ASME
IDETC-CIE 2025

INTERNATIONAL DESIGN ENGINEERING TECHNICAL CONFERENCES & COMPUTERS AND INFORMATION IN ENGINEERING CONFERENCE

HILTON ANAHEIM
ANAHEIM, CALIFORNIA, USA

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INTERNATIONAL DESIGN ENGINEERING TECHNICAL CONFERENCES & COMPUTERS AND INFORMATION IN ENGINEERING CONFERENCE

Self-contained Electrical Conductivity Sensing Spikes for Monitoring of Levee Wetting and Drying Cycles

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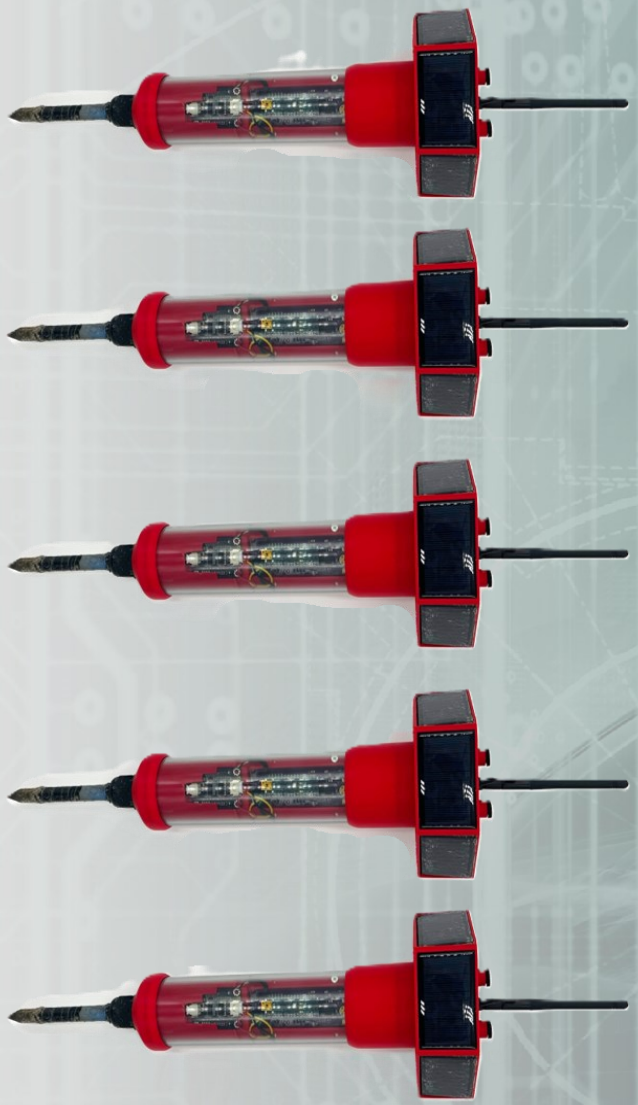
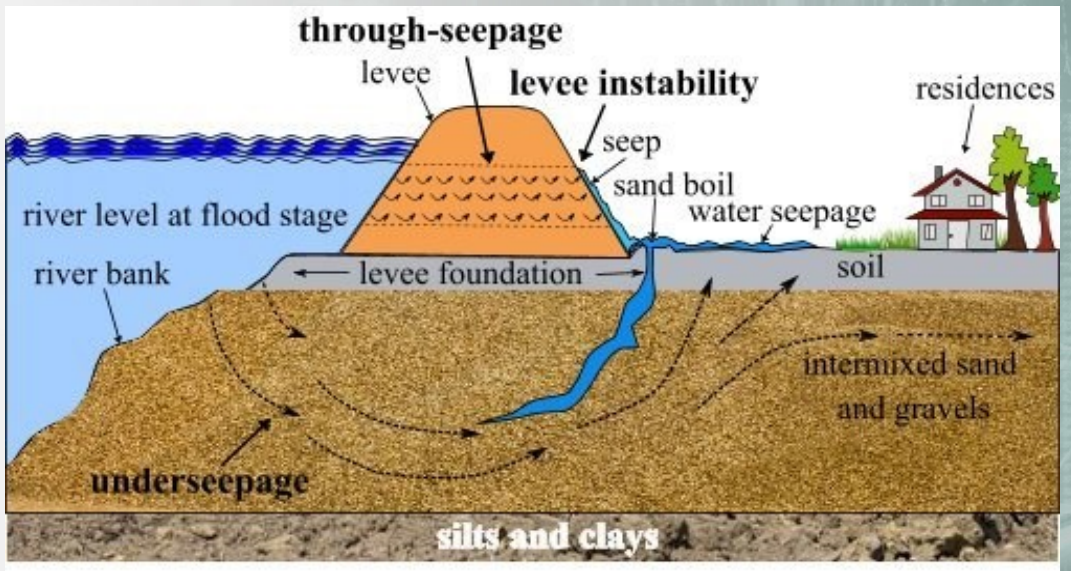
Outline

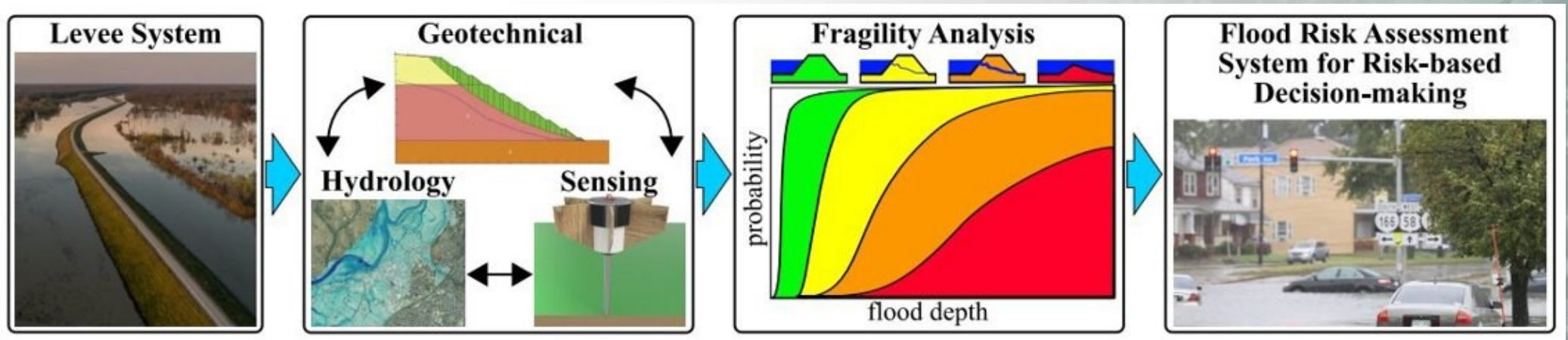
- ❑ Introduction
- ❑ Risk assessment
- ❑ Previous work
- ❑ Paper focus
- ❑ Data analysis
- ❑ Future work



Introduction

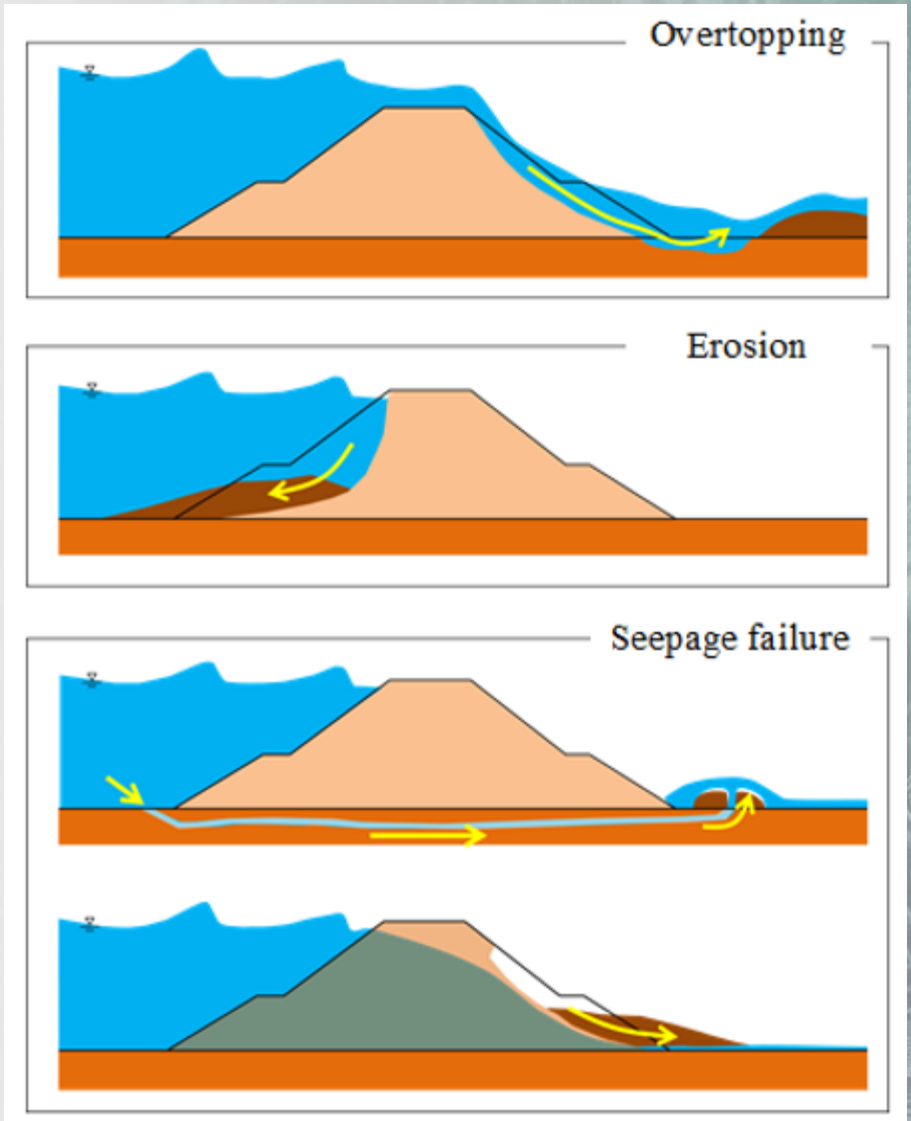
- Levees are human-made embankments built to prevent the overflow of water bodies (e.g. rivers).
- Critical in safeguarding communities and assets From flood damage.
- Typically made of compacted dirt
  - Erosion from moving water increases risk of breaching





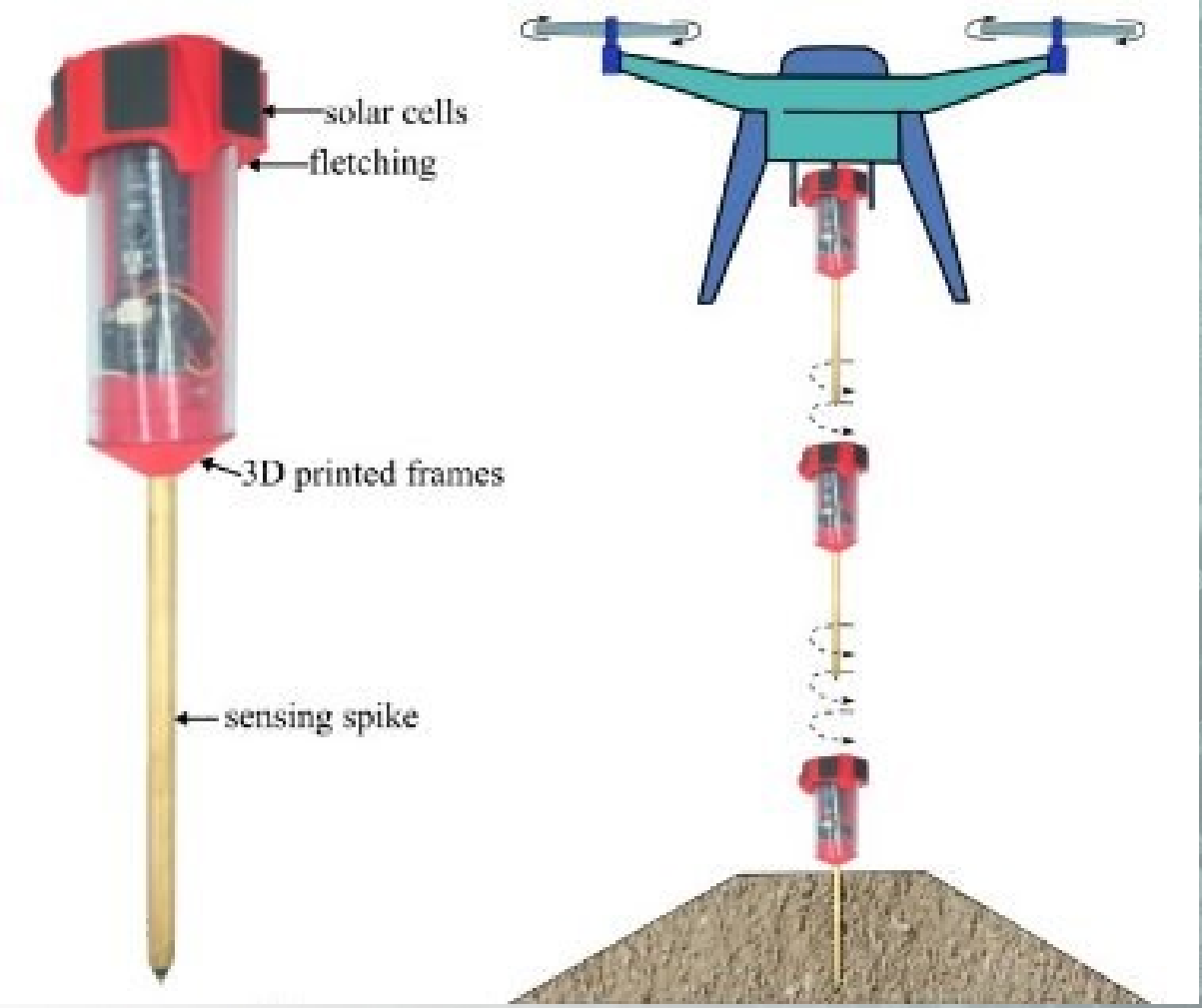
Risk Assessment of Levee Breach

- This work is part of a larger effort to develop a data-driven fragility framework for risk assessment of levee breach.
- This presentation will focus on the development of a network of wireless sensing spike packages for soil conductivity levels in levees.
- This work is being done in close collaboration with experts in data-driven assessment, geo-technical, and hydrology.



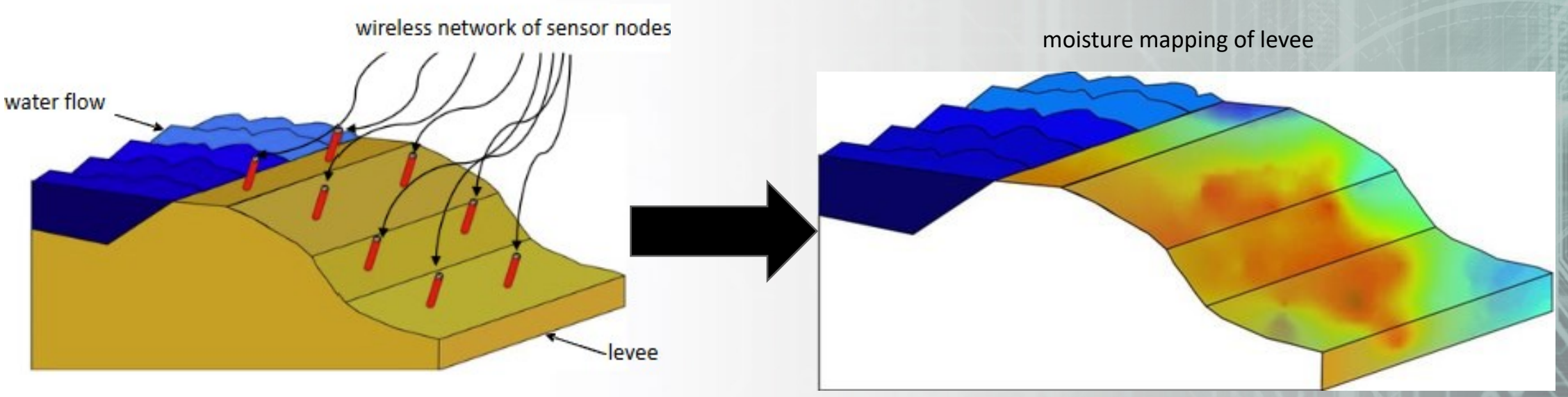
Conductivity-based Monitoring of a Levee

- Goal is to make UAV-deployable sensor systems.
- Currently working on sensor design (deployment comes later)



Monitoring using Wireless Sensor Network

- A wireless sensor network of sensor nodes is used to transmit data directly to a base station hub.

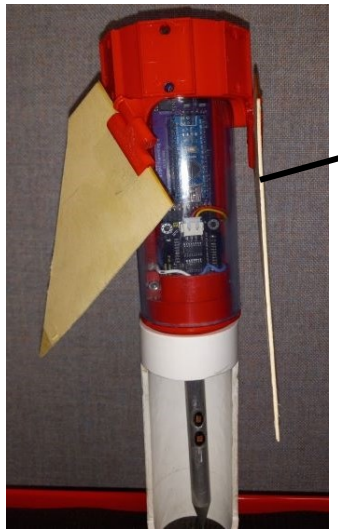


Hardware Progress Overview

1

3

5



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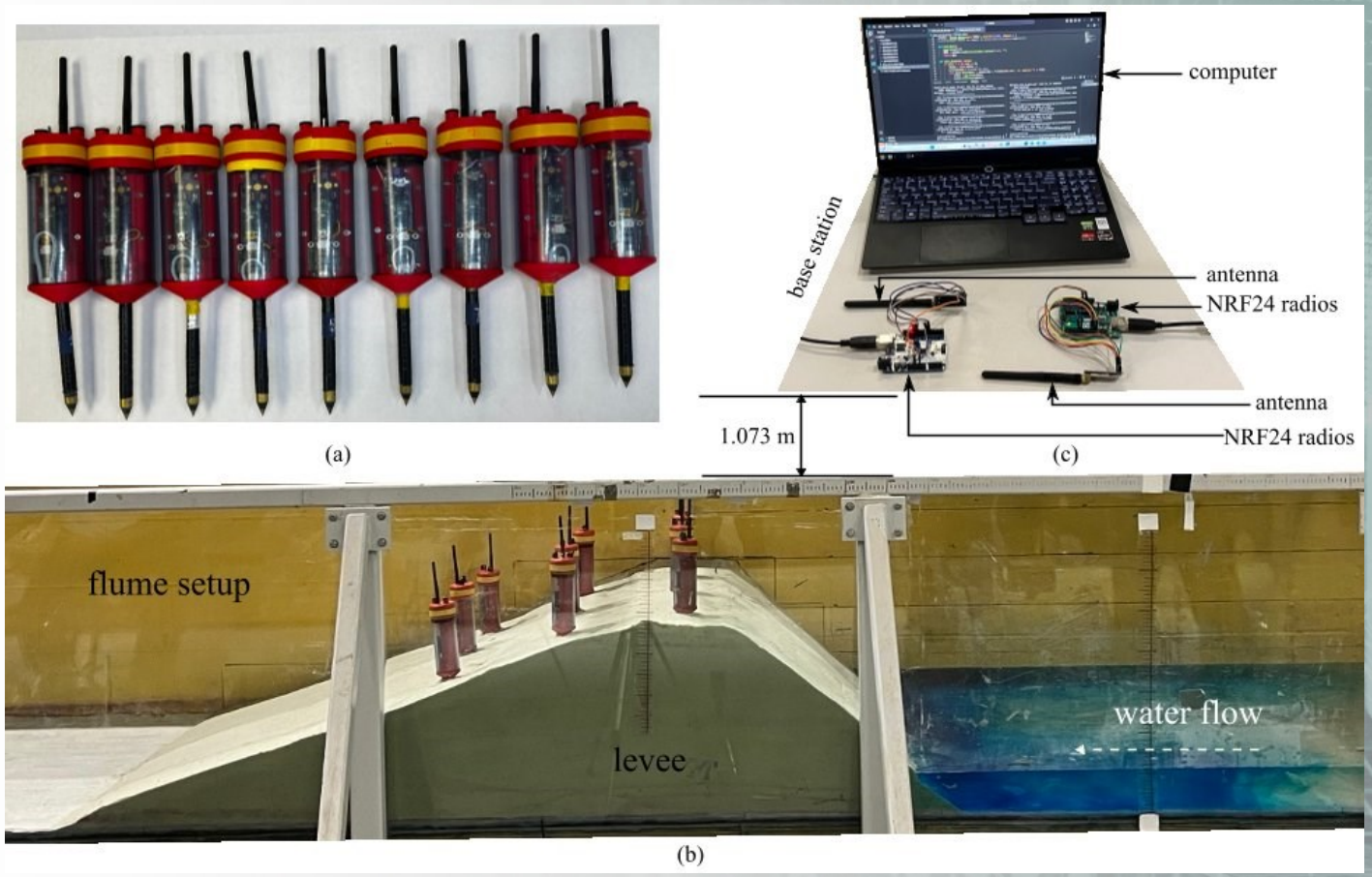
Soil Saturation Experiment Setup

- Experimental validation of wireless soil saturation monitoring system utilizing a sand-filled levee model constructed within a controlled flume environment.



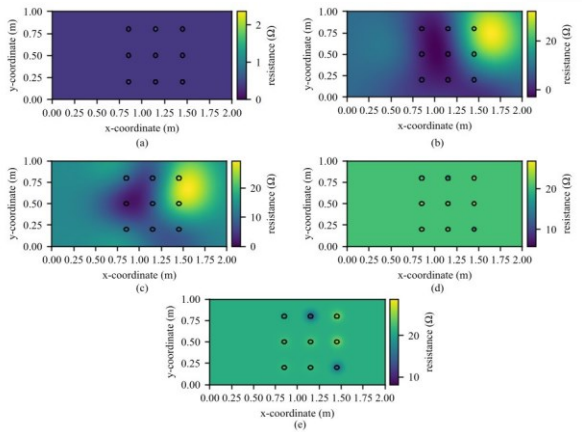
Soil Saturation Visualization

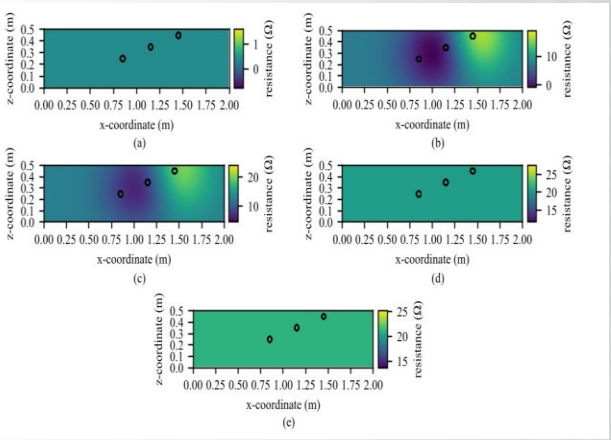
XY plane

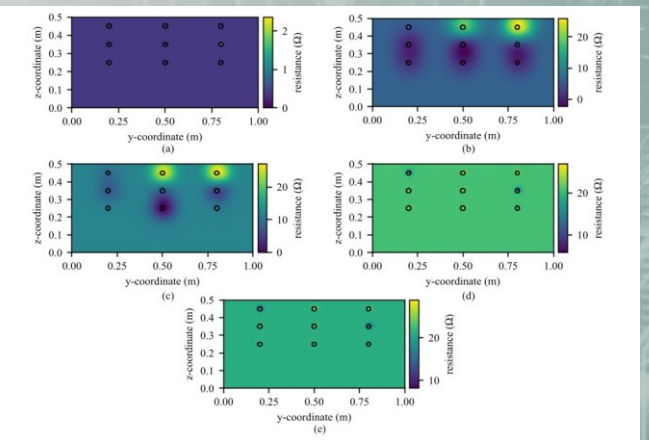
XZ plane

YZ plane

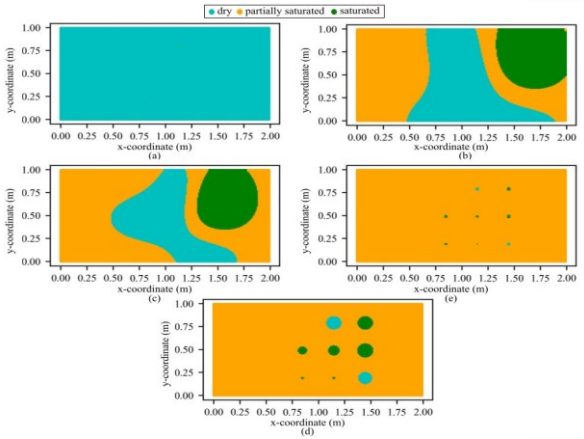
kriging

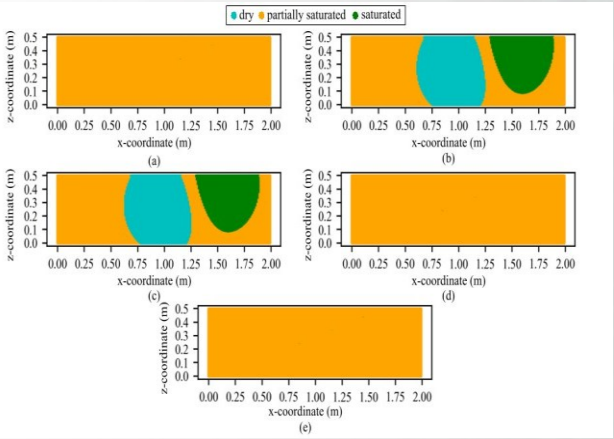


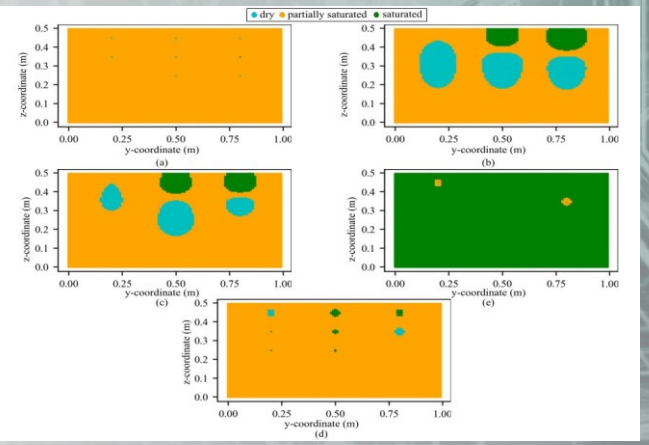




clustering

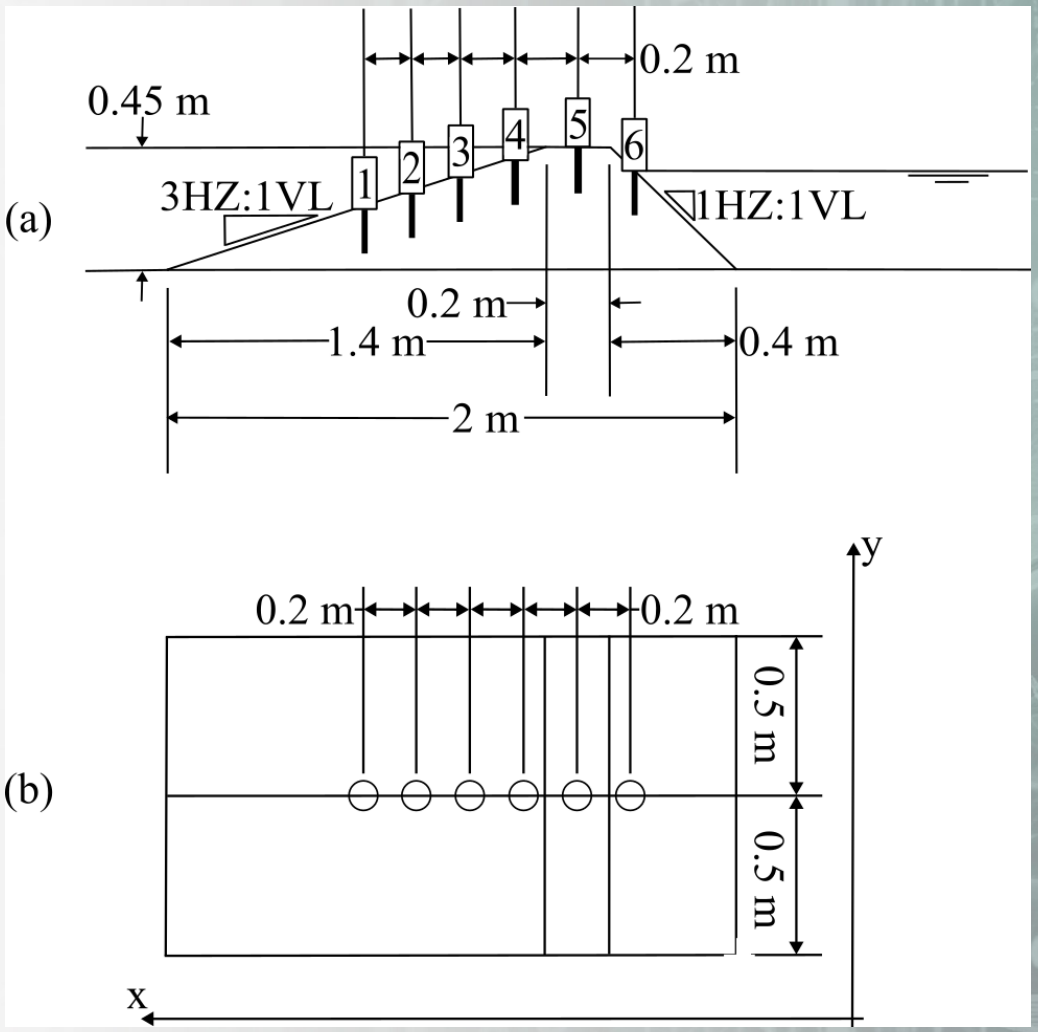






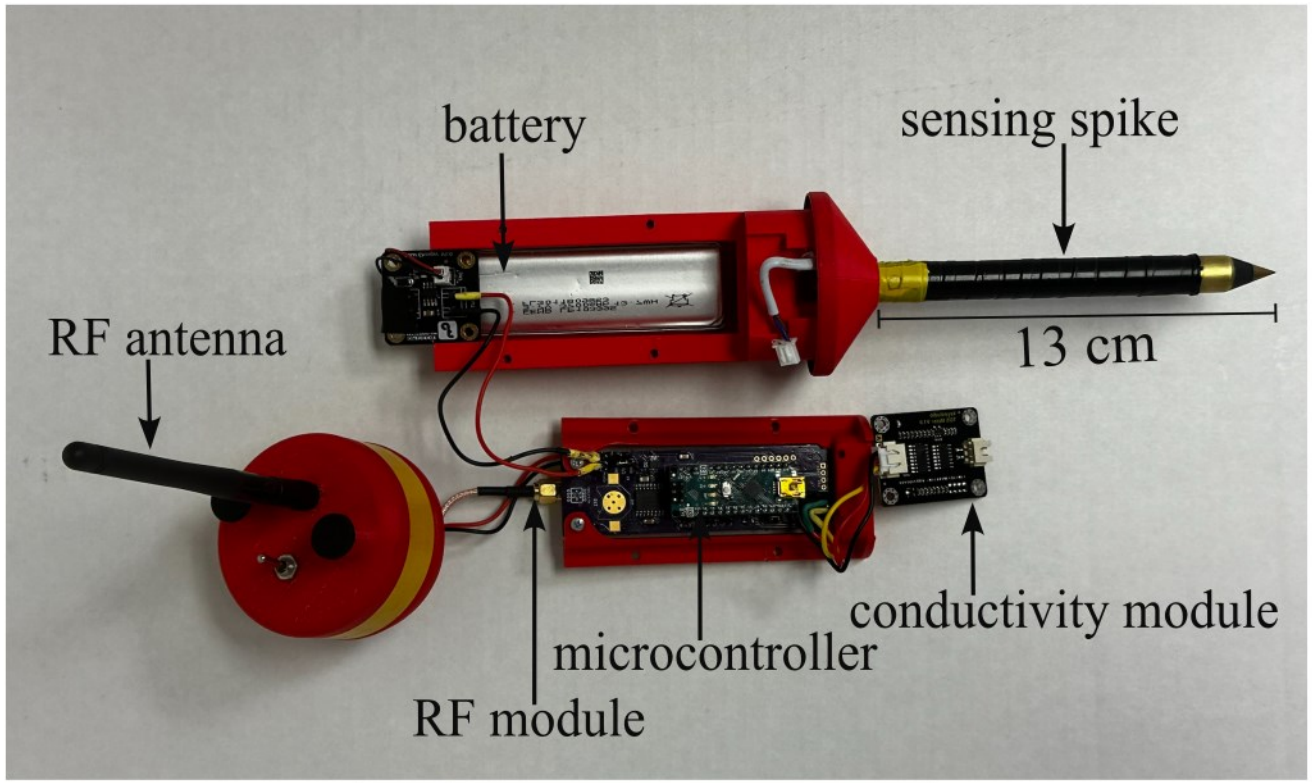
IDETC 2025 Paper Focus

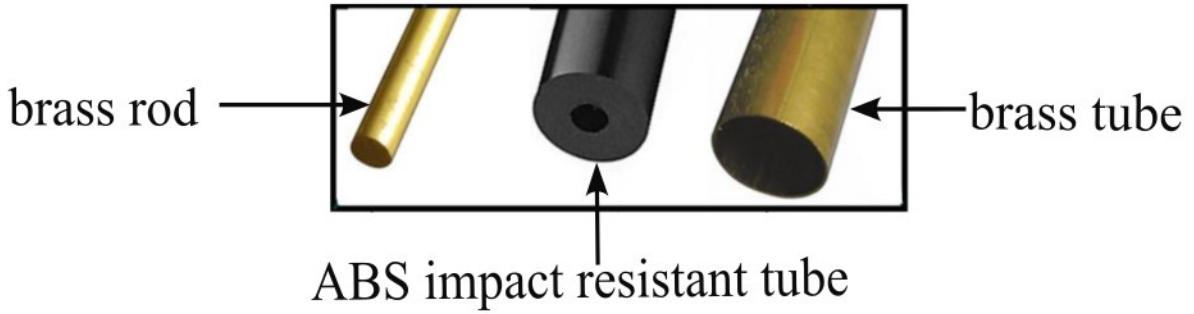
- This paper focuses on the long-term capability of the current wireless sensing spike package network.
- The long-term performance is important for continuous real-time in-situ monitoring in outdoor environments.



SPECIES Columbia V0.6.0

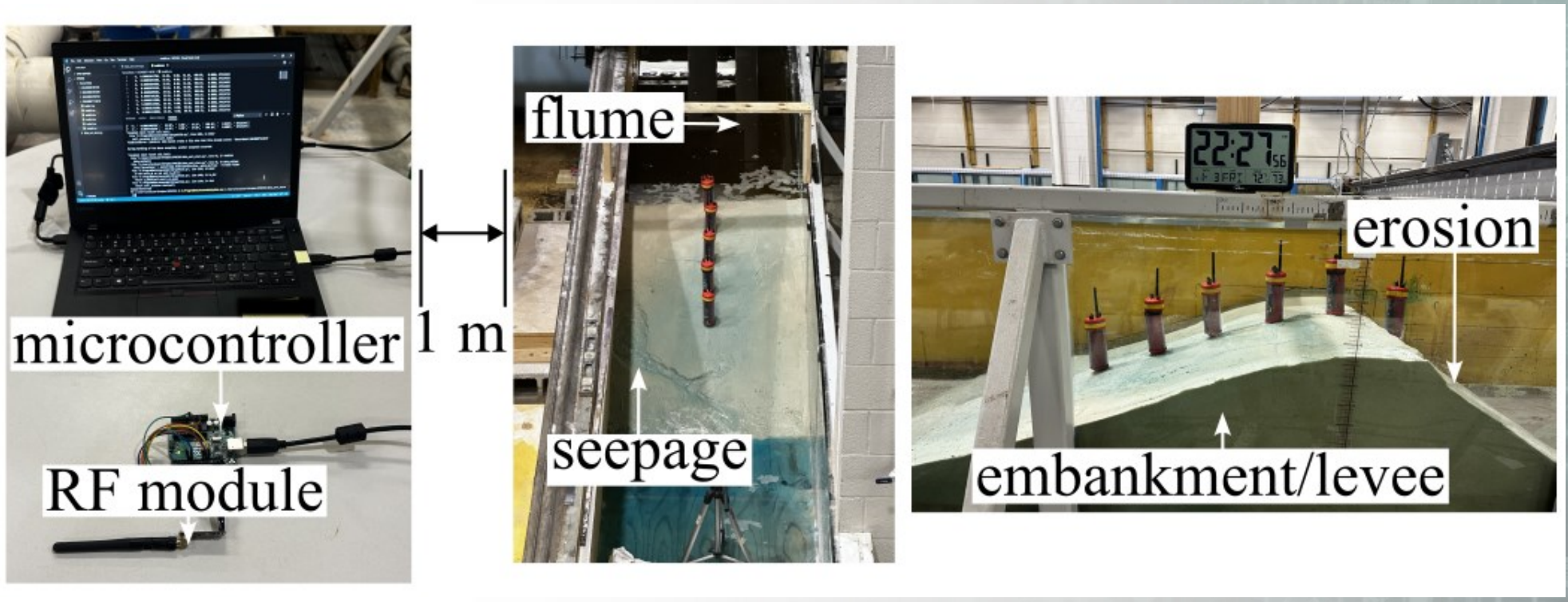
- Changes from Mississippi V0.1:
  - 3D printed PLA housing + clear PVC tube
  - Upgraded RF module (external antenna)
  - Total dissolved solids (TDS) for EC measurements
  - BME280 for internal environment readings





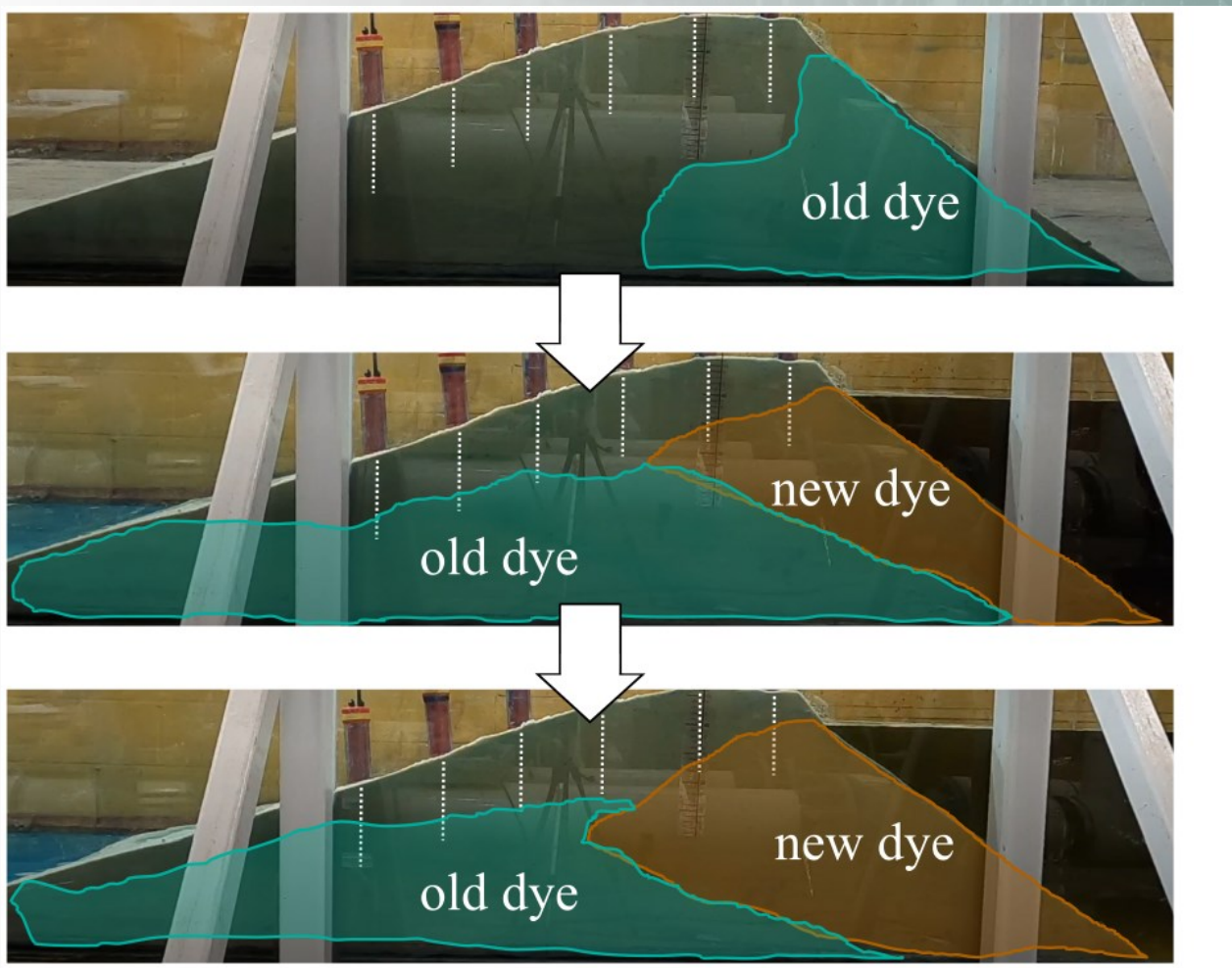
Experimental Setup

- 6 spikes in a straight line across a levee
- Controlled and monitored 144-hour test



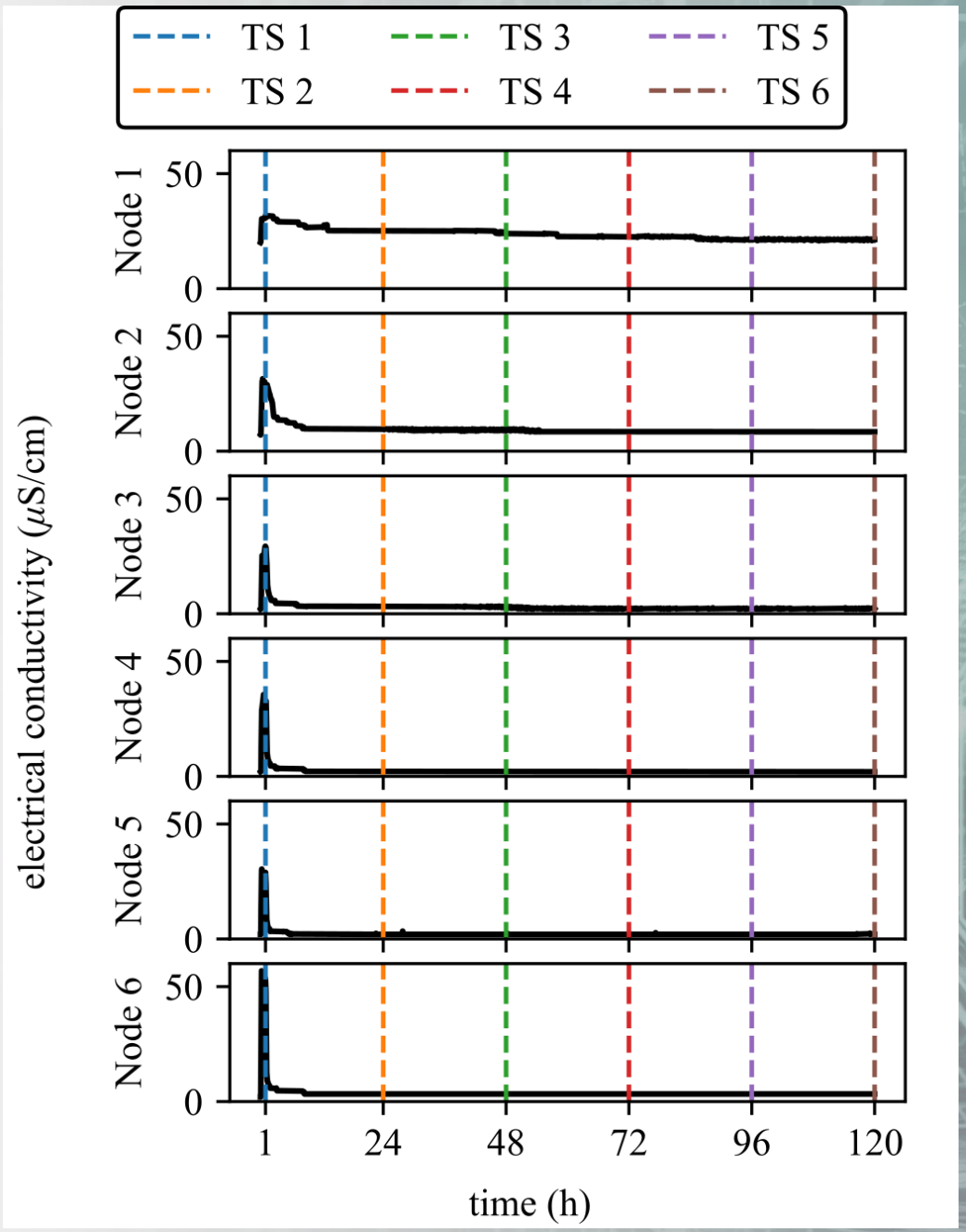
Levee Wetting

- **Visualizes Water Paths:** Dye traces reveal how water infiltrates and migrates through the levee over time, complementing sensor measurements.
- **Blue vs. Orange Dye:** Incoming orange dye pushes out remnants of blue dye from a prior test, clearly showing new infiltration fronts.

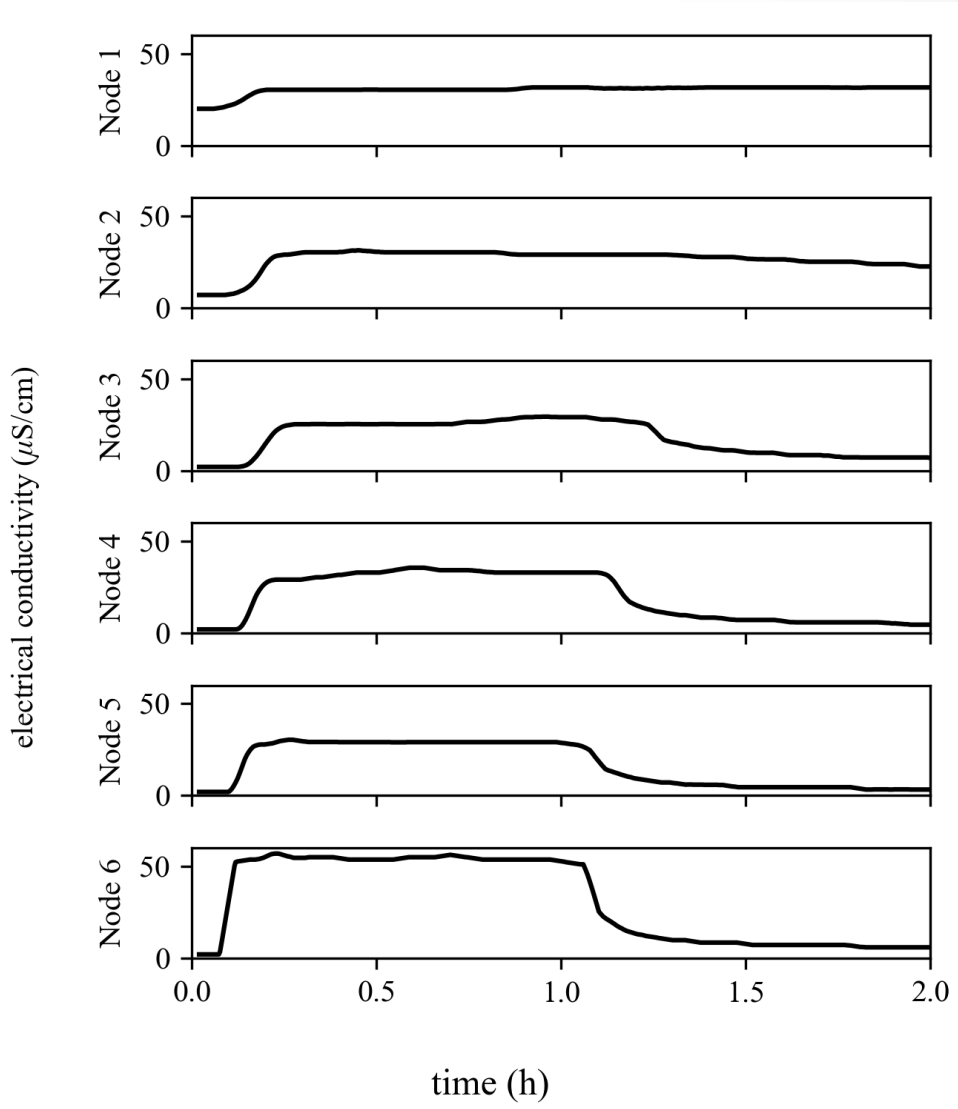


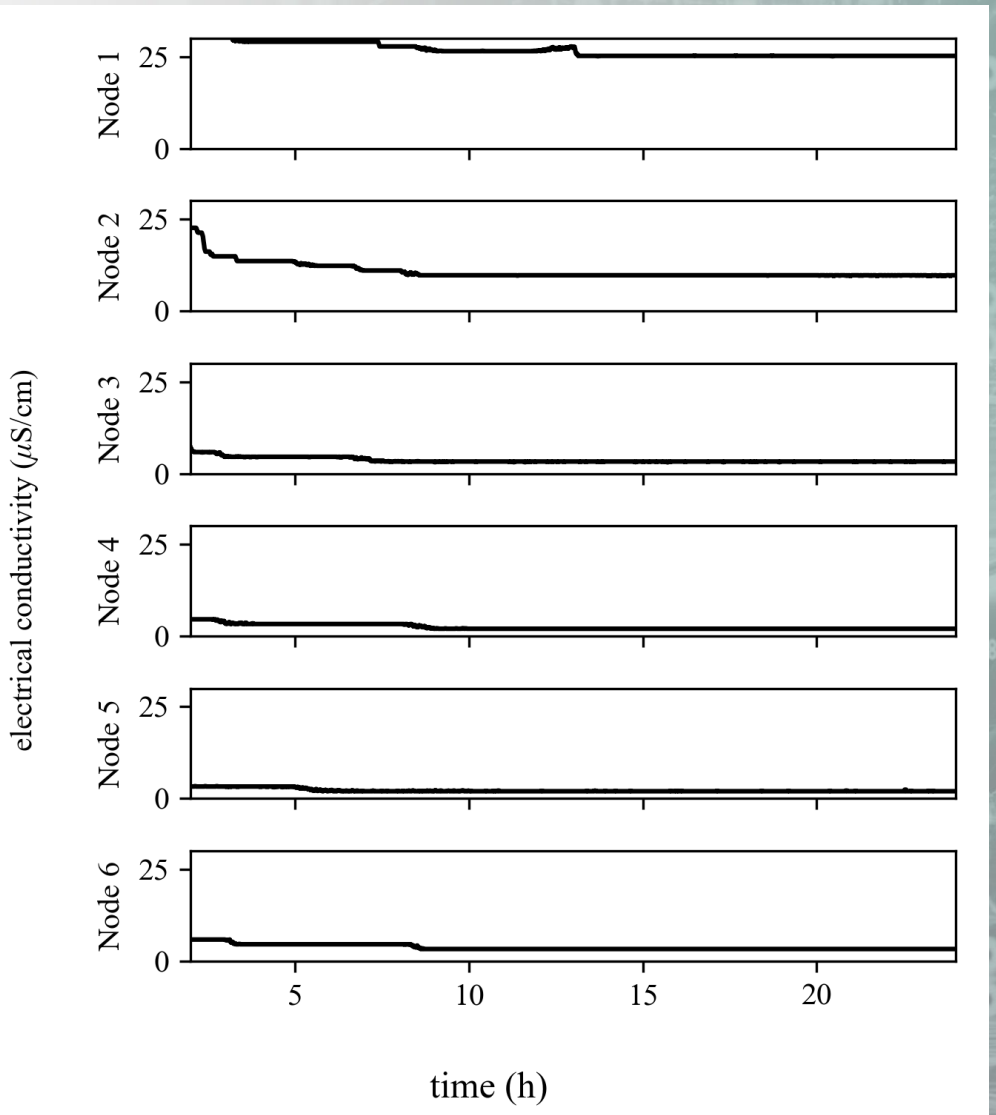
Experimental data

- **Individual Spike Trends:** Plots electrical conductivity over time for each sensing spike during the wetting-drying cycle.
- **Lower Spikes Retain Moisture:** Spikes 1 and 2, located near the base, record elevated electrical conductivity values for the longest duration, confirming water pooling at the bottom.
- **Faster Drying at Higher Locations:** Spikes 3-6, positioned higher on the embankment, show quicker decreases in conductivity as water drains downward.



Drying Cycle





Basis Splines

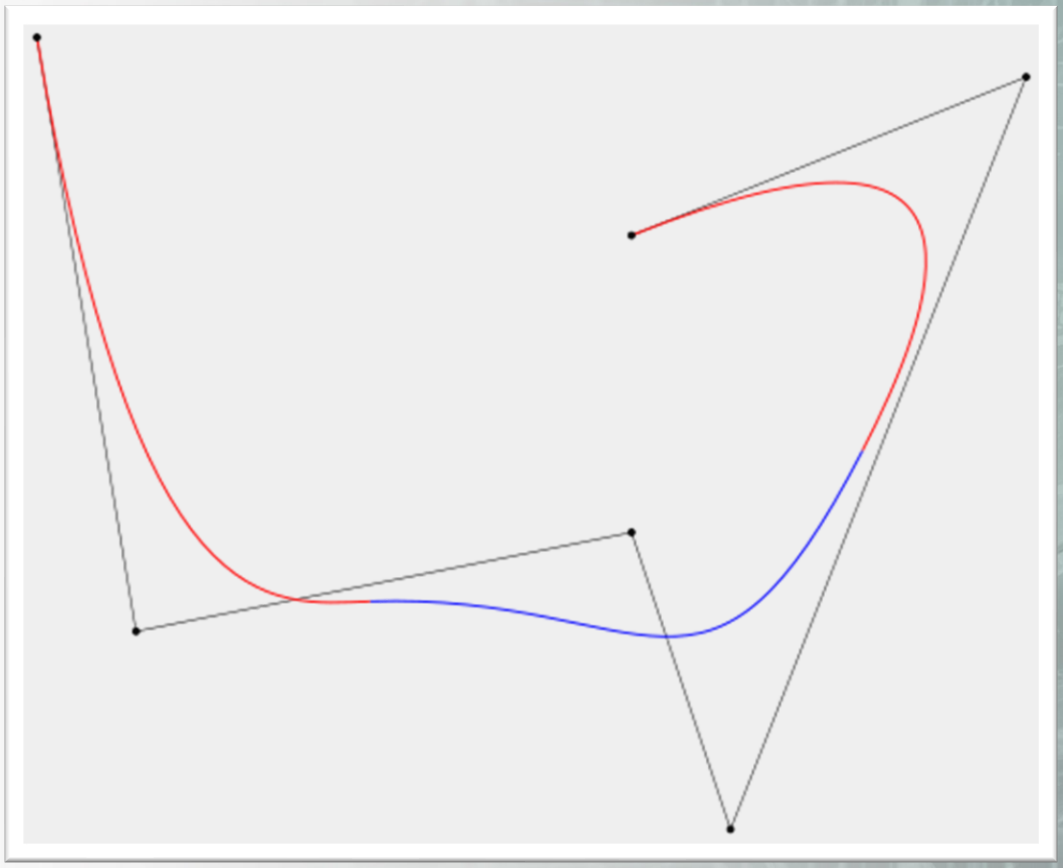
A B-Spine curve, $C(t)$ is given by

$$C(t) = \sum_{i=0} N_{i,k}(t) P_i$$

where $N_{i,k}$ are the basis functions of degree k, t is the parametric variable and P_i are the shape-defining control points.

B-splines are essentially a series of piece-wise polynomial functions used to fit non-linear models by dividing the dataset using the "knots", t_i:

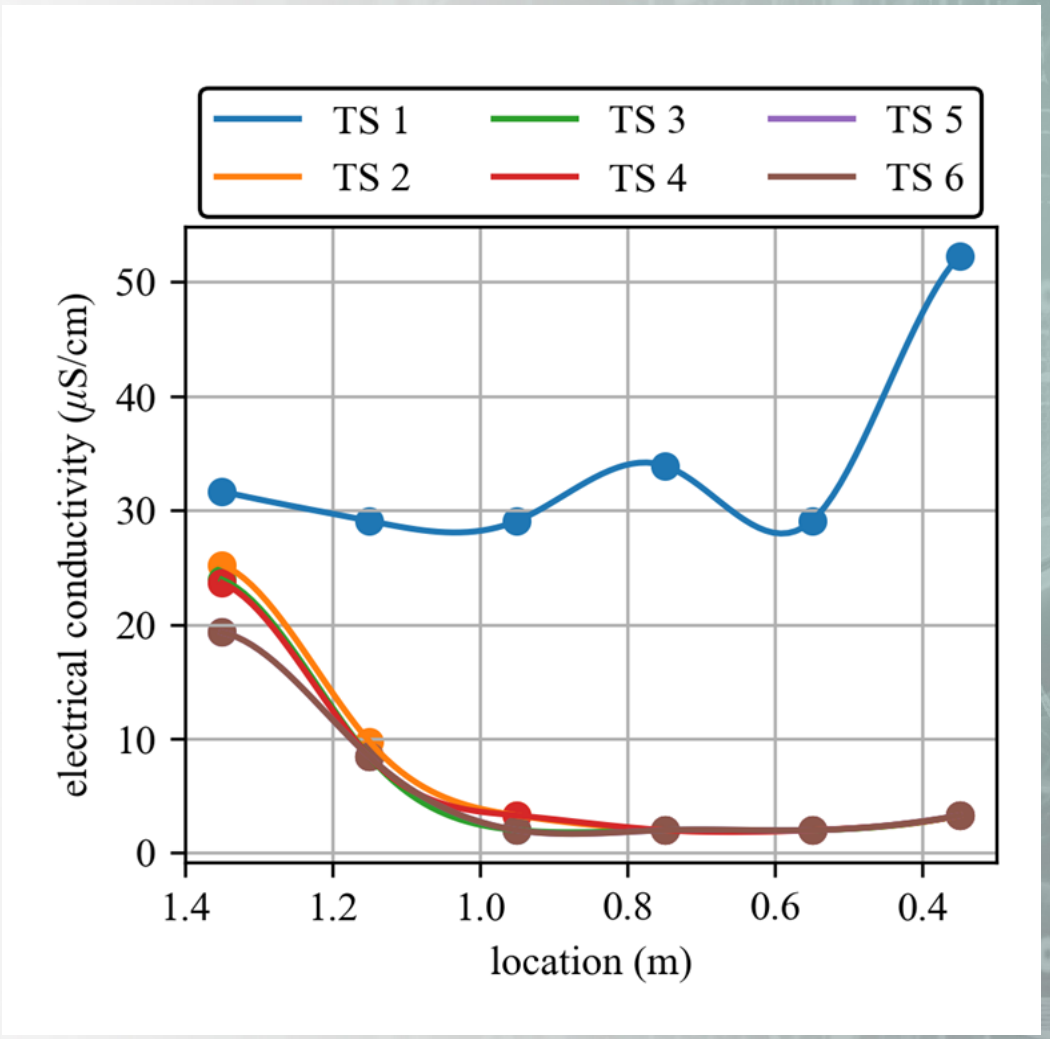
$$N_{i,0}(t) = \begin{cases} 1, t_i < t < t_{i+1} \\ 0, \text{otherwise} \end{cases}$$



https://commons.wikimedia.org/w/index.php?curid=29082536

Experimental Data

- The conductivity starts high as the levee is saturated.
- Conductivity rapidly drops as the water leaves the levee.

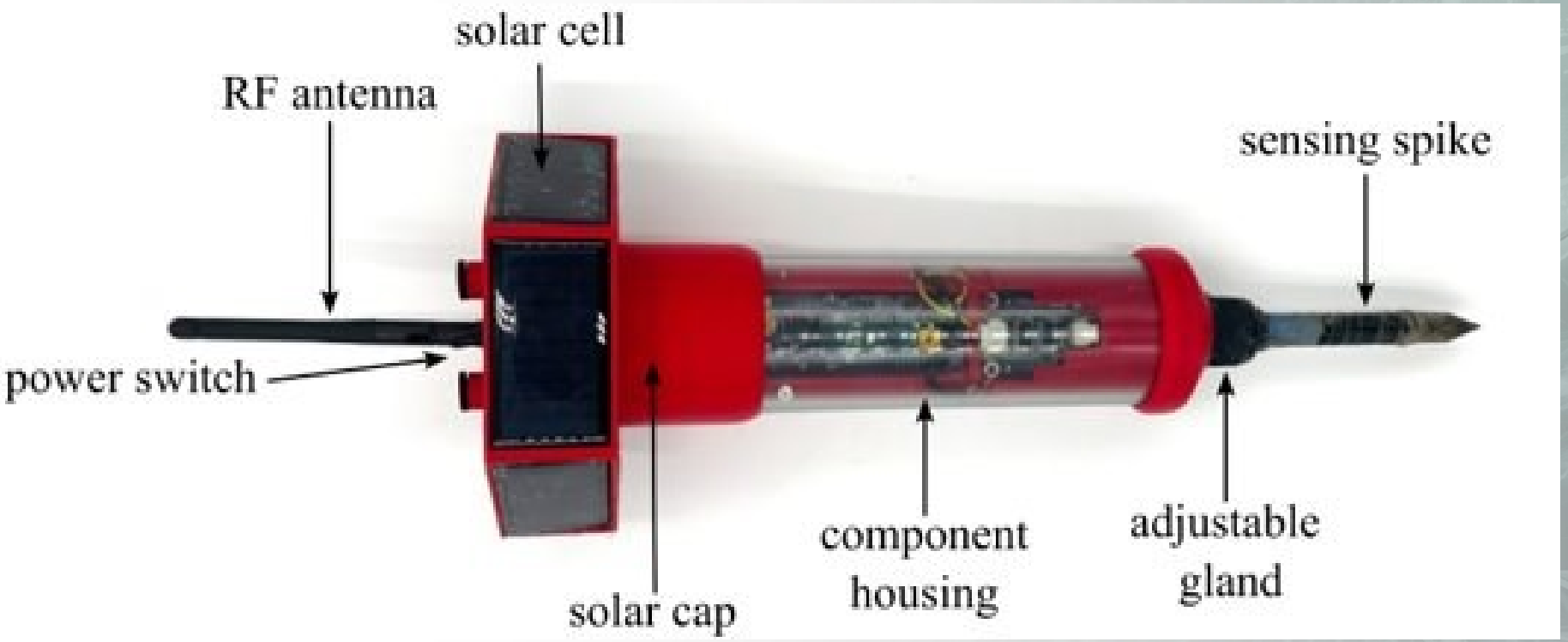


Conclusion

- Through this experiment, the self-contained electrical conductivity sensing spikes:
  - Reliably operate for extended time periods
  - Accurately measure electrical conductivity
  - Accurately transmit electrical conductivity data wirelessly
  - Accurately correspond to realistic wetting and drying cycles
- Offers a promising low-cost monitoring alternative
- Future work needed to increase robustness and accuracy

FUTURE WORK

- Future work aims to improve the resilience of the sensing spikes
  - Material choices
  - Housing designs
  - Sensors used (solar cells, IMU9DOF, geophones, RTD)



Acknowledgment

The authors gratefully acknowledge the financial support of the National Science Foundation through projects CMMI – 2152896, CPS – 2237696, and ITE – 2344357. The authors' opinions, results, conclusions, and recommendations in this material are their own and do not necessarily reflect the views of the National Science Foundation or the University of South Carolina.

Discussion

GitHub Repository

https://github.com/ARTS-Laboratory/Smart-Penetrometer-with-Edge-Computing-and-Intelligent-Embedded-Systems

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