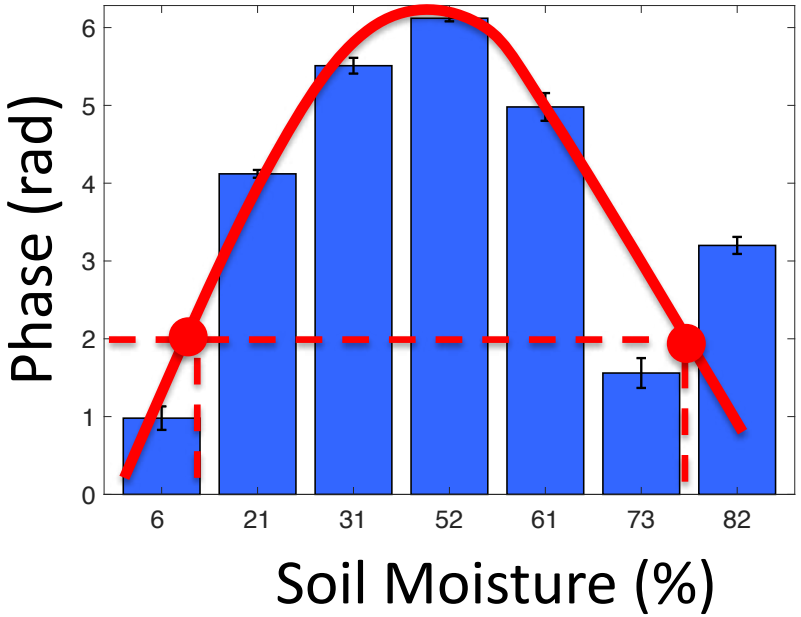


Which signal feature should we use?

Selecting A Robust Signal Feature

- **Don’t use phase**.

-- Two different soil moisture levels may have the same phase value.



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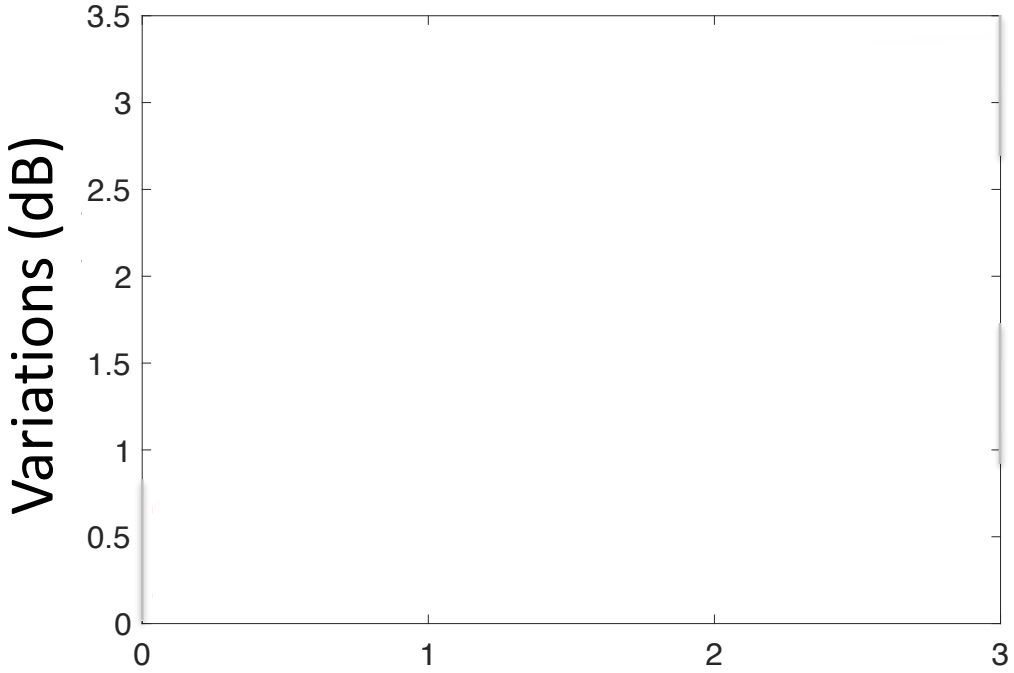

Comparison of variations of RSS and MRT in a dynamic environment

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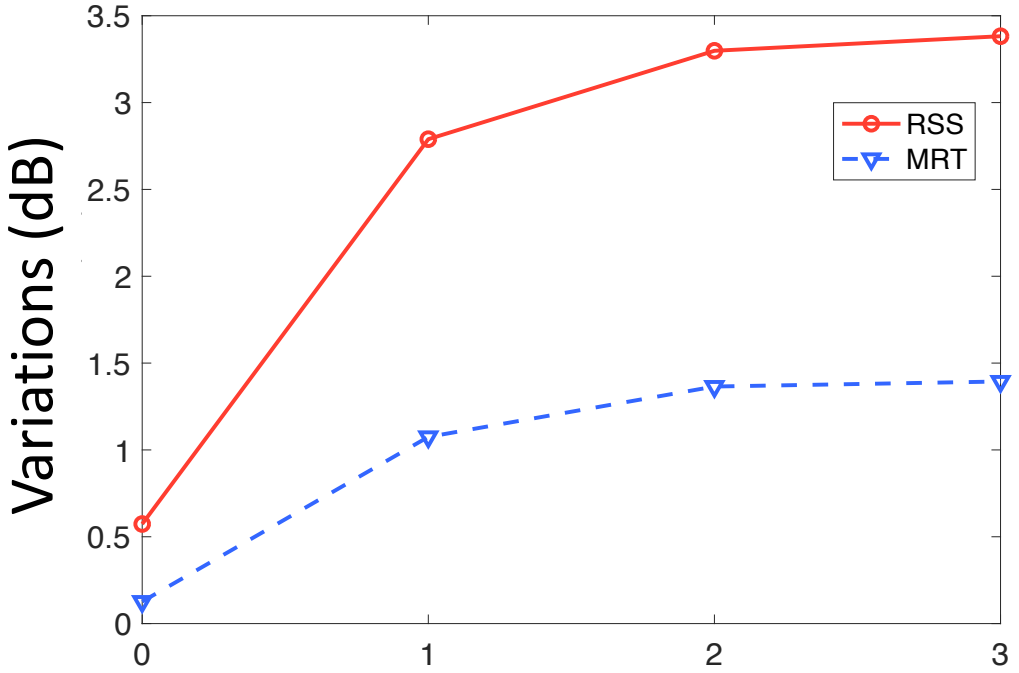

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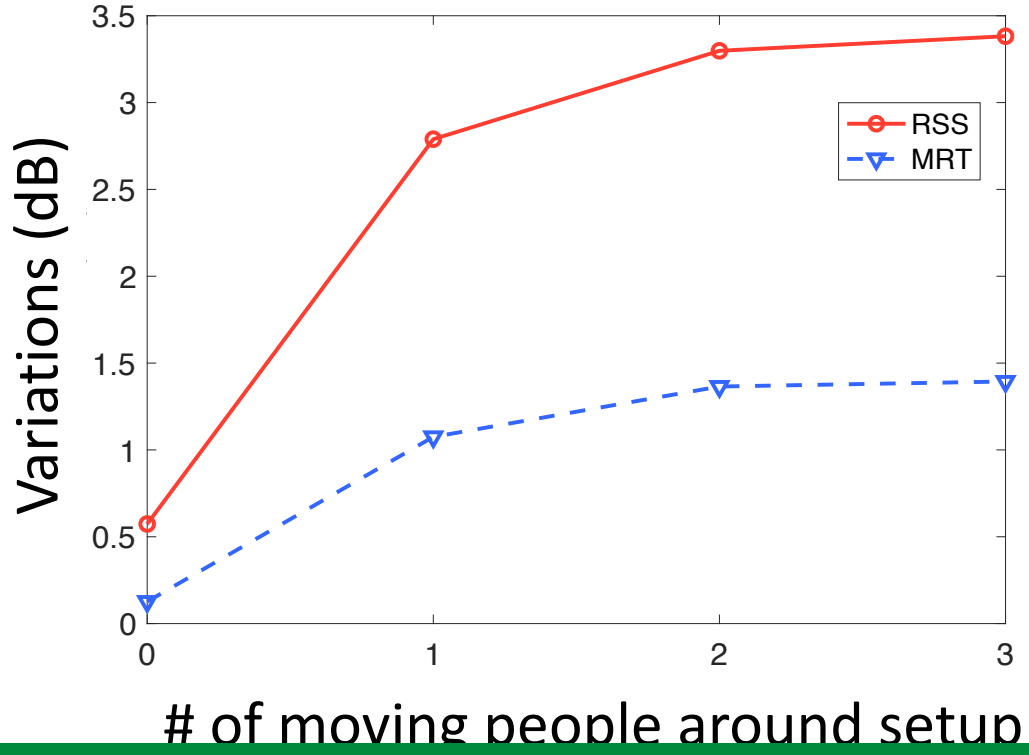


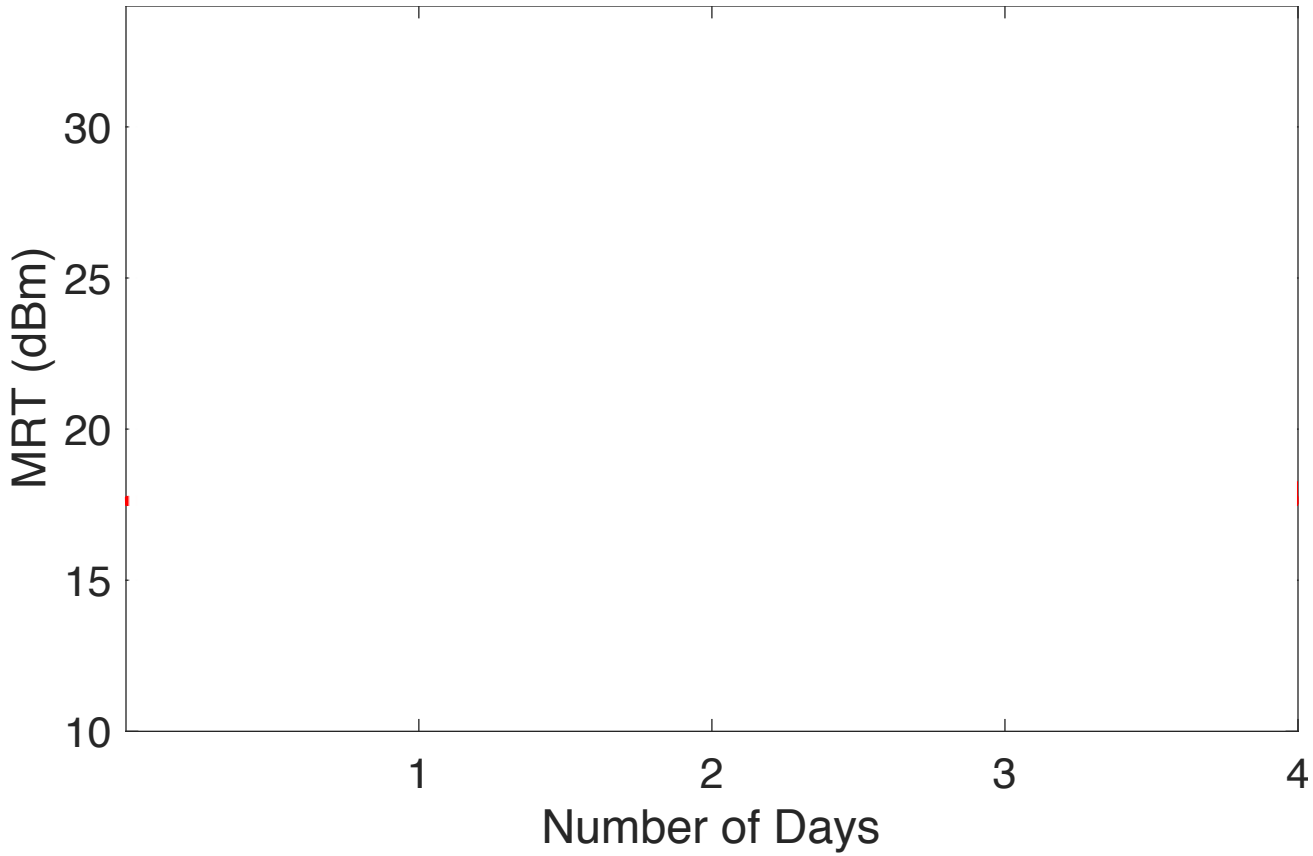
MRT is a better feature for moisture sensing

Challenges:

Changes in the *RF environment* and *pot locations* cause variations in MRT, resulting in errors for soil moisture estimations.

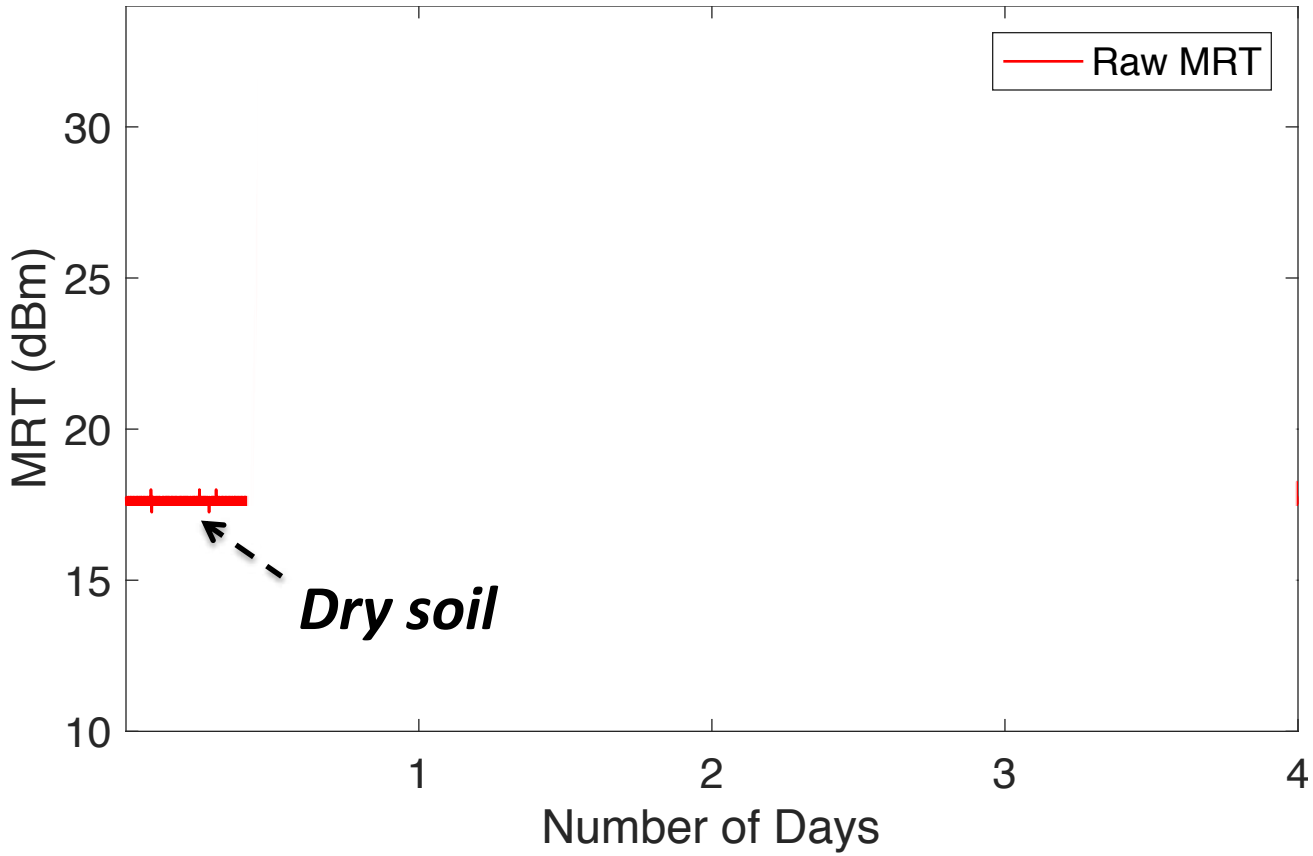
Challenge 1:
MRT variations by RF environment changes

Resilience to Environment Variations



(a) Static: no environment variation around the setup

Resilience to Environment Variations



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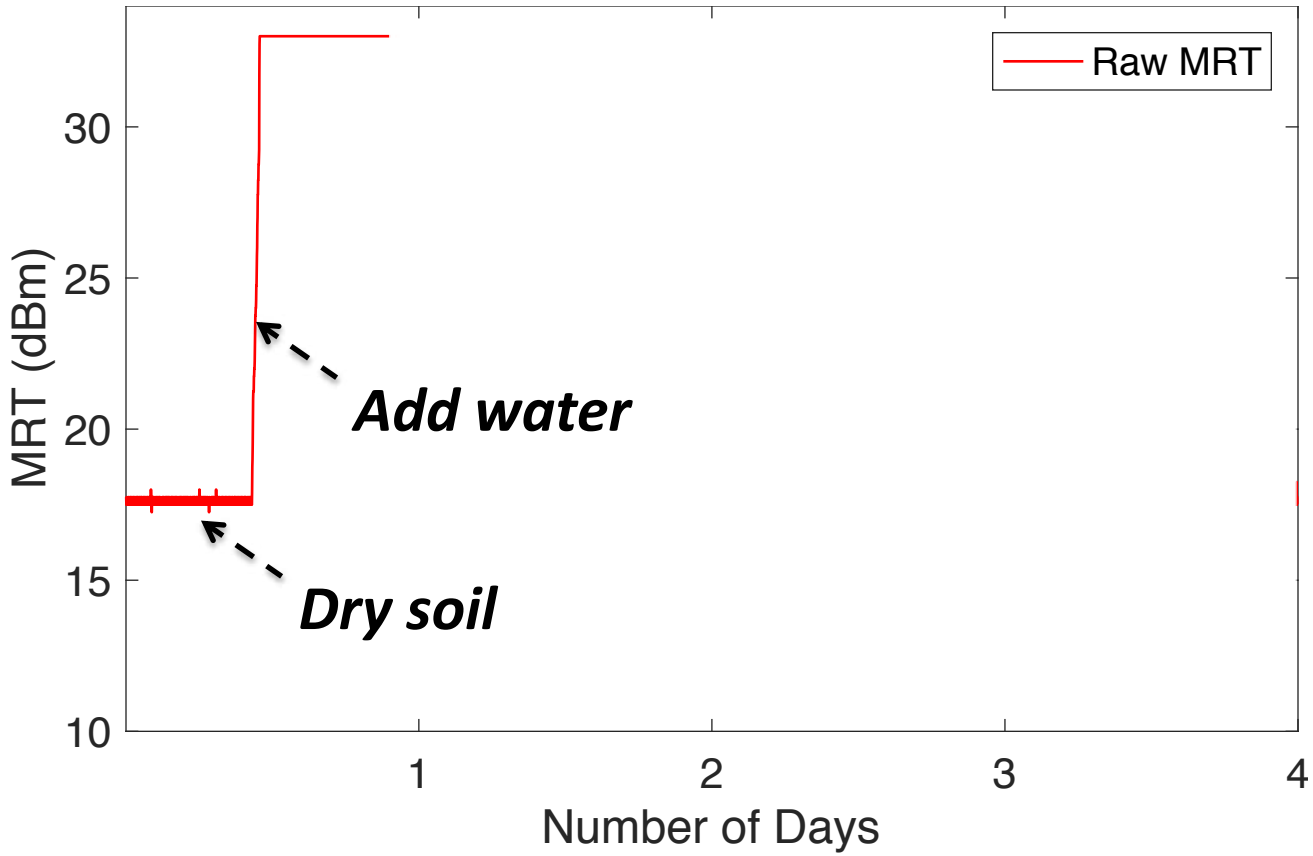

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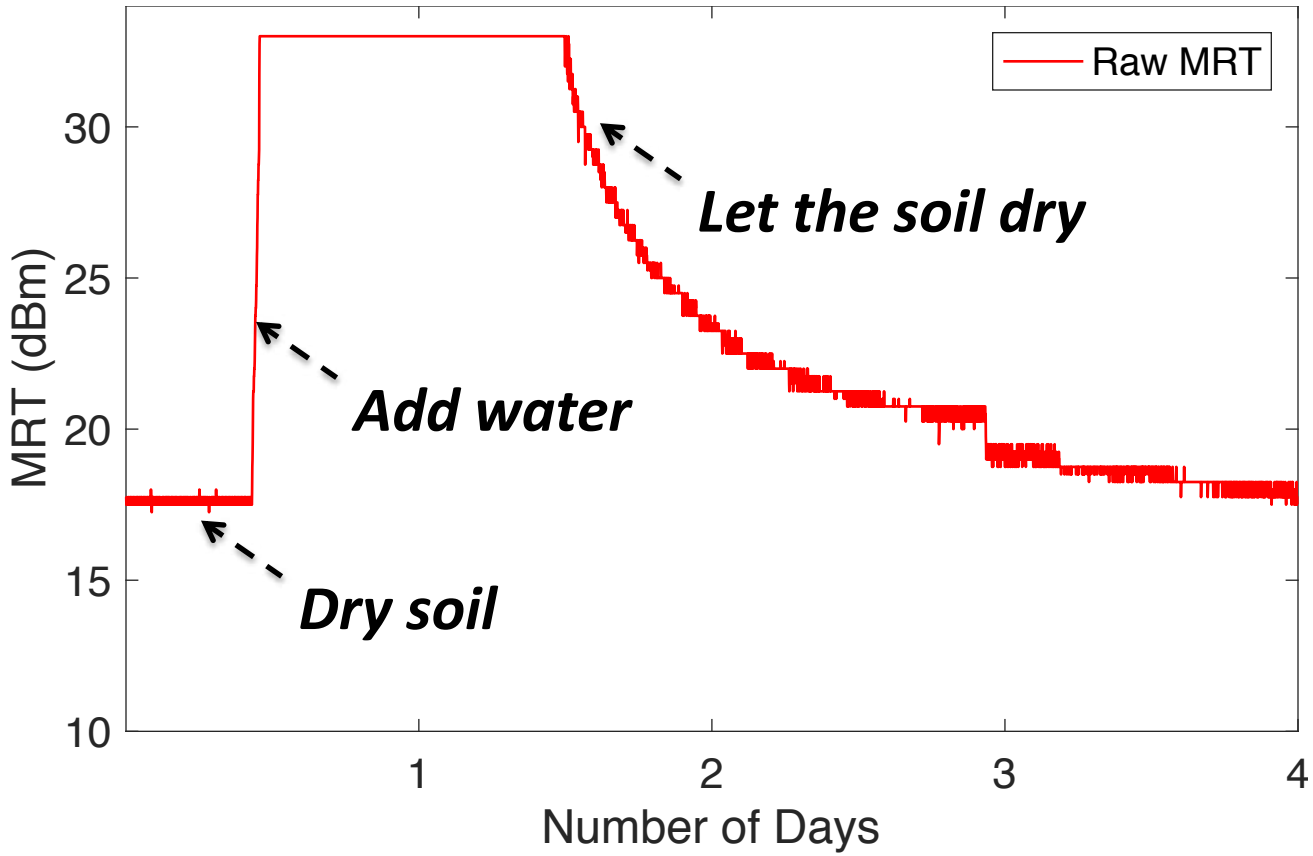

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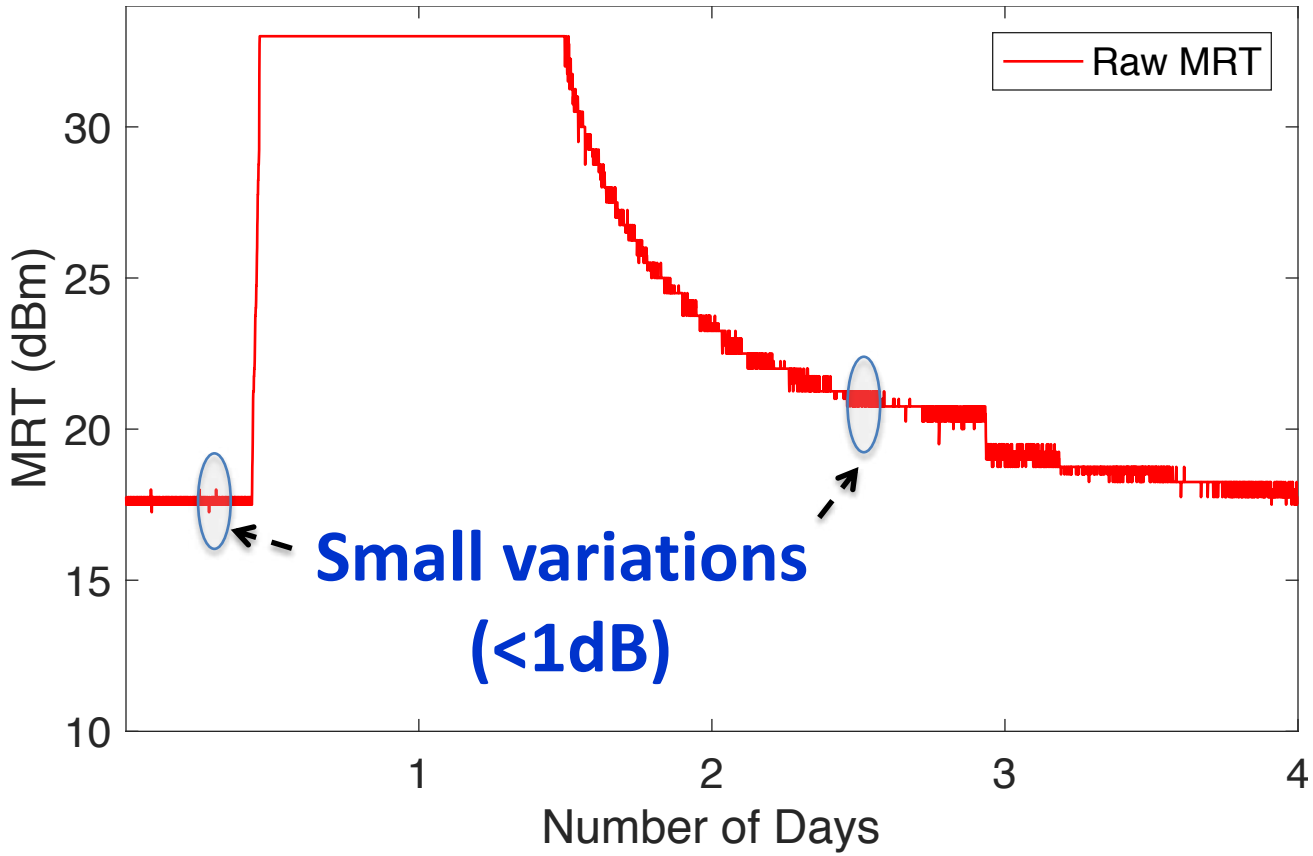

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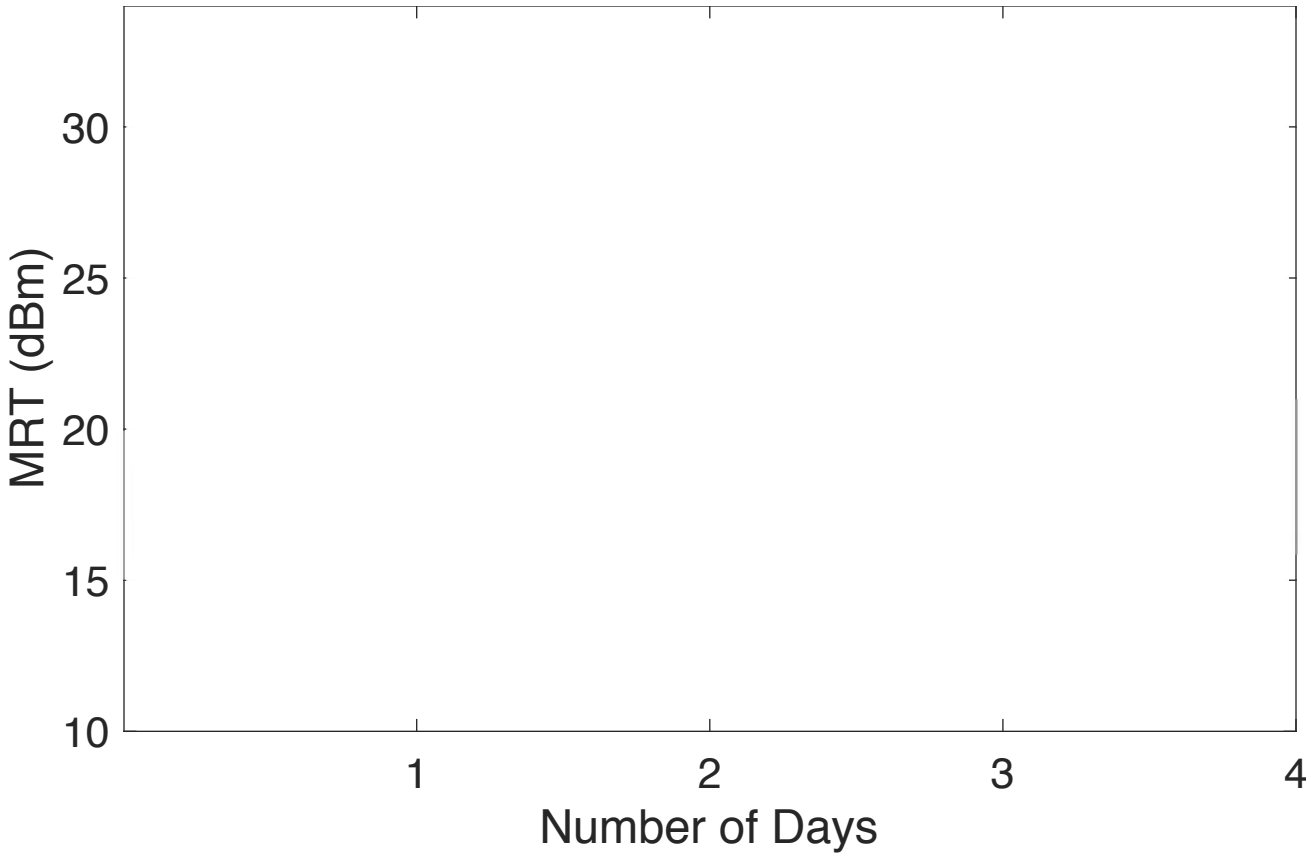
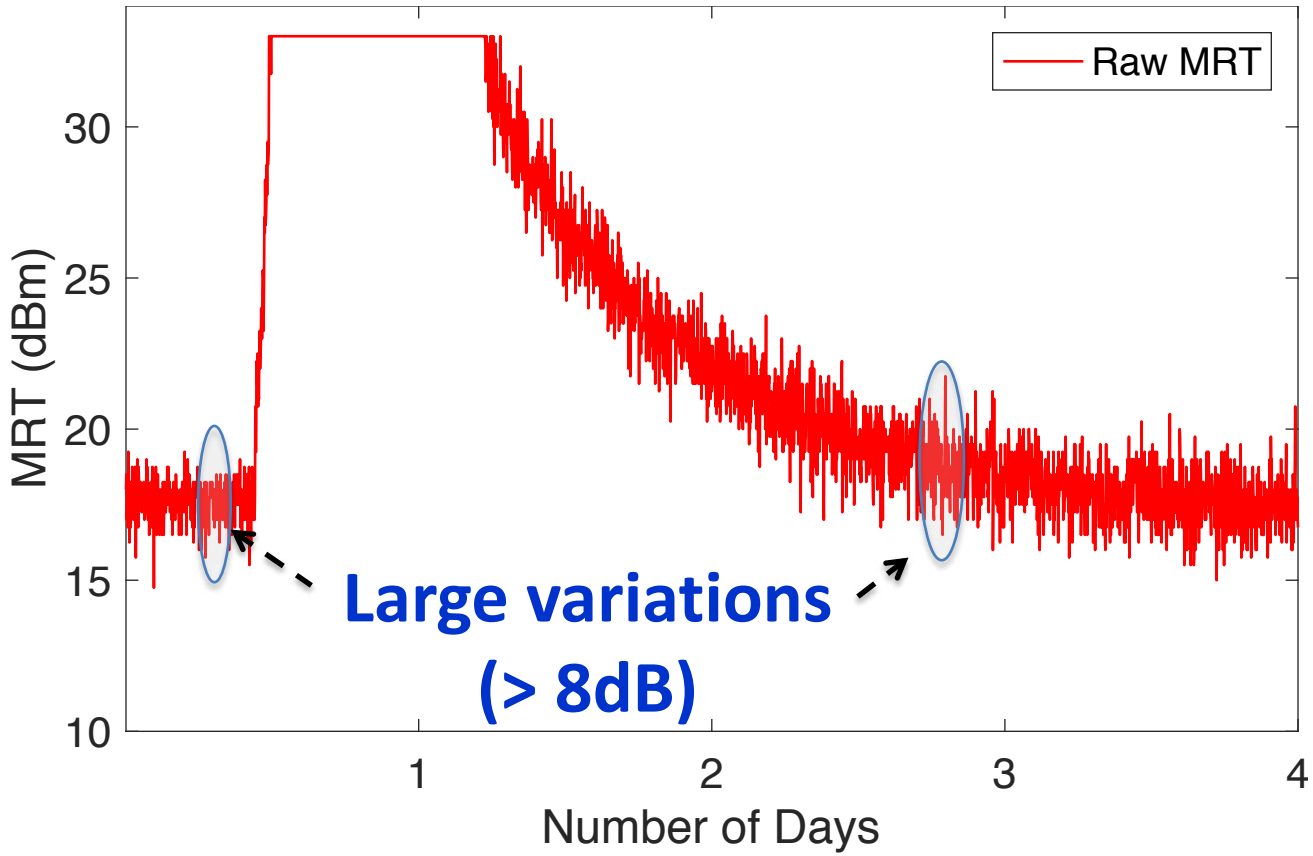


(b) Dynamic: multiple people move around the setup

Resilience to Environment Variations



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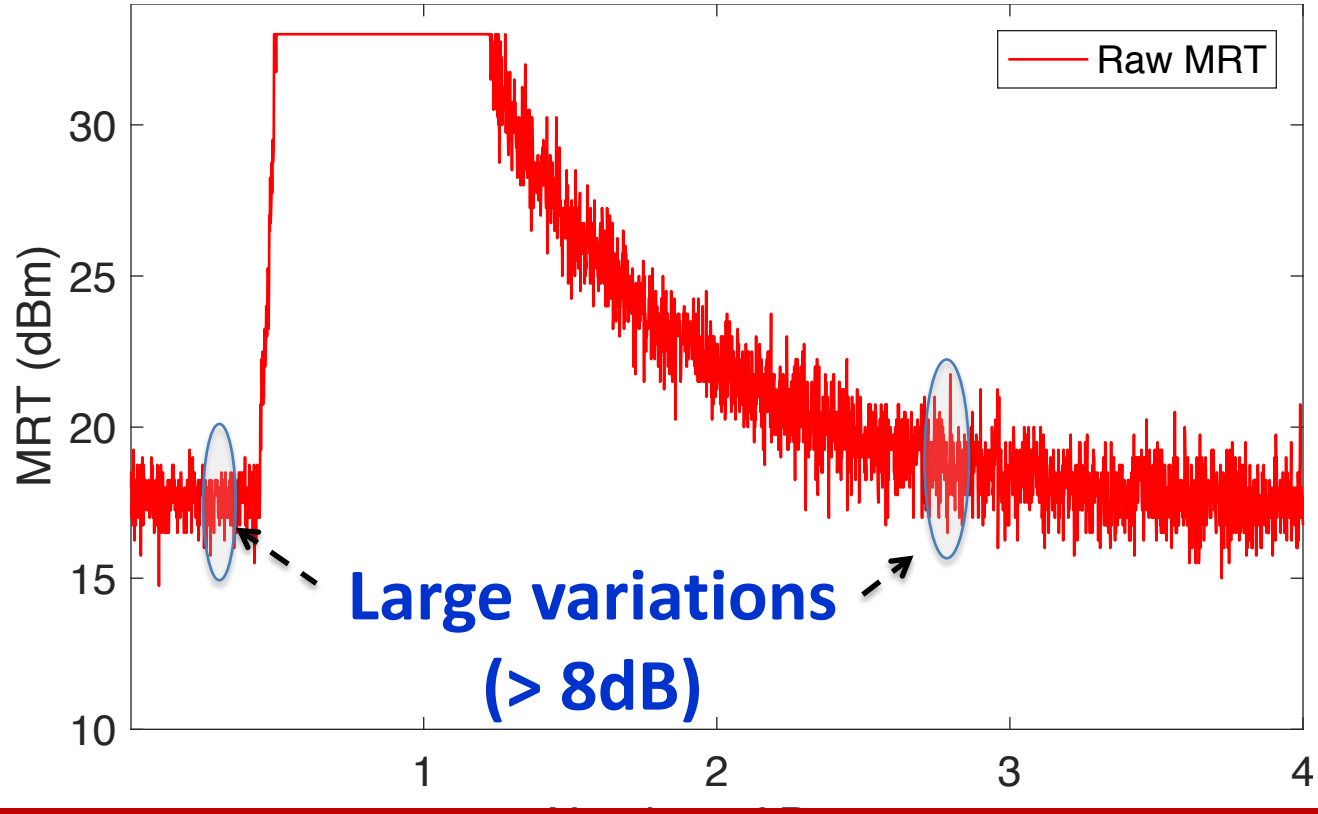
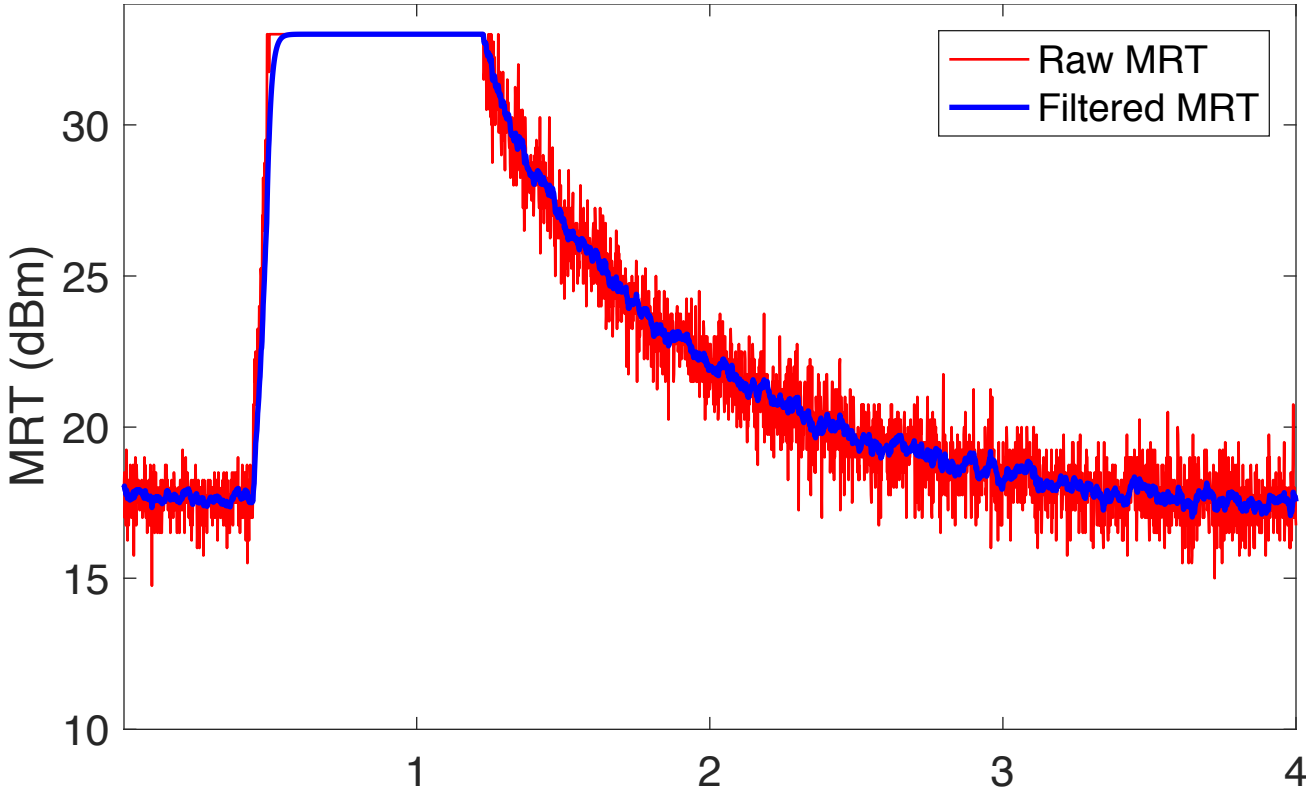


Key observation: changes of moisture are much slower than changes in an RF environment

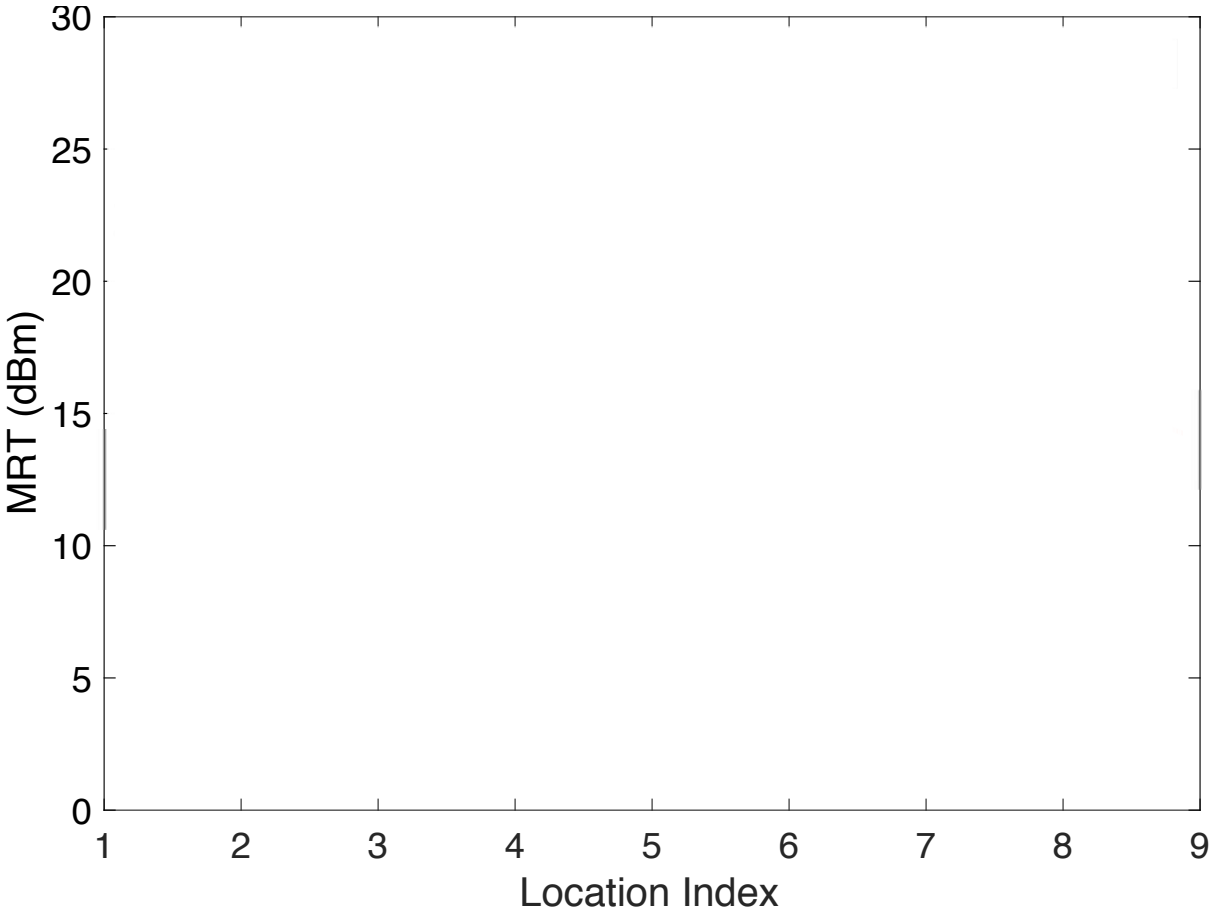
Resilience to Environment Variations



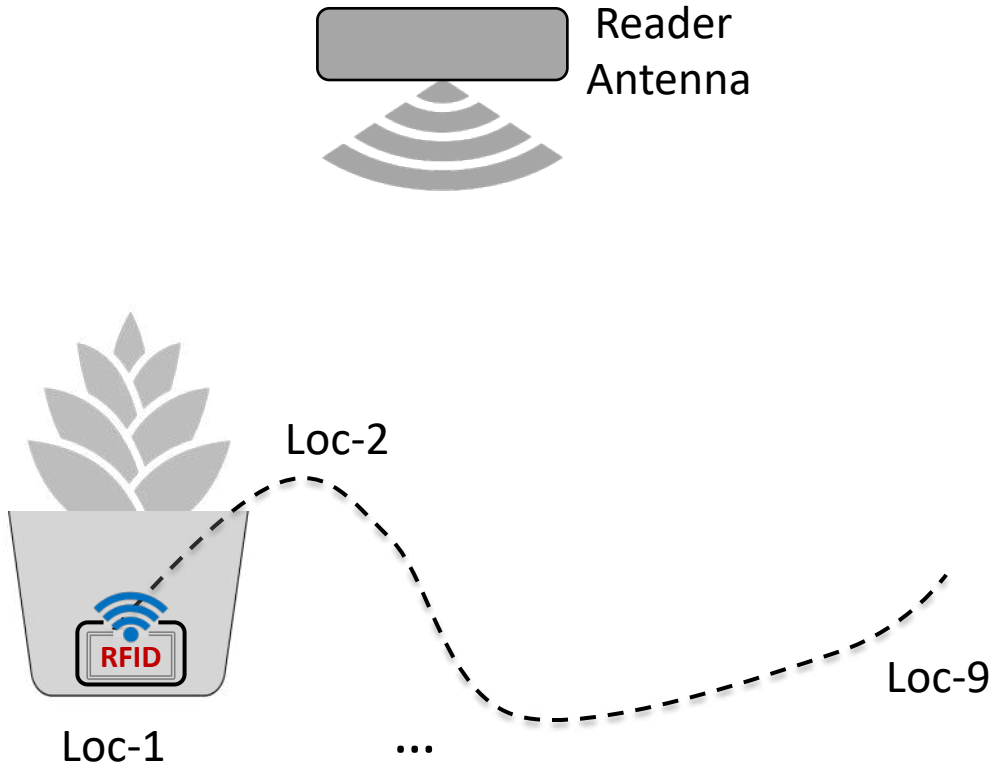
A low pass filter removes environment variations

Challenge 2:
MRT variations by pot/tag location changes

Resilience to Changes in Tag/Pot Locations

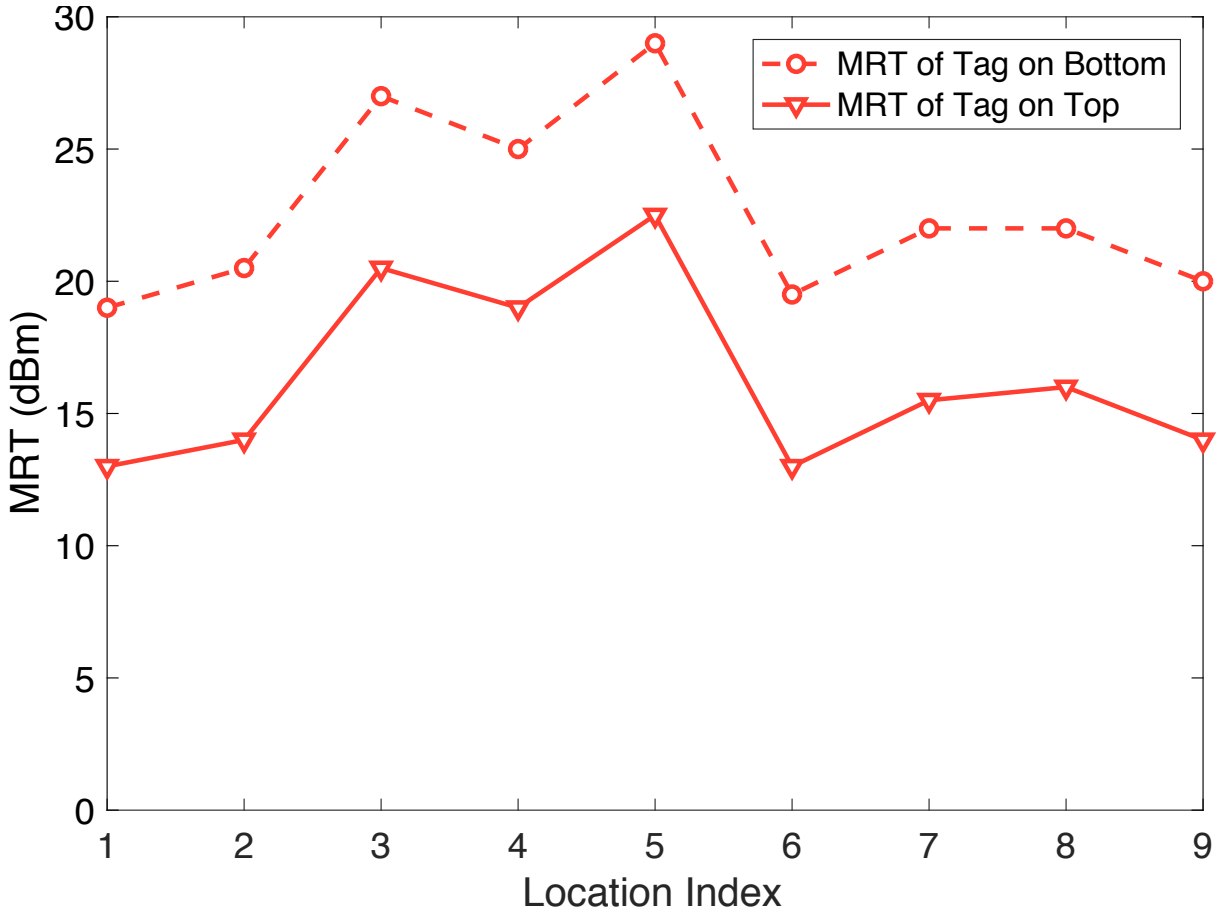


Soil moisture is fixed



One Tag on a pot

Resilience to Changes in Tag/Pot Locations



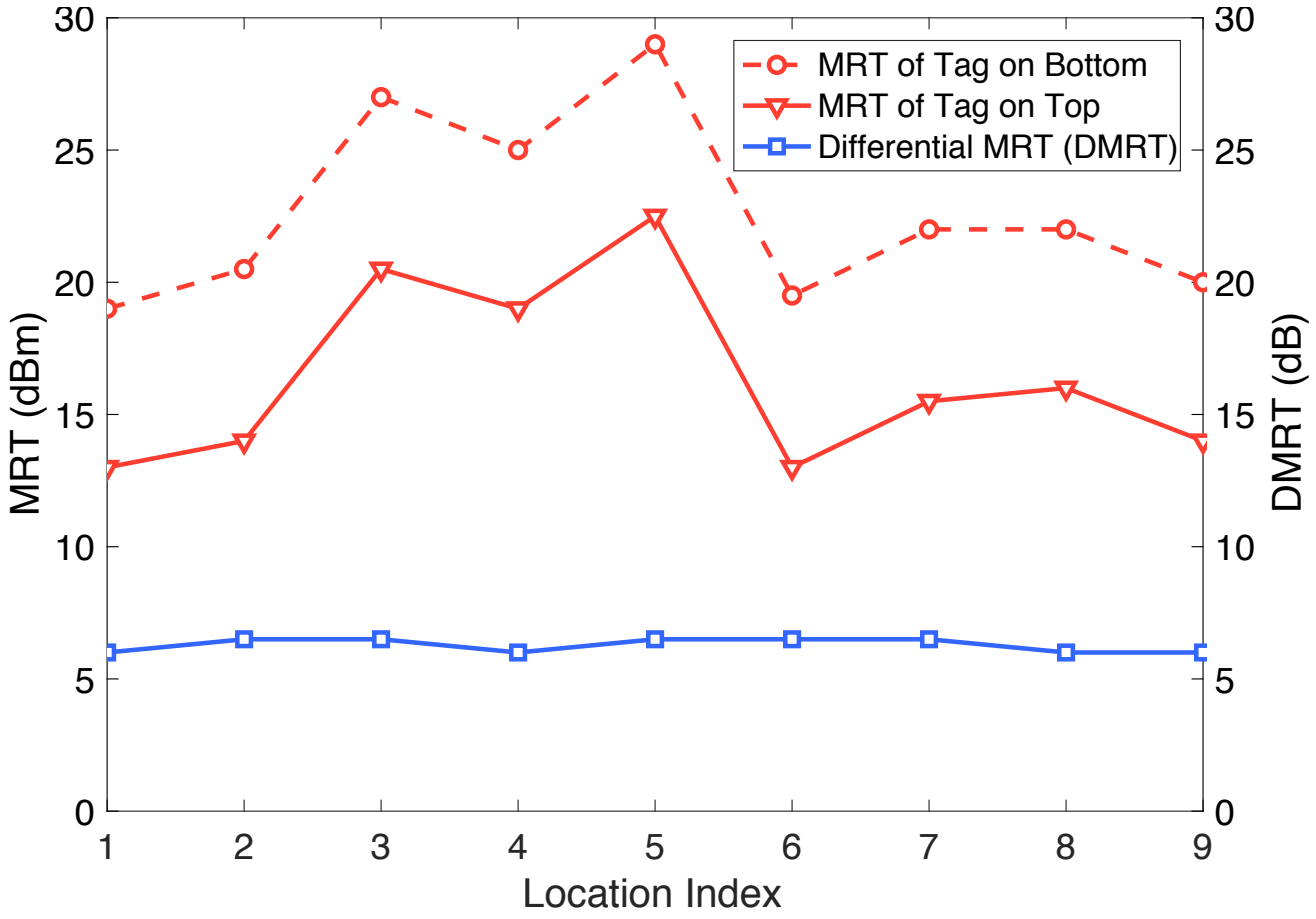
Soil moisture is fixed

Reference Tag (above the soil)

Sensing Tag

Two Tags on a pot

Resilience to Changes in Tag/Pot Locations



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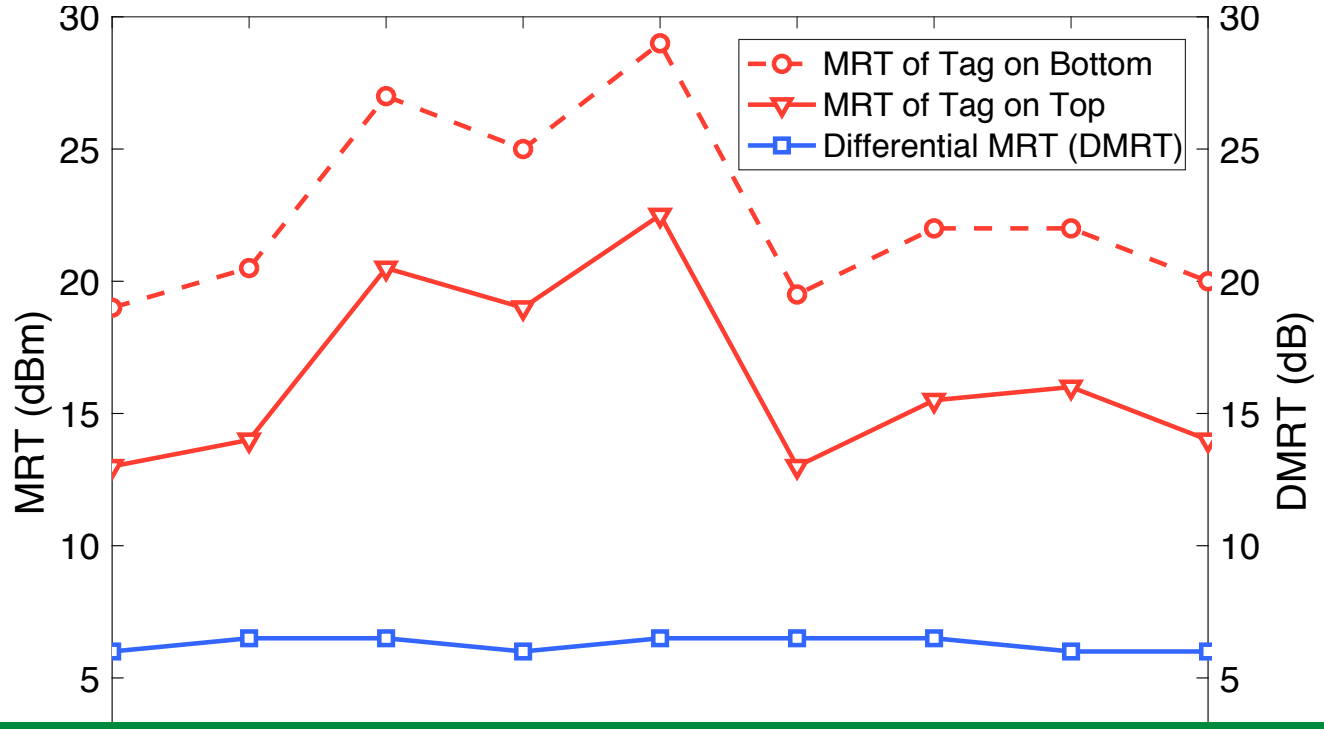


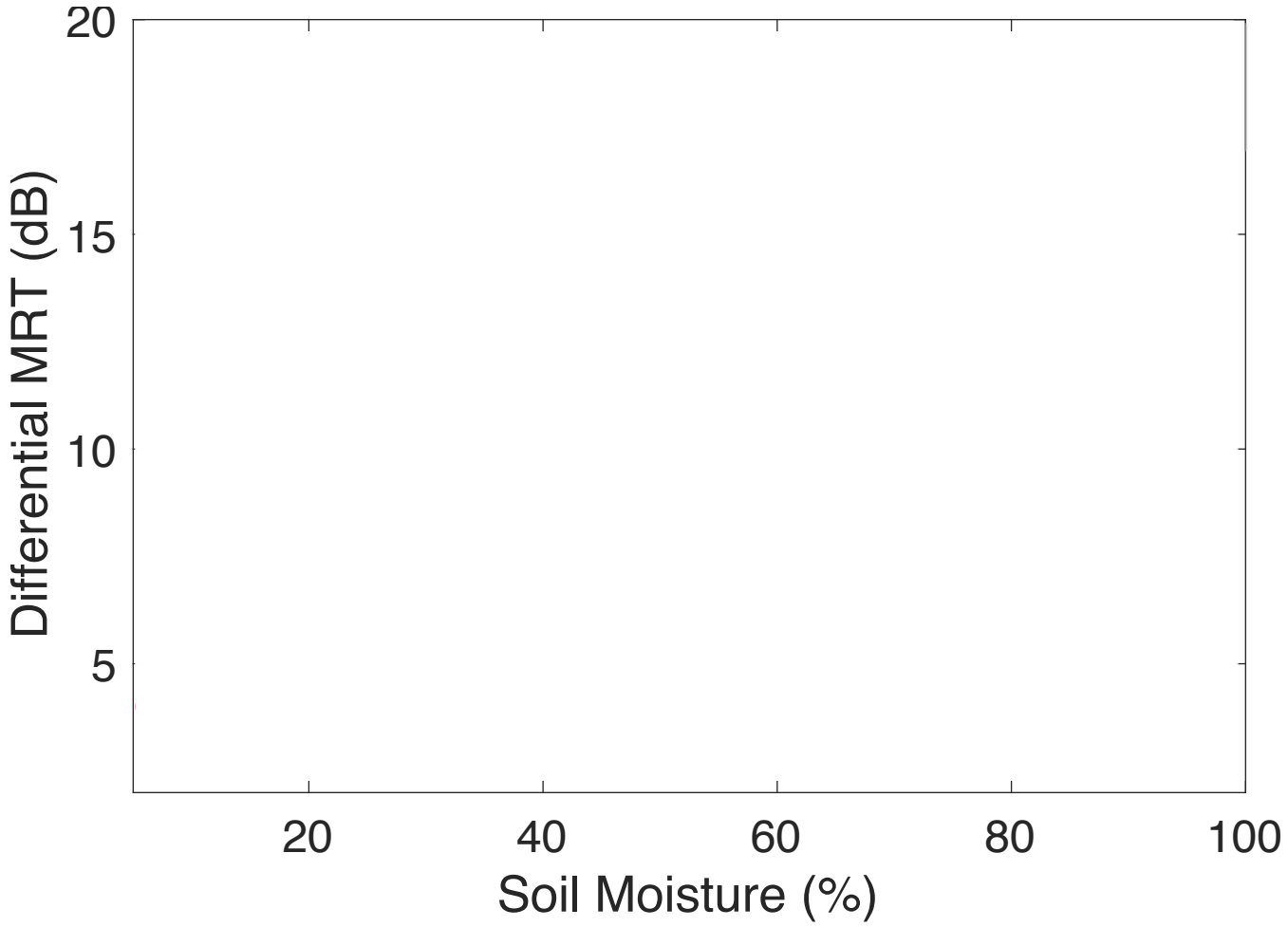
Reference Tag
(above the soil)

Sensing Tag

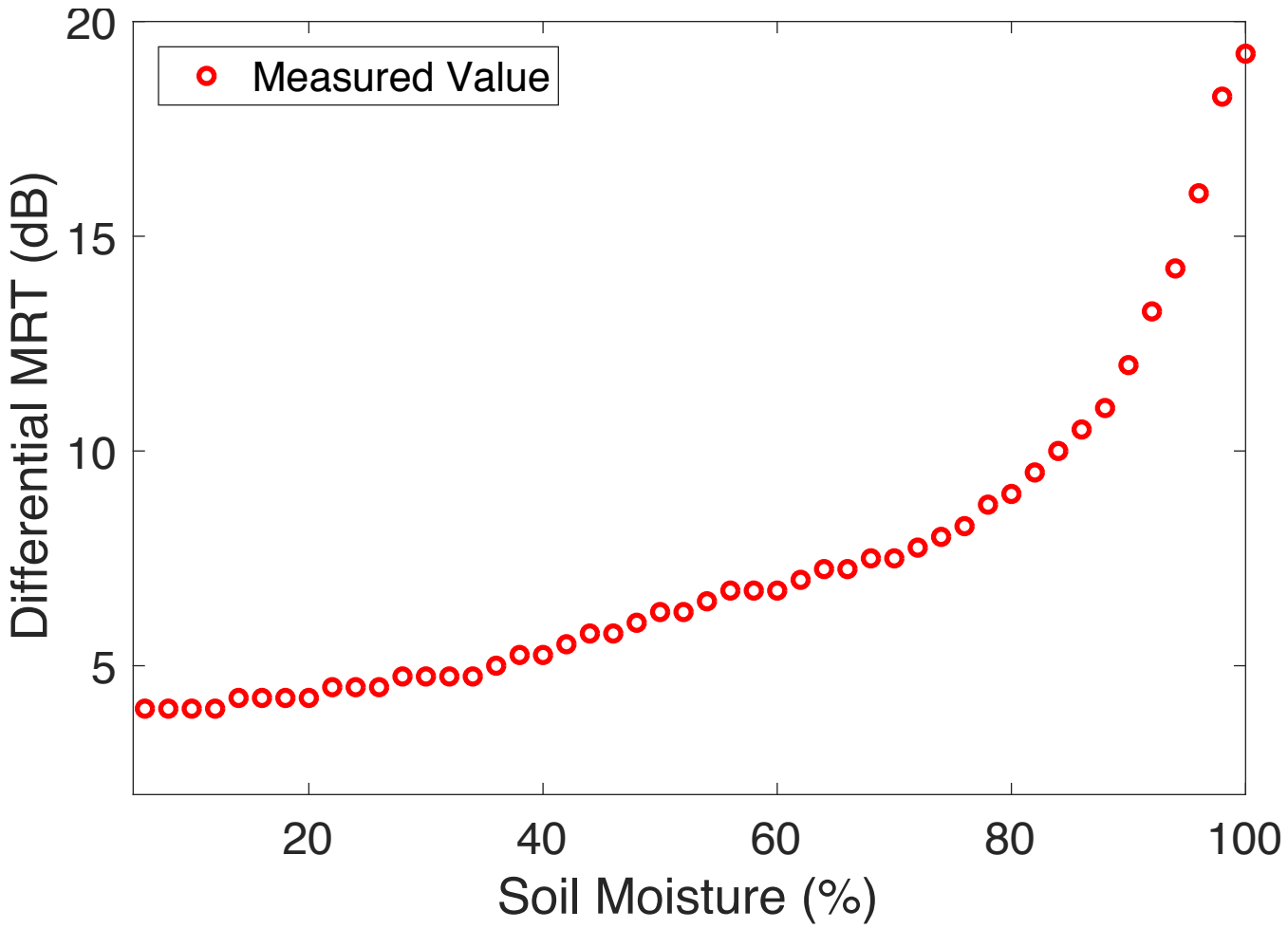
Differential MRT removes location variations

Does differential MRT changes by soil moisture?

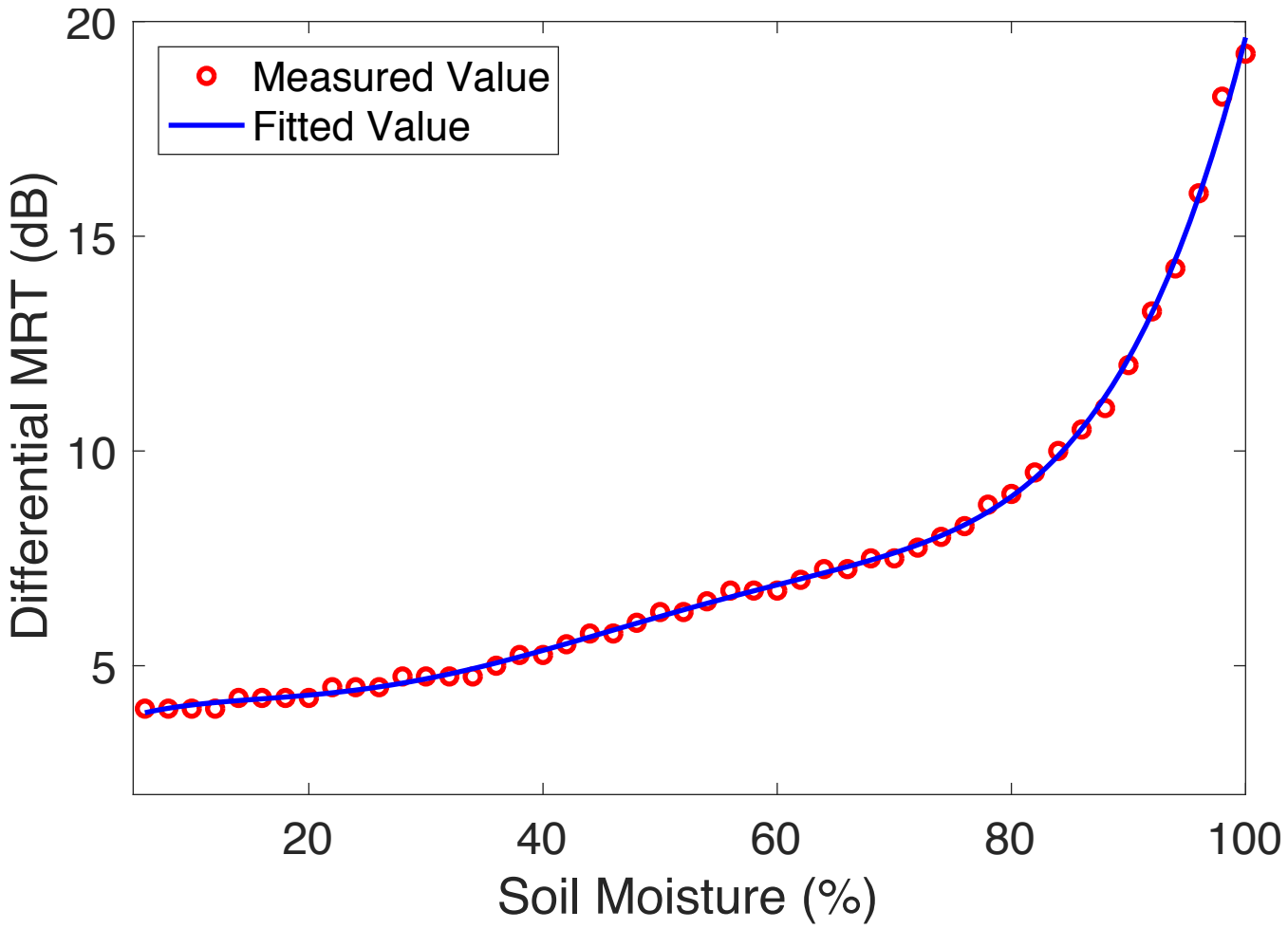
Differential MRT *vs.* Soil Moisture



Differential MRT *vs.* Soil Moisture



Differential MRT *vs.* Soil Moisture



Calibration: Mapping DMRT readings to soil moisture levels.

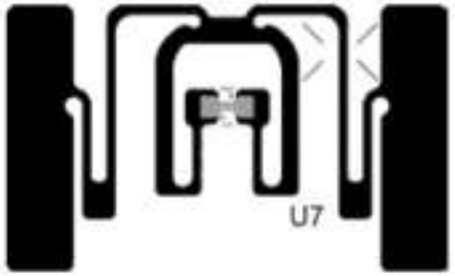
$$\textbf{Moisture level} = f(\textbf{DMRT})$$

Implementation & Results

Hardware

An Impinj R420 reader

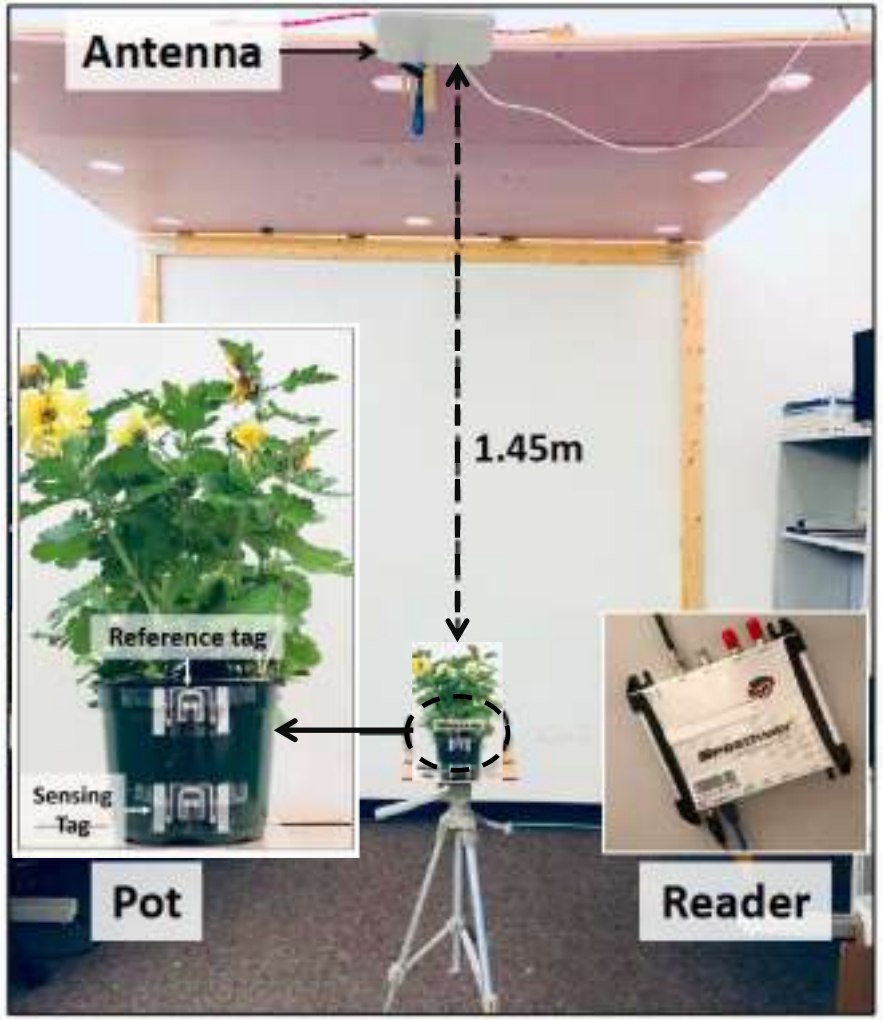
One reader antenna



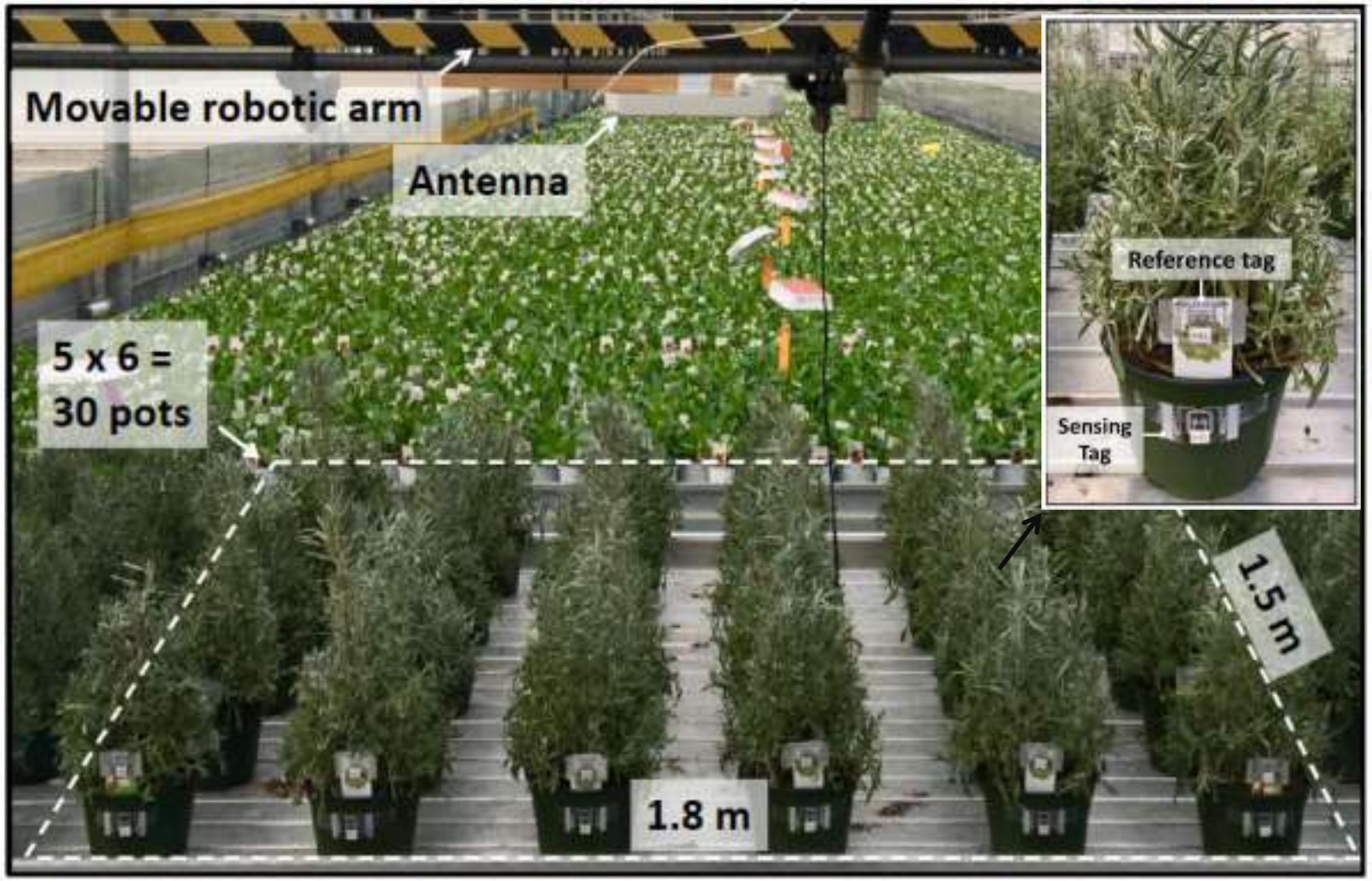
Size: 5cm x 3cm

60 RFID tags (AD-383u7)

Environment



Lab environment

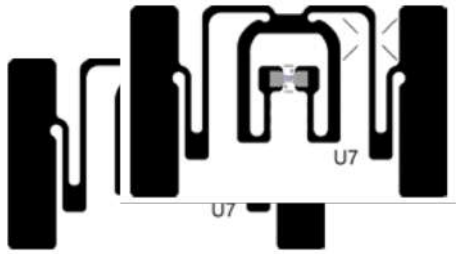


Real greenhouse

Comparison with dedicated soil moisture sensors

Sensor-1: SEN-13637 ($10)

Sensor-2: ECHO-EC5 ($170)



GreenTag: 2 RFID tags (<$0.4)

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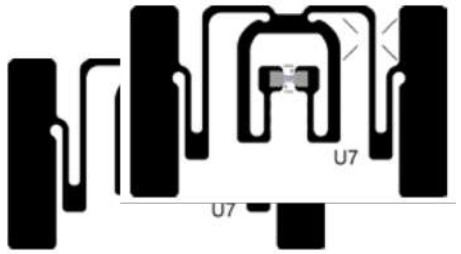
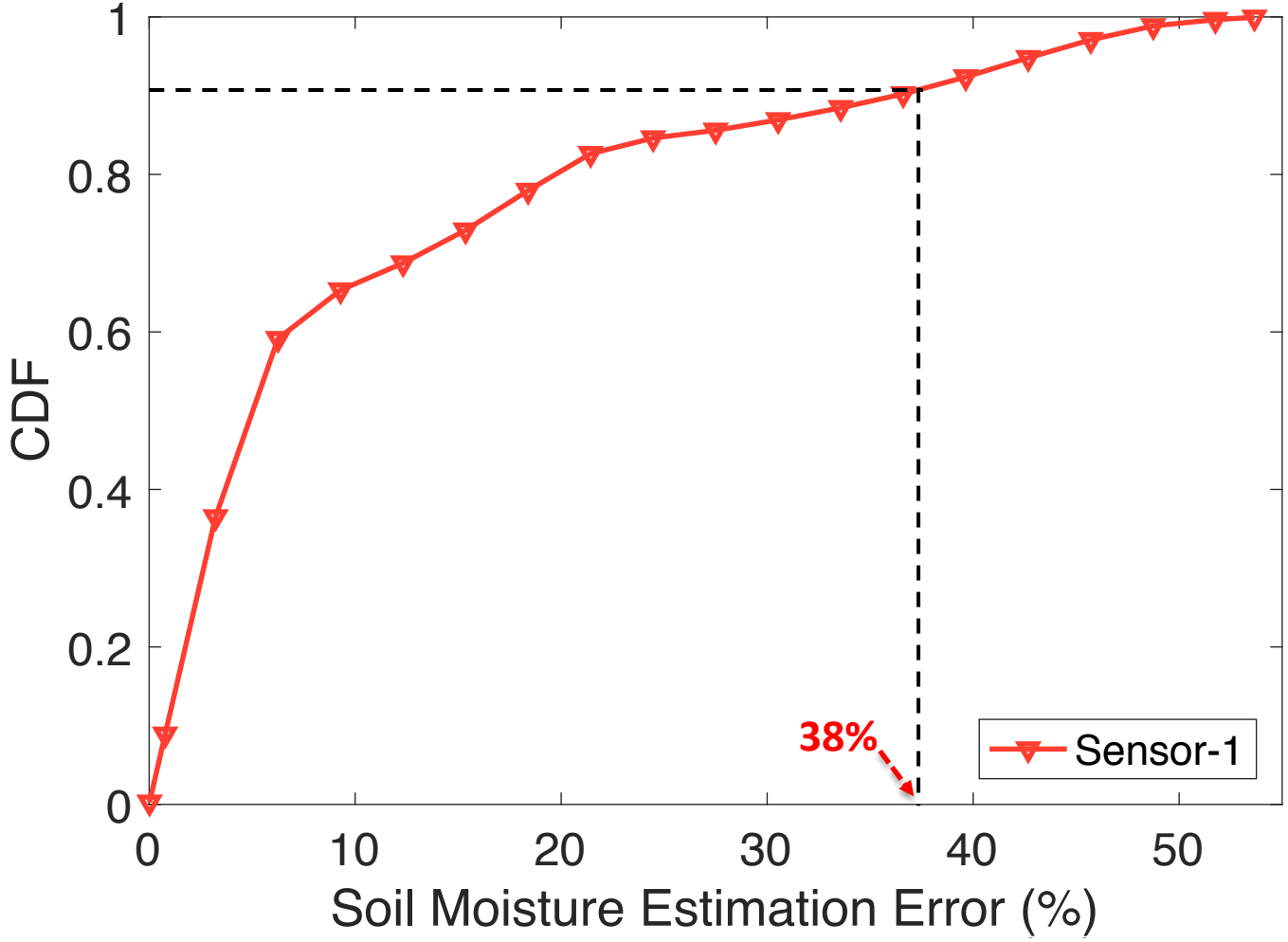
Sensor-2: ECHO-EC5 ($170)



GreenTag: 2 RFID tags (<$0.4)



Comparison with dedicated soil moisture sensors

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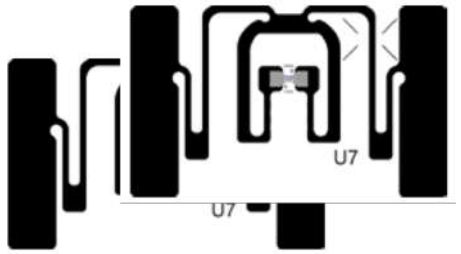

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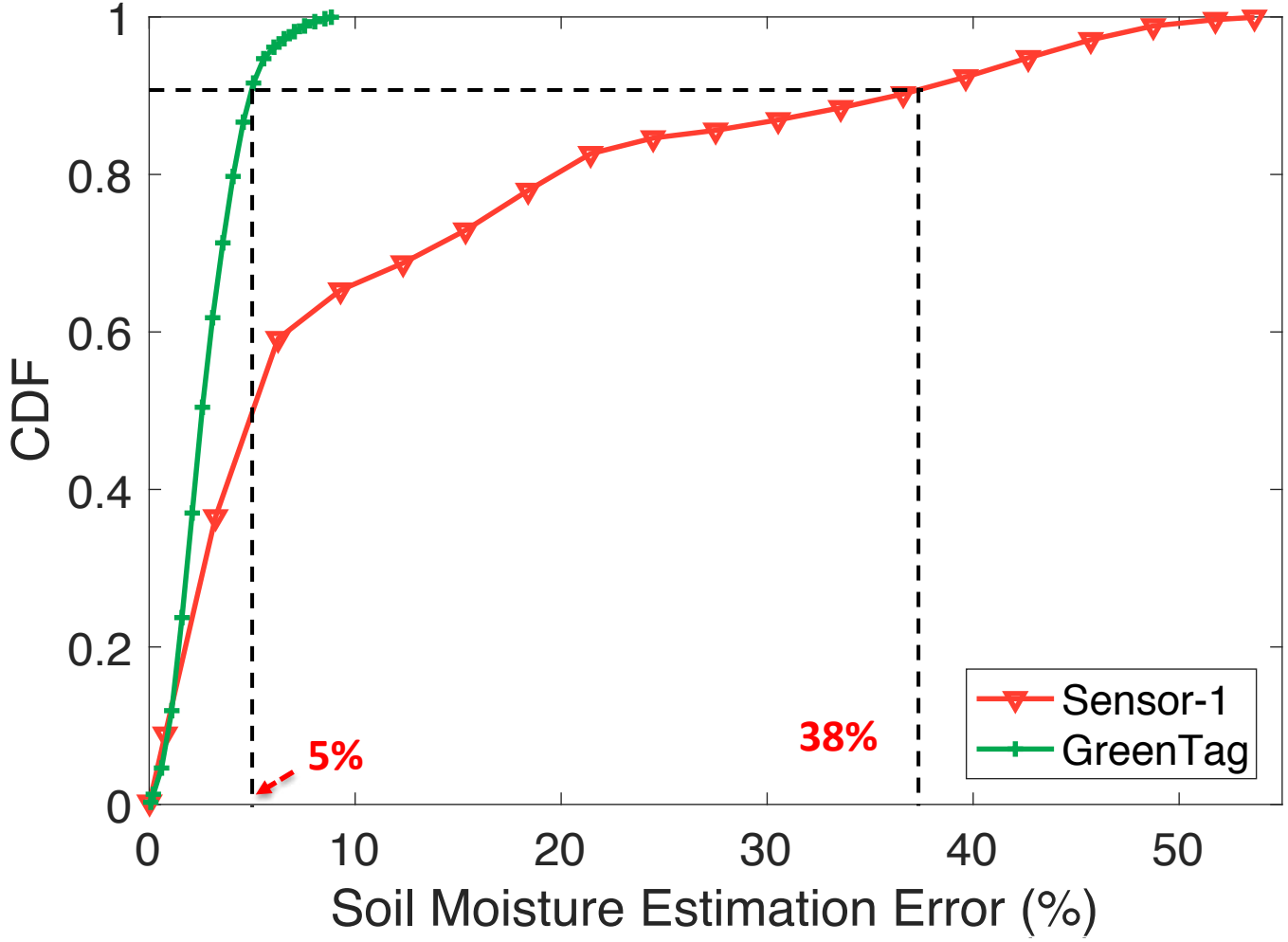

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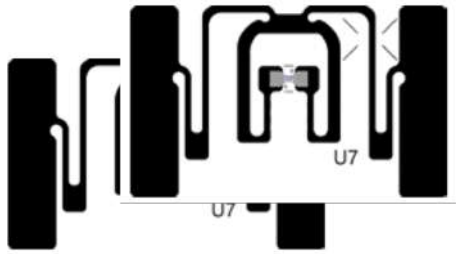

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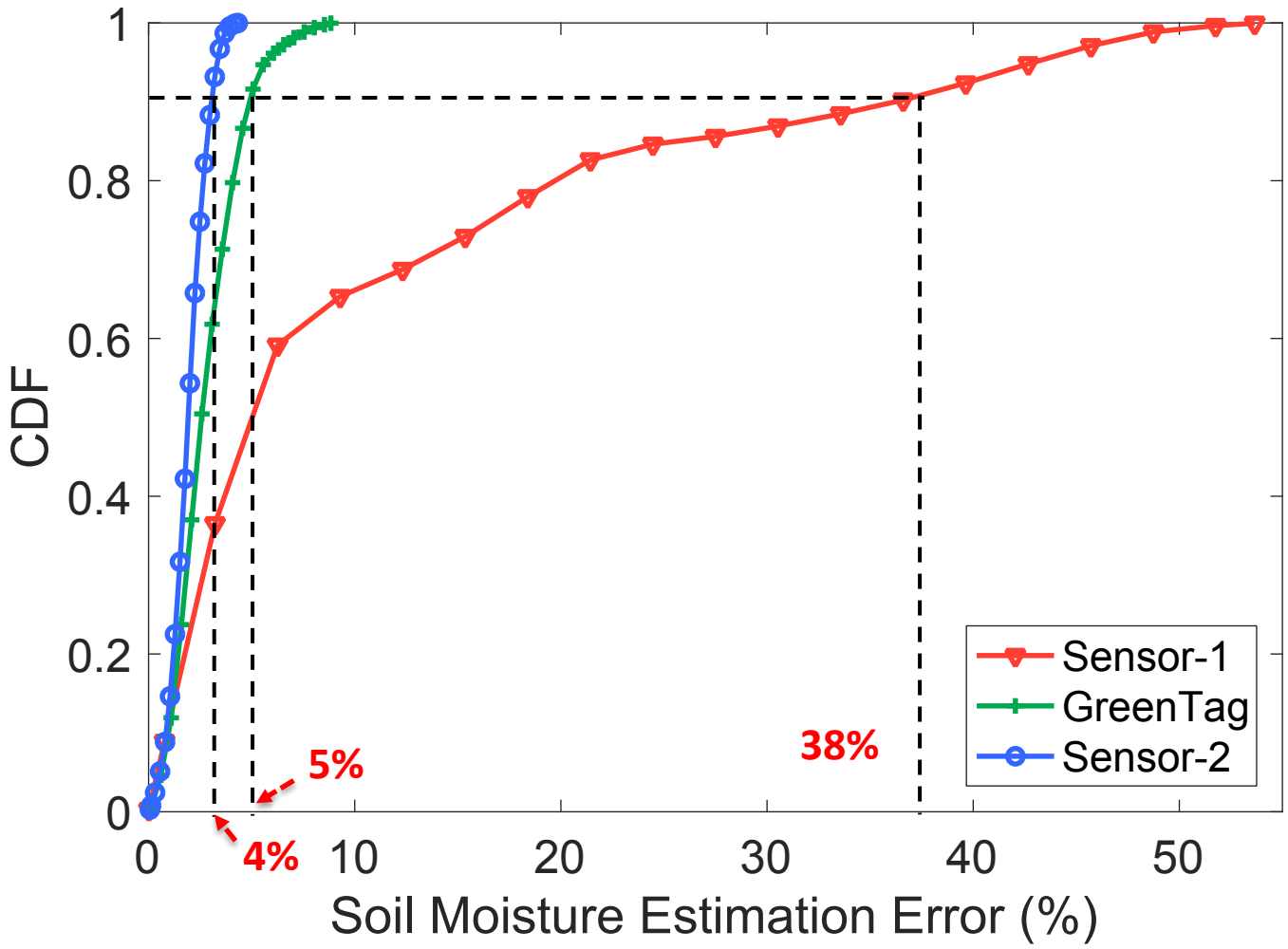
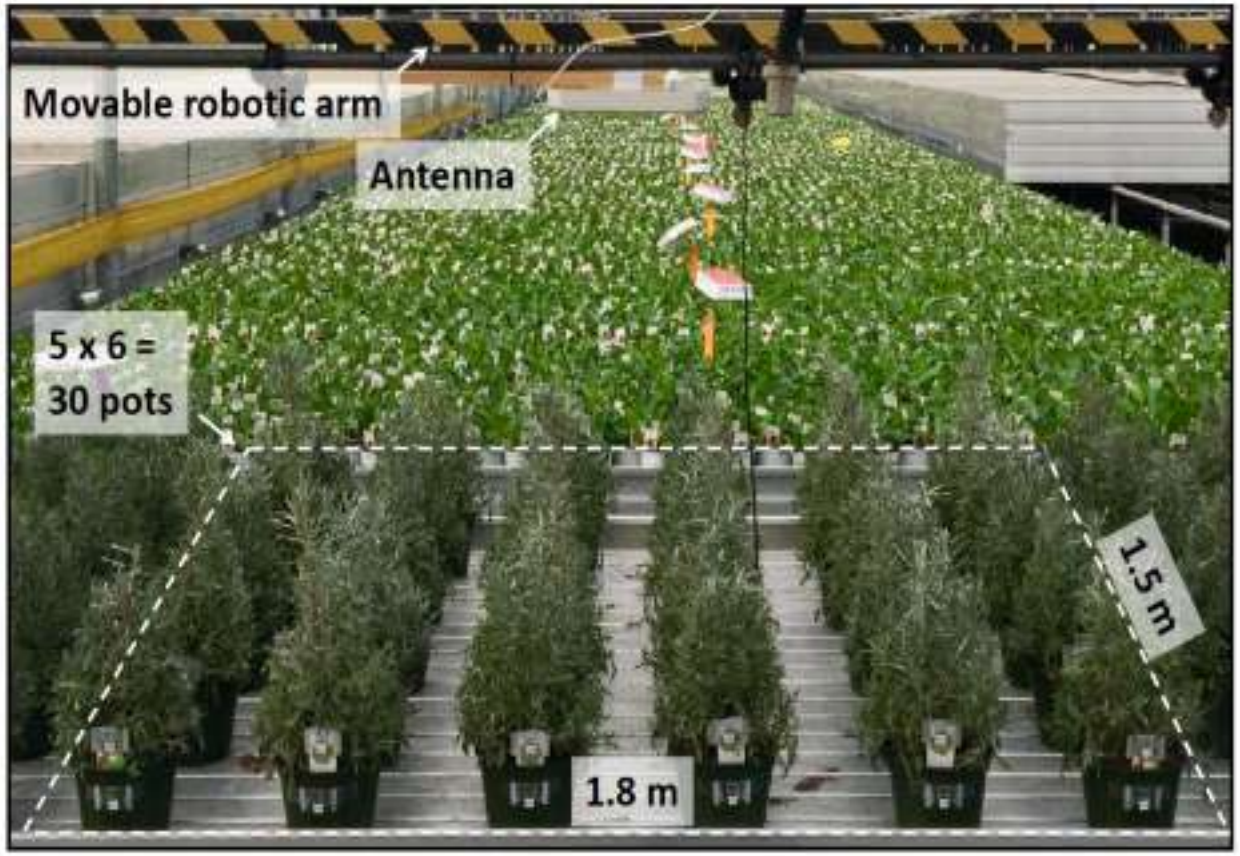


Case Study: 60 tags on 30 pots in a greenhouse



Deployment at **Sunrise Greenhouse Ltd**

https://www.sunrisegreenhouses.ca

The system is calibrated with one pot and tested on all pots.

"Sunrise Greenhouse" is interested in the 3 moisture levels:

- **Dry** (0-40%), water plants immediately
- **Moist** (40%-85%): an ideal moisture range for watering plants
- **Wet** (85%-100%): an ideal moisture range for shipping plants

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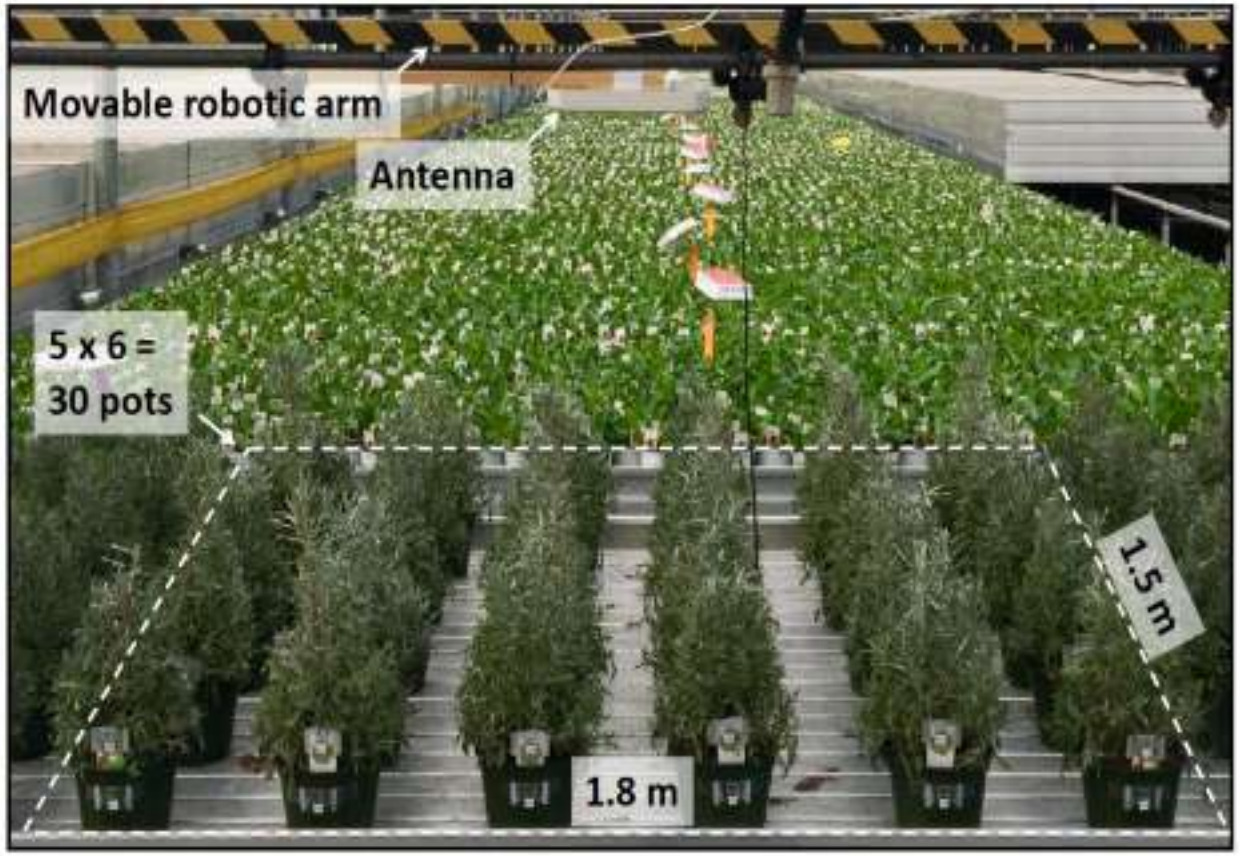

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Estimated Soil Moisture

Ture Soil Moisture	Dry Soil	Moist Soil	Wet Soil
Dry Soil	0.95	0.05	
Moist Soil	0.04	0.91	0.05
Wet Soil		0.04	0.96

Confusion matrix over 30 pots

Conclusion

1. GreenTag is a low-cost RFID-based soil moisture sensing system whose accuracy (5%) is comparable to expensive moisture sensors.

2. GreenTag is able to make irrigation more intelligent and improve the productivity of greenhouses.