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DISTRIBUTED REAL-TIME SOIL SATURATION ASSESSMENT IN LEVEES USING A NETWORK OF WIRELESS SENSOR PACKAGES WITH CONDUCTIVITY PROBES

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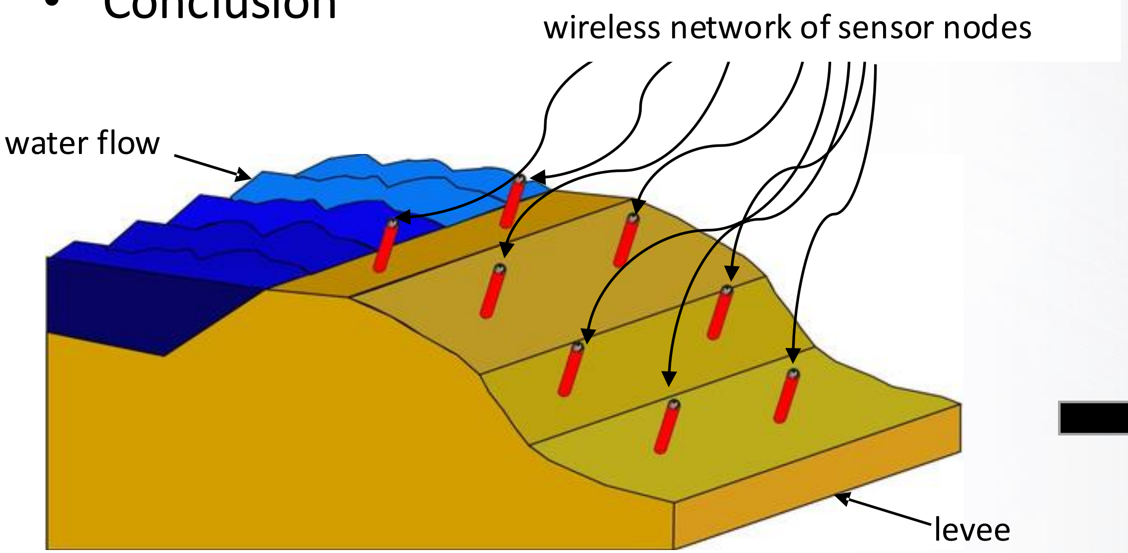
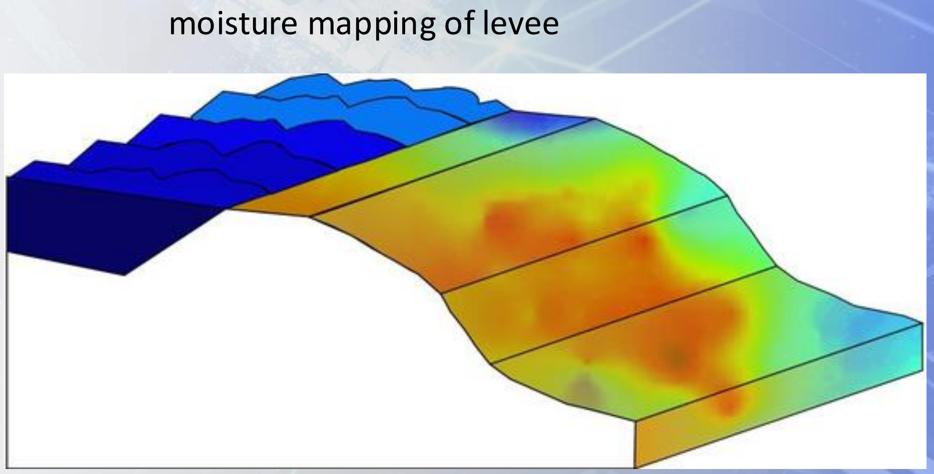
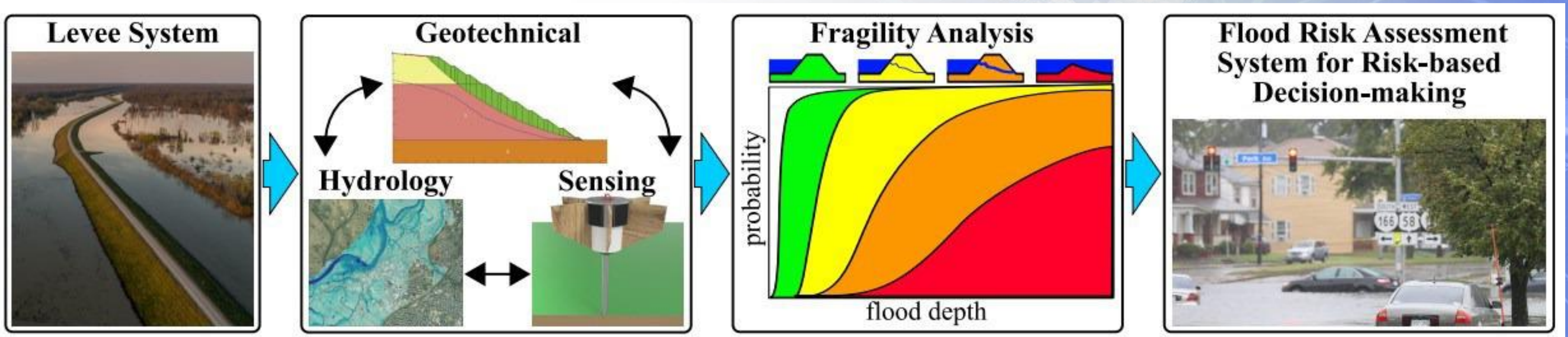




Introduction

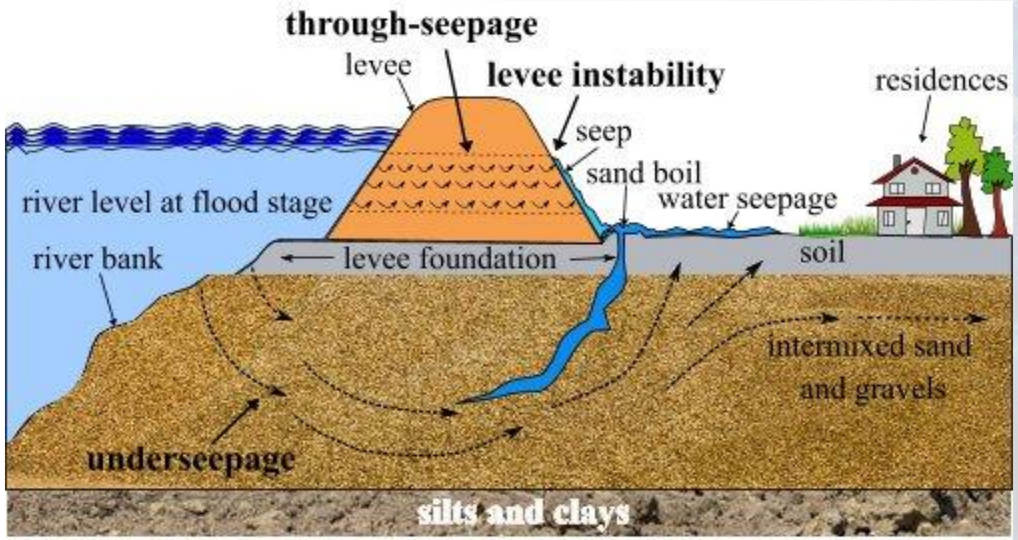
RISK ASSESSMENT OF LEVEE BREACH

- 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 is close collaboration with experts in data-driven risk assessment, geo-technical, and hydrology.



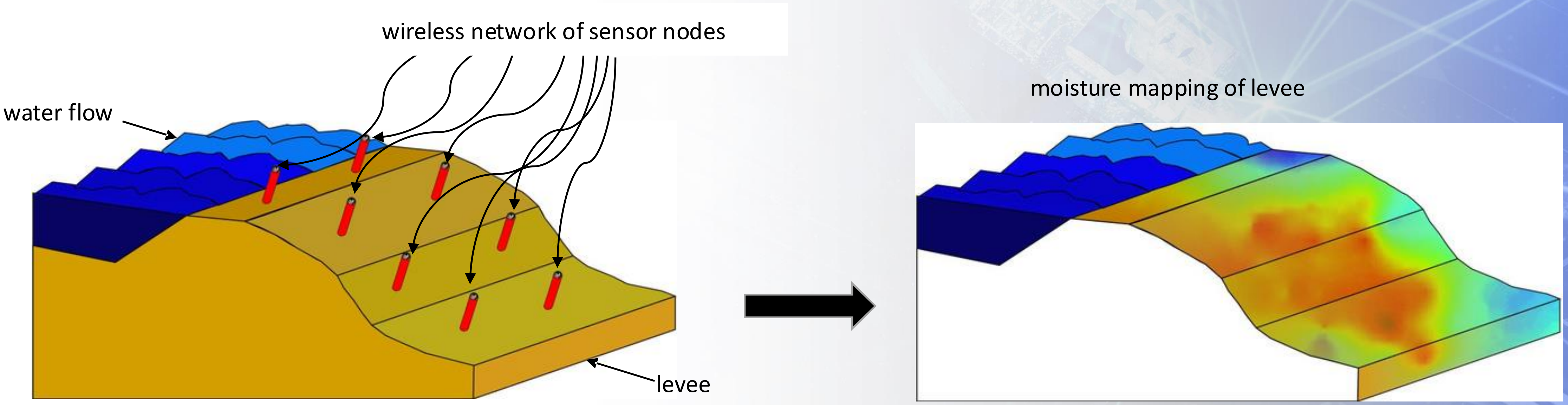
LEVEES

- A levee is a human-made embankment built to prevent the overflow of a river.
- Critical in safeguarding communities and assets from flood damage.
- Typically made of compacted dirt – erosion from fast-moving waters cause prone to breach.



CONDUCTIVITY-BASED MONITORING & WIRELESS SENSOR NETWORK

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



KRIGING

- **Kriging** is a spatial interpolation method with a few key types or models.
- **Simple kriging** assumes the model: $Z(x) = \mu + \epsilon(x)$ where,
  - Z is the kriging predicted value at x
  - μ is a known constant
  - ϵ is error (small scale variation) at x
  - Simple and not really used in practice
- **Ordinary kriging** assumes the model: $Z(x) = \mu + \epsilon(x)$ where,
  - μ is an unknown constant
  - Assumption of a constant mean is unreasonable for this case
- **Universal kriging** assumes the model: $Z(x) = \mu(x) + \epsilon(x)$ where,
  - $\mu(x)$ is a deterministic function
  - Also called kriging with extermal drift or regression kriging

Methodology

CONTRIBUTIONS

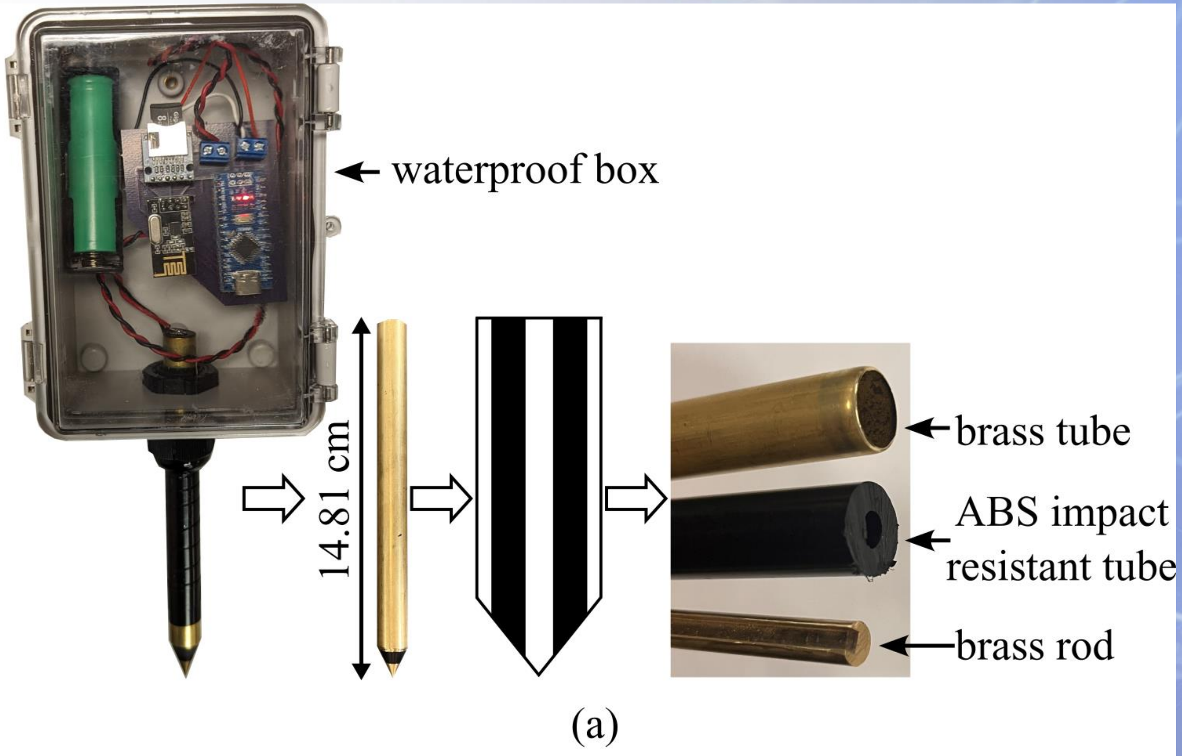
- Developing a network of wireless sensing spike packages
- Expanding the available data through kriging

HARDWARE DEVELOPMENT

- Developing the wireless communication network of the sensing spike packages
- Experimental setup

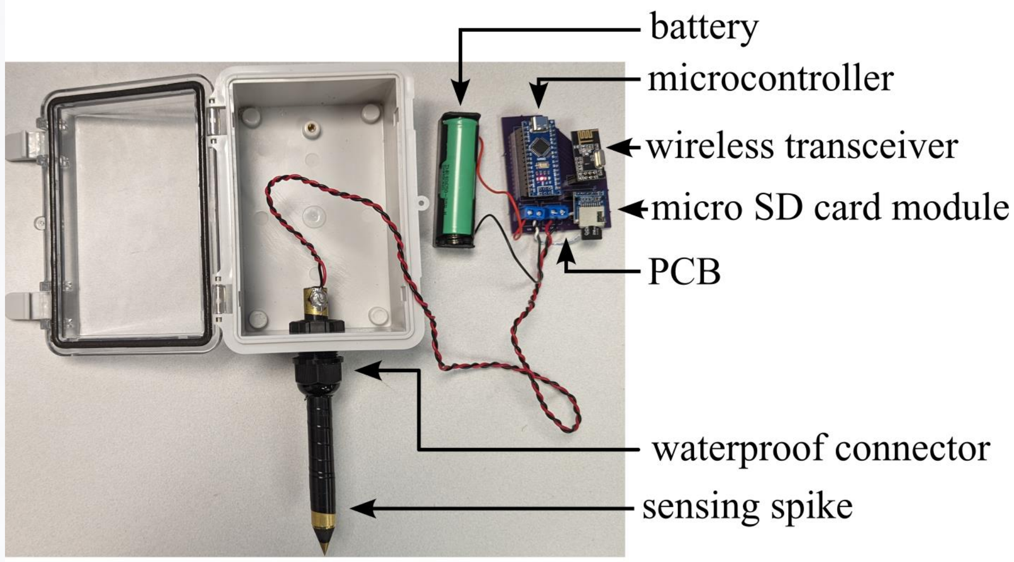
WIRELESS SENSOR PACKAGE

- Waterproof box containing electronics
- Conductivity is measured between the brass rod and tube in the spike



WIRELESS SENSOR PACKAGE

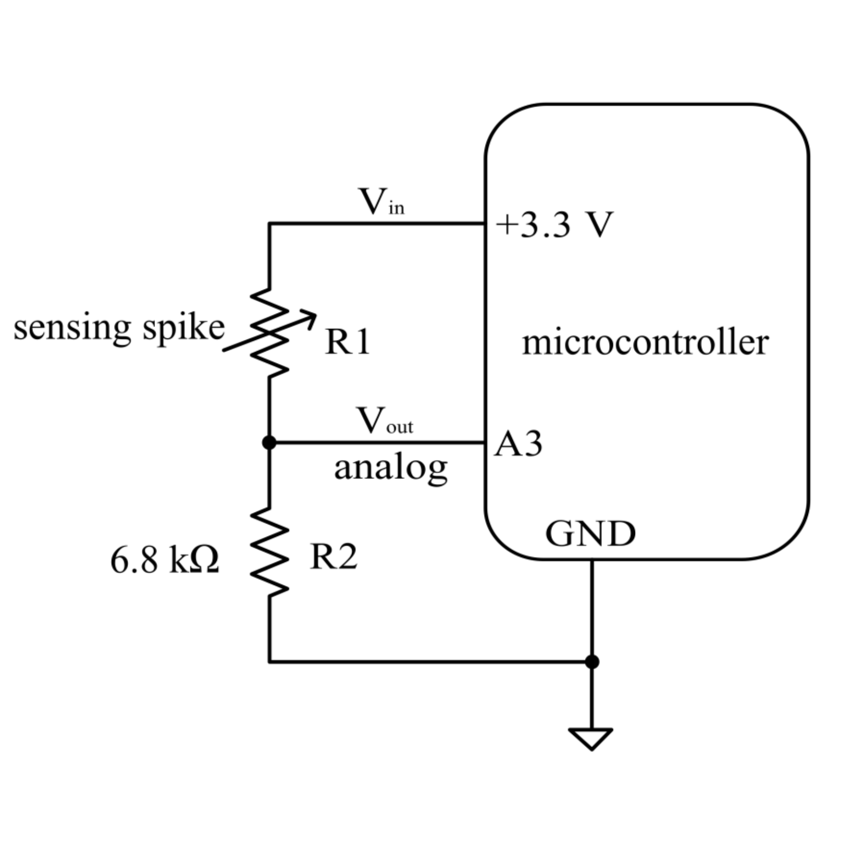
- Lithium polymer batteries are used for their high-power density and desirable recharging properties.
- An Arduino Nano microcontroller is employed as the core processor of the package for its desirable footprint.
- An nRF24L01+ wireless transceiver module is utilized for data transmission.
- A MicroSD card module is used to save data on device.
- A ½ inch waterproof connector is utilized to connect the sensing spike



(b)

SENSING NODE DATA

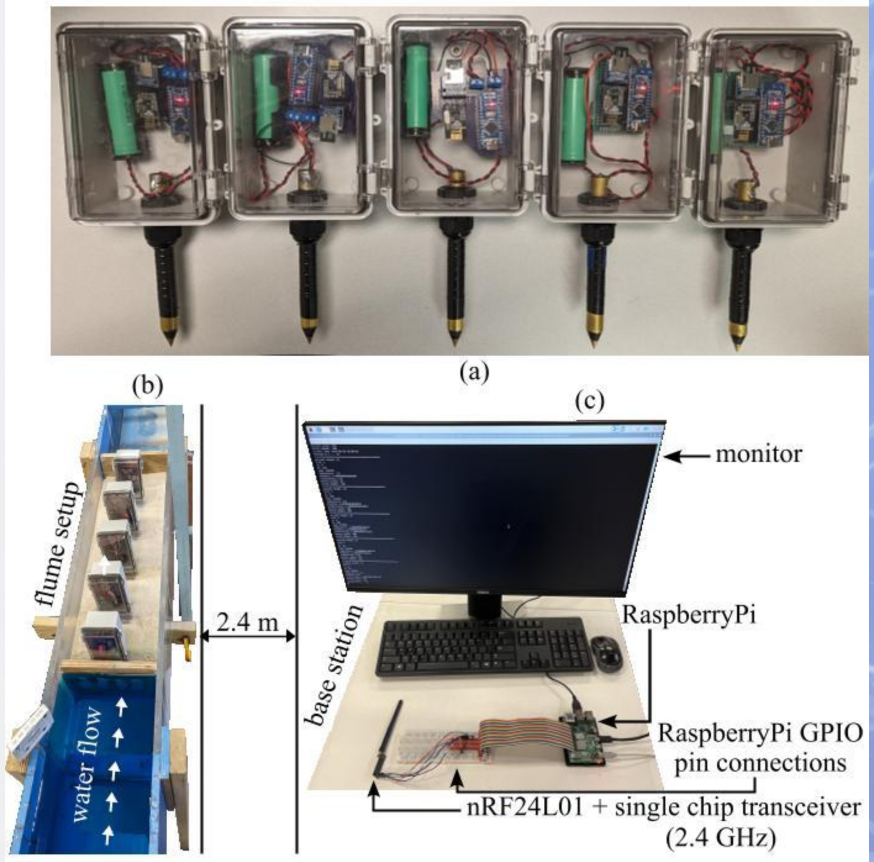
- This paper focuses on the wireless communication network aspect of the sensing spikes, so only conductivity data is recorded and transmitted.
- The sensing spike is modeled as a resistor in a voltage divider to obtain the analog V_{out} signal.



Experimental Setup

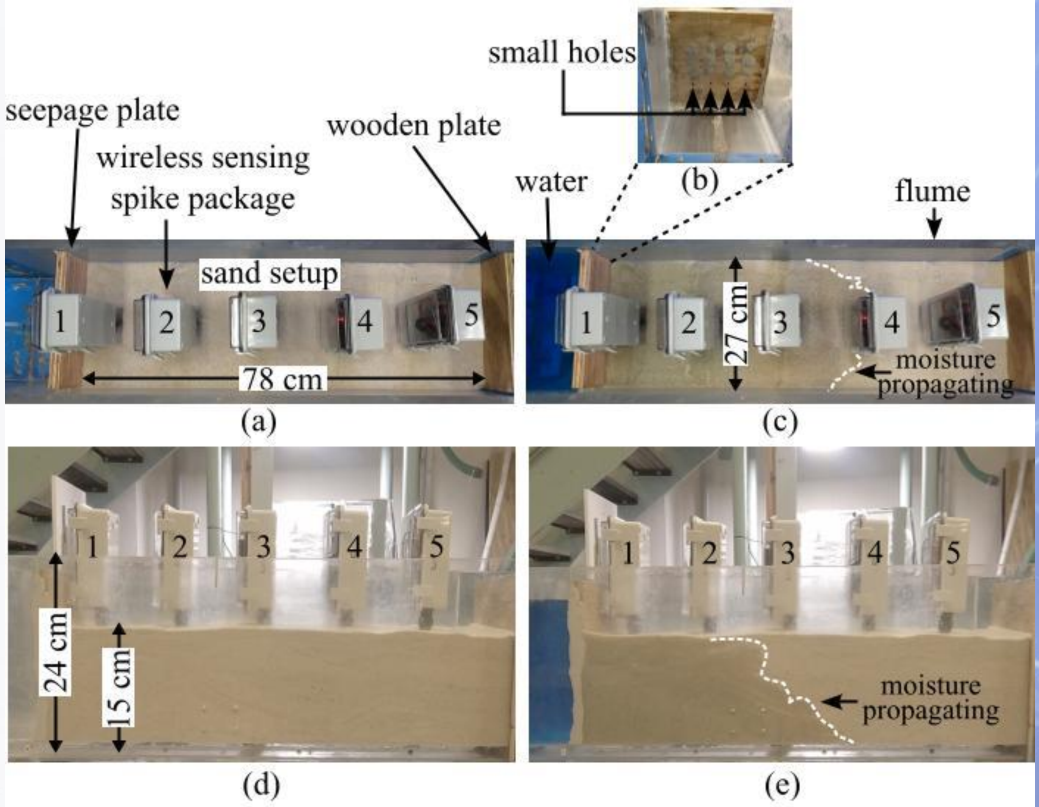
WIRELESS SENSOR PACKAGE SOIL SATURATION TEST

- **Base Station —**
  - RaspberryPi used as main controller
  - nRF24L01+ wireless transceiver module for communication with the 5 spike nodes
  - Positioned 2.4 m away from the flume setup



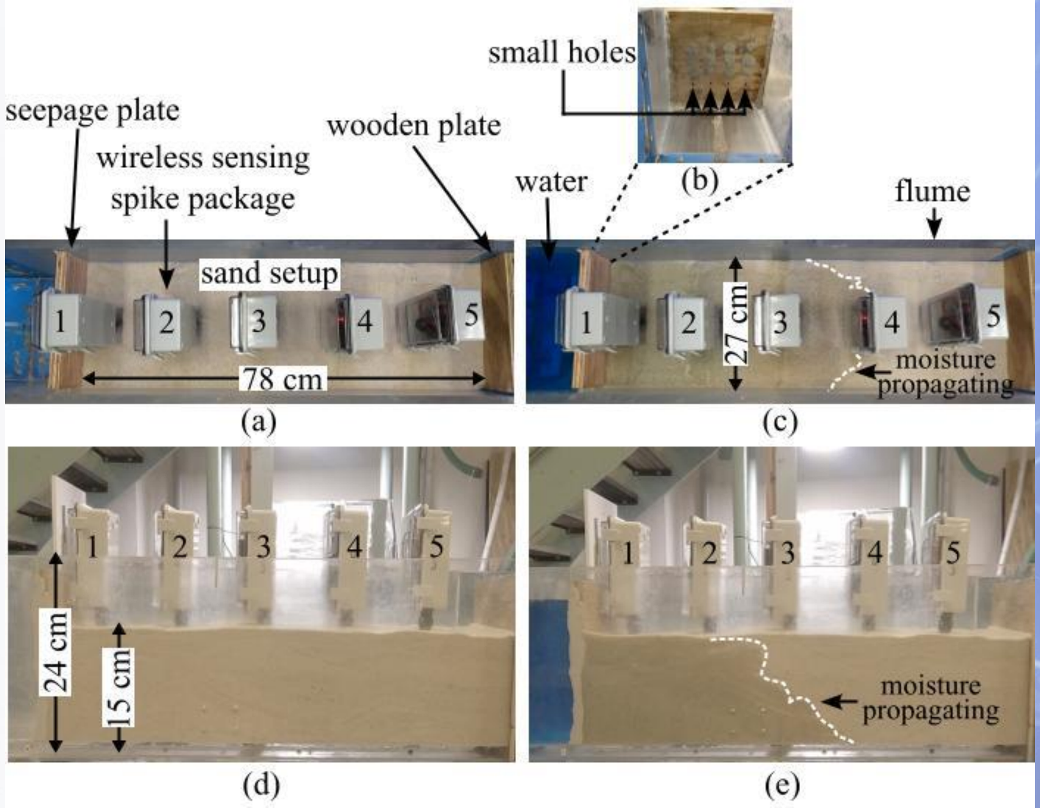
EXPERIMENTAL SETUP

- A wooden plate with small holes was placed against the flow of water in the flume, labeled as seepage plate.
- A container of 78 x 27 cm is used
- Sand is then filled and compacted to a height of 15 cm



MOISTURE TEST WITH WIRELESS SENSING NODES

- Water slowly propagates across the sand, saturating the sand
- Each node is placed in-line, downstream from the seepage plate
- Conductivity measurements are transmitted to the base station from each node and recorded



DATA INTERPOLATION

- Ordinary kriging is used to interpolate the data for all the spatial points.
- The spikes' locations are $S = [s_1, s_2, \ldots, s_5]$
- The coordinates of the spikes are $[X, Y] = [(x_1, y_1), (x_2, y_2), \ldots, (x_5, y_5)]$
- The voltage measurements are $V = [v_1, v_2, \ldots, v_5]$
- The desired prediction from the kriging model is $v_k = \mu + \epsilon(s_k)$

where,

v_k is continuous accurately map at all possible $s_k = (x_k, y_k)$

$\mu =$ the true mean of the entire dataset, the desired estimation is performed by ordinary kriging

$\epsilon(\cdot) =$ the error caused by small scale variation at s.

- The estimation $\hat{v}_k = \sum_{i=1}^{n} \lambda_i v_i$
- The loss function $L_{kriging} = E(v_k - \sum_{i=1}^{n} \lambda_i v_i) - 2m(\sum_{i=1}^{n} \lambda_i - 1)$
- The $[X, Y, V]$ is used to train the Gaussian variogram models.

CLUSTERING

- This work classifies moisture levels in earthen levees into three clusters
  - dry
  - partially saturated
  - saturated
- K-means clustering algorithm is used.
- The squared Euclidean distance is used with Voltage(v) being the sole feature considered as like

$$\|s_p - s_q\|_2^2 = (v_p - v_q)^2$$

- The iterative approach is followed to minimize the within-cluster sum of squared error (SSE) or cluster inertia.

$$L_{SSE} = \sum_{i=1}^{n} \sum_{j=1}^{m} \omega_{(i,j)} \|v_i - c_j\|_2^2$$

where,

c_j is the centroid for cluster j

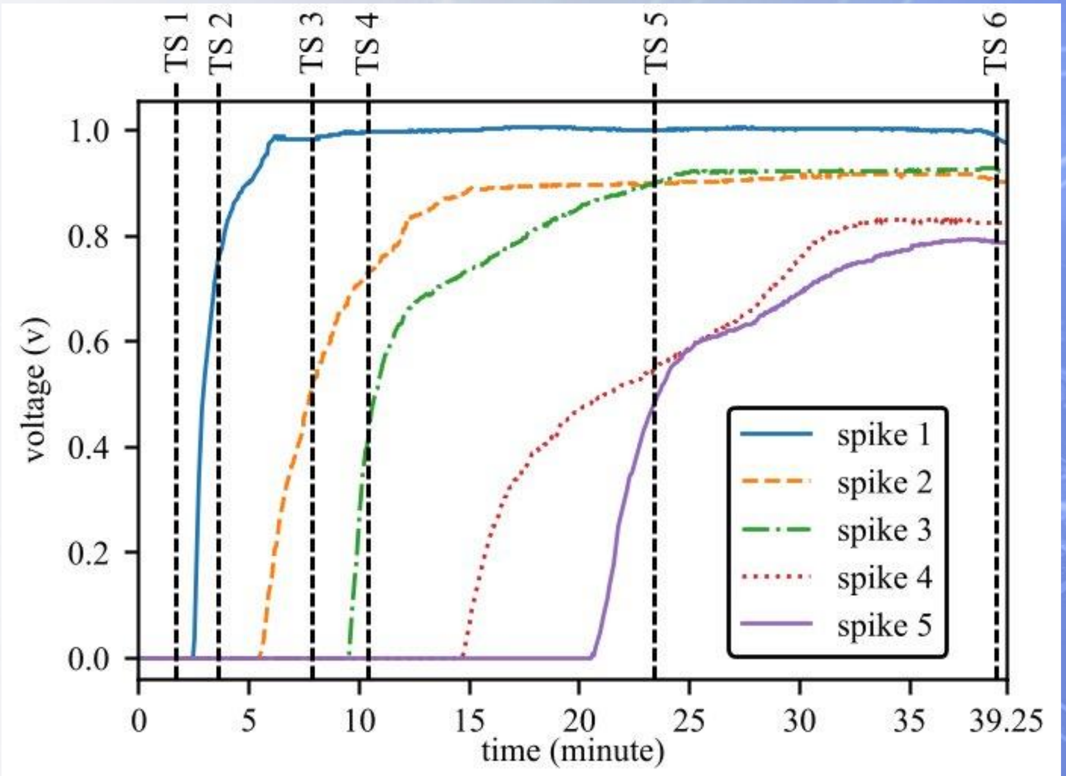
$\omega_{(i,j)} = 1$ if the sample v_i is in cluster j or 0 otherwise.

$m = 3$ for three clusters.

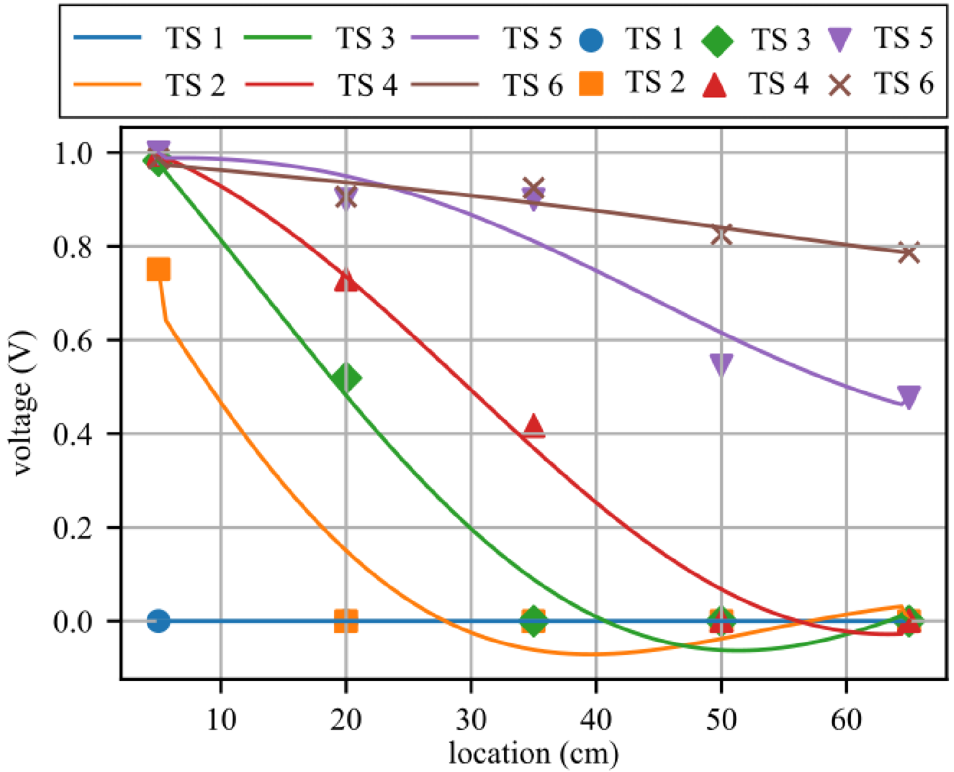
Results & Discussion

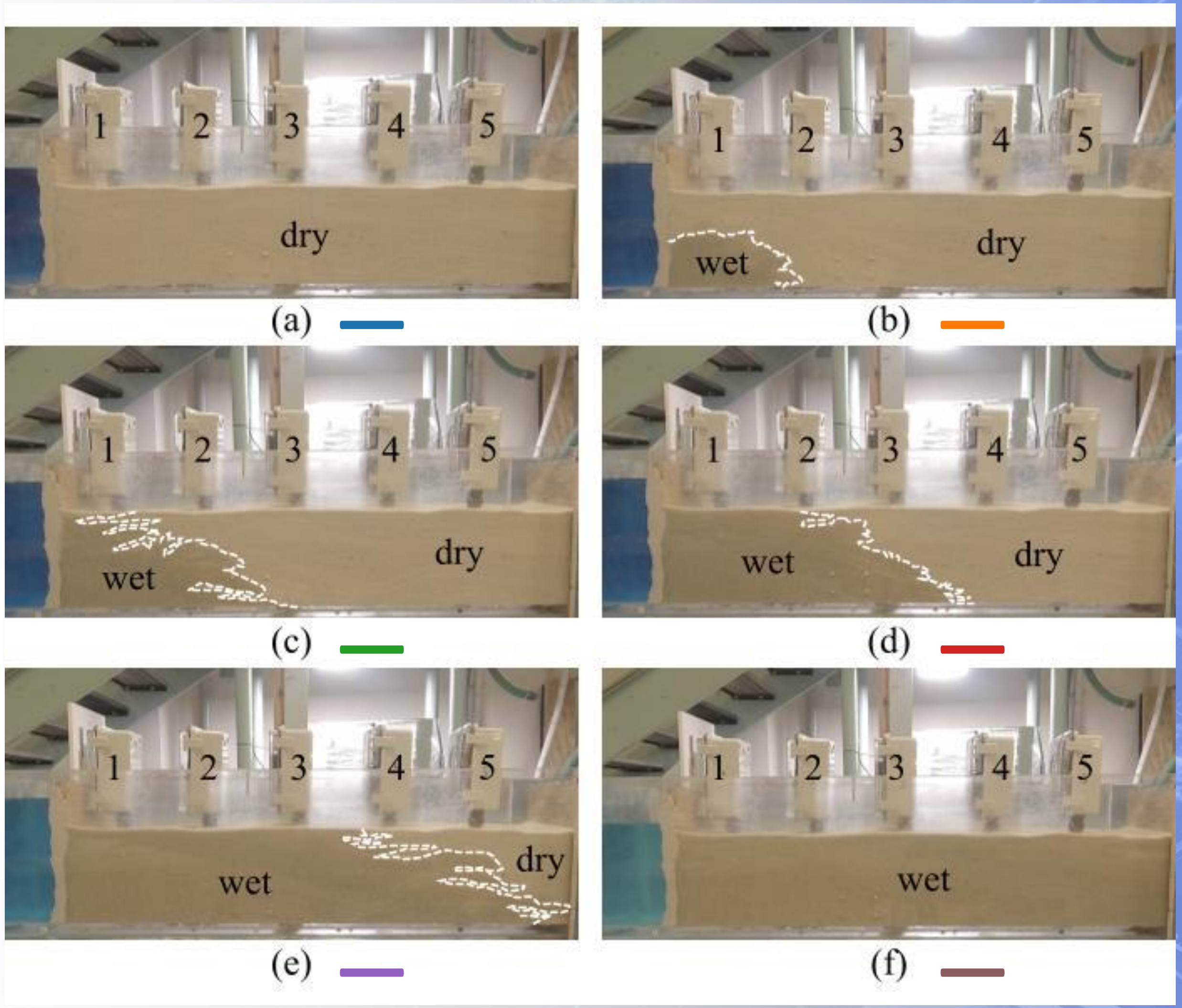
MOISTURE TEST OF WIRELESS SENSING SPIKE NETWORK

			voltage (V)				
			spike 1	spike 2	spike 3	spike 4	spike 5
time stamp (s)	TS 1	100	0.000	0.000	0.000	0.000	0.000
	TS 2	216	0.751	0.000	0.000	0.000	0.000
	TS 3	472	0.983	0.519	0.000	0.000	0.000
	TS 4	624	0.996	0.729	0.416	0.000	0.000
	TS 5	1402	1 .000	0.900	0.9 00	0.545	0.477
	TS 6	2339	0.987	0.906	0.925	0.825	0.787



1D KRIGING RESULTS





Conclusion

CONSLUSION

- A preliminary experiment of the development and validation of a UAV-deployable wireless sensing spike network for soil conductivity levels in levees.
- Demonstrated a wireless network of sensing spikes in lab-scale testing.
- To identify possible levee failure concerns and maintenance needs, this work evaluates soil conditions utilizing a wireless network of conductivity sensing spikes.

Open-Source Hardware Designs

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

ACKNOWLEDGEMENT

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Thanks!

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