ENTS: Experiences in Co-Designed Environmental Sensing

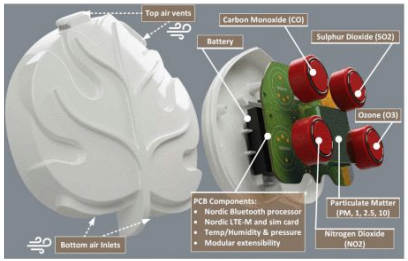
2026 UC Open

John Madden

UC SANTA CRUZ

Wireless Sensor Networks (WSNs)

Pible [3]



Eclipse [1]

Duemer [2]

Signpost [5]

Synergy [4]

[1] M. I. G. Daepp *et al.*, "Eclipse: An End-to-End Platform for Low-Cost, Hyperlocal Environmental Sensing in Cities," in *2022 21st ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN)*, May 2022, pp. 28–40. doi: 10.1109/IPSN54338.2022.00010.

[2] M. Deumer *et al.*, "A battery-free wearable system for on-device human activity recognition using kinetic energy harvesting," in *Proceedings of the 2023 International Conference on Embedded Wireless Systems and Networks*, in EWSN '23. International Conference on Embedded Wireless Systems and Networks (EWSN), 2023, pp. 163–169.

[3] F. Fraternali, B. Balaji, Y. Agarwal, L. Benini, and R. Gupta, "Pible: battery-free mote for perpetual indoor BLE applications," in *Proceedings of the 5th Conference on Systems for Built Environments*, Shenzen China: ACM, Nov. 2018, pp. 168–171. doi: 10.1145/3276774.3282822.

[4] M. P. Andersen, G. Fierro, and D. E. Culler, "System Design for a Synergistic, Low Power Mote/BLE Embedded Platform," in *2016 15th ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN)*, Apr. 2016, pp. 1–12. doi: 10.1109/IPSN.2016.7460722.

[5] J. Adkins *et al.*, "The Signpost Platform for City-Scale Sensing," in *2018 17th ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN)*, Porto: IEEE, Apr. 2018, pp. 188–199. doi: 10.1109/IPSN.2018.00047.

What has worked

Puma Project [1]

Telos [2]

[1] “Santa Cruz Puma Project.” Accessed: Apr. 20, 2026. [Online]. Available: https://www.santacruzpumas.org/
[2] J. Polastre, R. Szewczyk, and D. Culler, “Telos: enabling ultra-low power wireless research,” in *IPSN 2005. Fourth International Symposium on Information Processing in Sensor Networks, 2005.*, Los Angeles, CA, USA: IEEE, 2005, pp. 364–369. doi: 10.1109/IPSN.2005.1440950.

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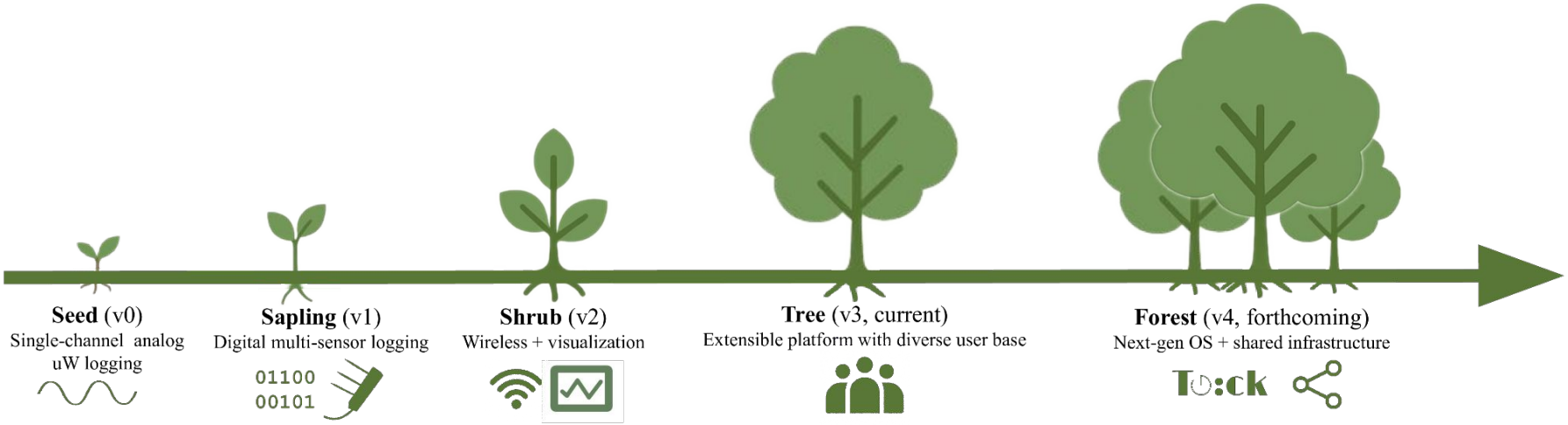
Design principles for successful WSNs

01 **Design for breadth**

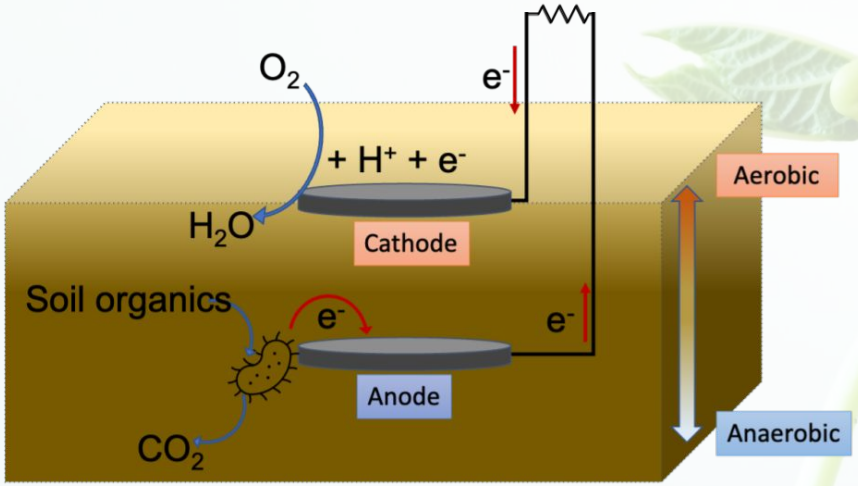
02 **Extensibility**

03 **Co-design and outreach**

Environmental NeTworked Sensing (ENTS)



Use case: uW level power measurements



[1]

[3]

[2]

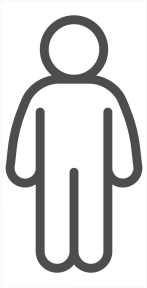
[1] Keithley, "DAQ6510 Data Acquisition and Logging, Multimeter System." Accessed: Jun. 27, 2025. [Online]. Available: https://www.tek.com/en/products/keithley/digital-multimeter/keithley-daq6510

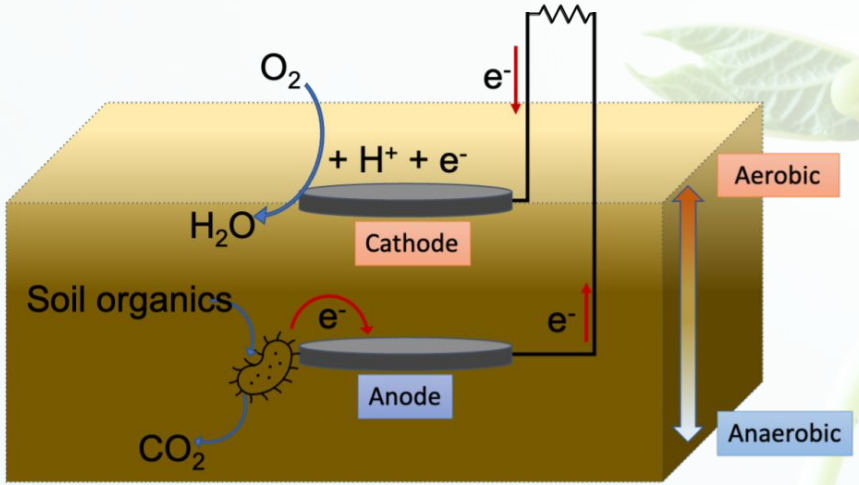
[2] Fluke, "Fluke 117 Multimeter." Accessed: Apr. 20, 2026. [Online]. Available: https://www.fluke.com/en-us/product/electrical-testing/digital-multimeters/fluke-117

[3] Magical Microbes, "MudWatt: Grow a Living Fuel Cell," Magical Microbes. Accessed: Apr. 20, 2026. [Online]. Available: https://www.magicalmicrobes.com/products/mudwatt-clean-energy-from-mud

Seed (v0) → Sapling (v1) → Shrub (v2) → Tree (v3) → Forest (v4)

Use case: uW level power measurements





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[1] Keithley, "DAQ6510 Data Acquisition and Logging, Multimeter System." Accessed: Jun. 27, 2025. [Online]. Available: https://www.tek.com/en/products/keithley/digital-multimeter/keithley-daq6510

[2] Fluke, "Fluke 117 Multimeter." Accessed: Apr. 20, 2026. [Online]. Available: https://www.fluke.com/en-us/product/electrical-testing/digital-multimeters/fluke-117

[3] Magical Microbes, "MudWatt: Grow a Living Fuel Cell," Magical Microbes. Accessed: Apr. 20, 2026. [Online]. Available: https://www.magicalmicrobes.com/products/mudwatt-clean-energy-from-mud

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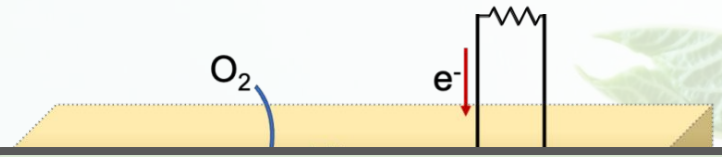

Takeaway: To build an effectual WSN platform, start by being good for one thing, in our case analog measurement.

[3]

[2]

[1] Keithley, “DAQ6510 Data Acquisition and Logging, Multimeter System.” Accessed: Jun. 27, 2025. [Online]. Available: https://www.tek.com/en/products/keithley/digital-multimeter/keithley-daq6510

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[3] Magical Microbes, “MudWatt: Grow a Living Fuel Cell,” Magical Microbes. Accessed: Apr. 20, 2026. [Online]. Available: https://www.magicalmicrobes.com/products/mudwatt-clean-energy-from-mud

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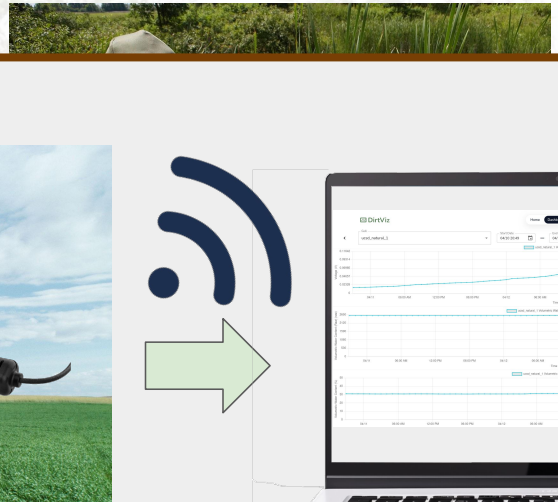
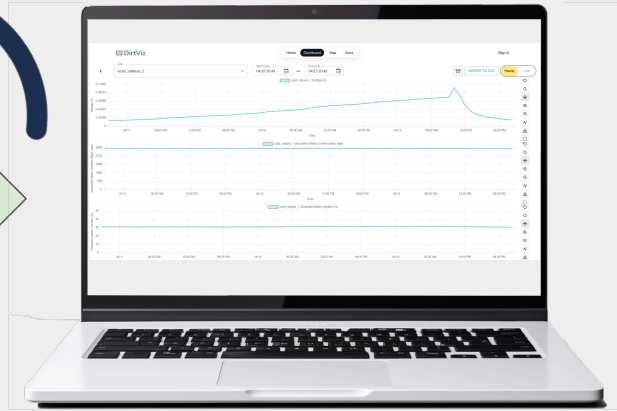
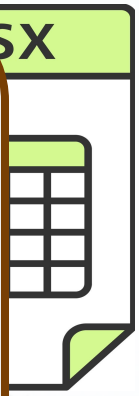
Problem: Hand collected data is slow

Seed (v0) → Sapling (v1) → Shrub (v2) → Tree (v3) → Forest (v4)

Goal: Enable wireless data collection

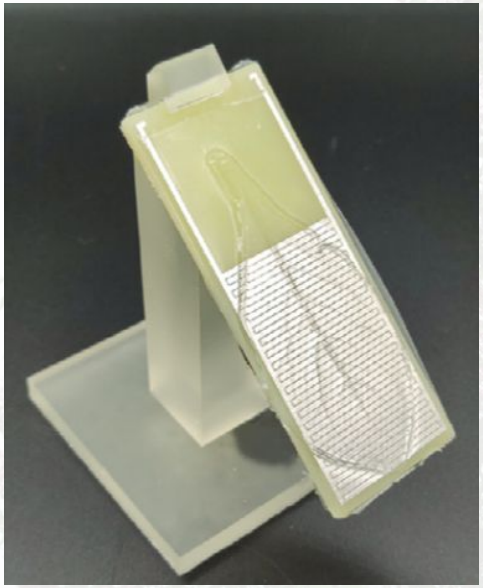






Seed (v0) → Sapling (v1) → **Shrub (v2)** → Tree (v3) → Forest (v4)

Use case: Biomemetic leaf wetness sensor



[1] B. H. Nguyen, G. S. Gilbert, and M. Rolandi, "A Bio-Mimetic Leaf Wetness Sensor from Replica Molding of Leaves," *Advanced Sensor Research*, vol. 2, no. 6, p. 2200033, Jun. 2023, doi: 10.1002/adsr.202200033.

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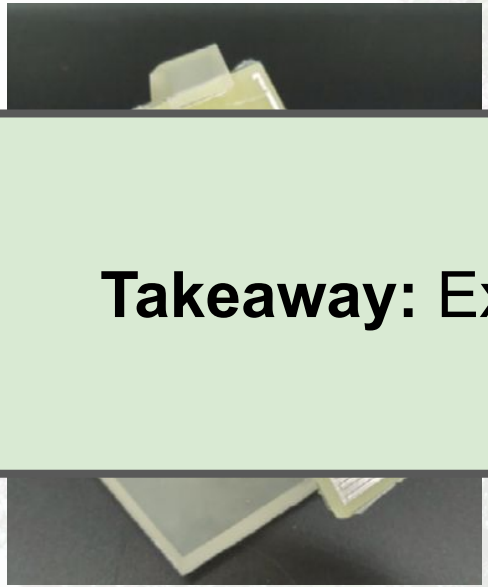
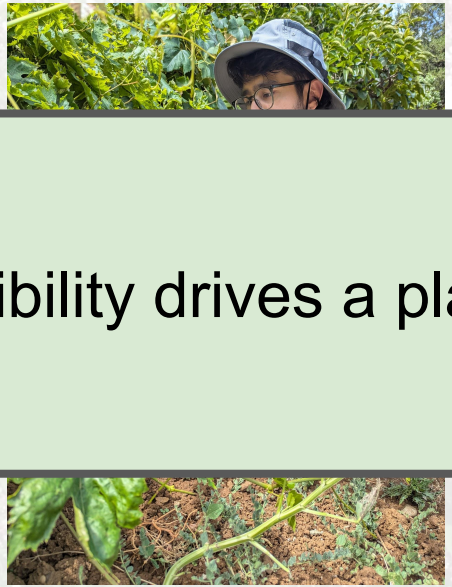
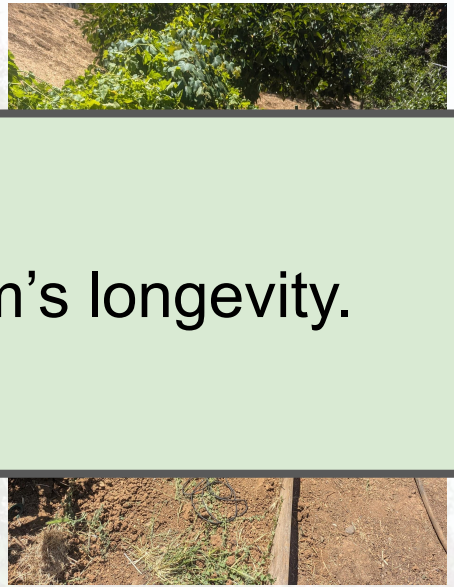

Takeaway: Extensibility drives a platform's longevity.

[1] B. H. Nguyen, G. S. Gilbert, and M. Rolandi, "A Bio-Mimetic Leaf Wetness Sensor from Replica Molding of Leaves," *Advanced Sensor Research*, vol. 2, no. 6, p. 2200033, Jun. 2023, doi: 10.1002/adsr.202200033.

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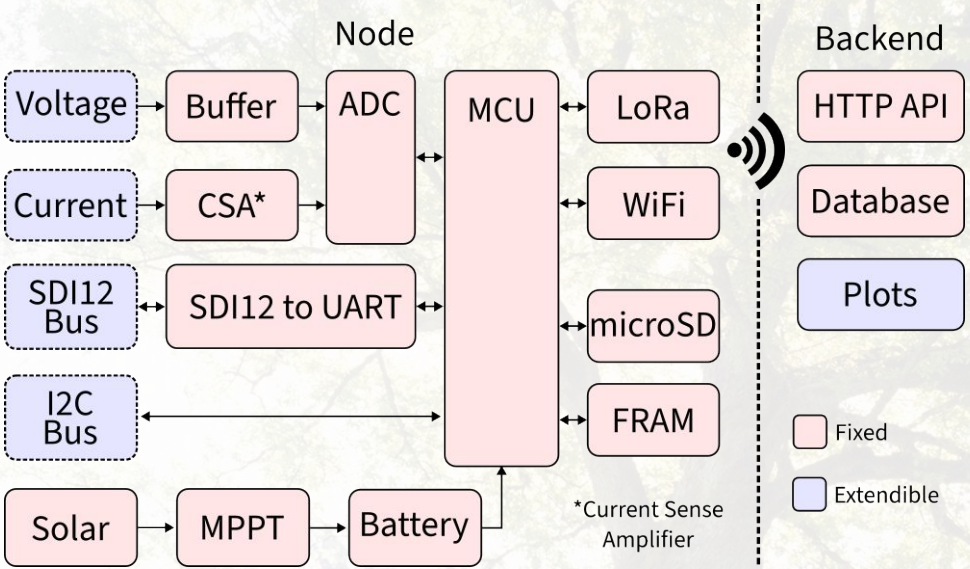
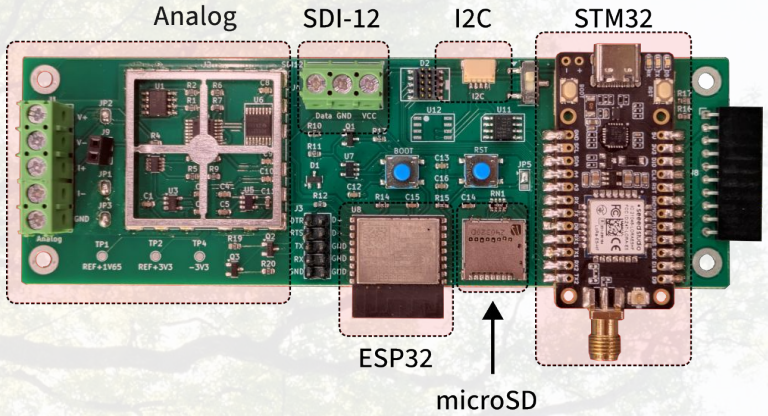
Current (Tree) platform overview





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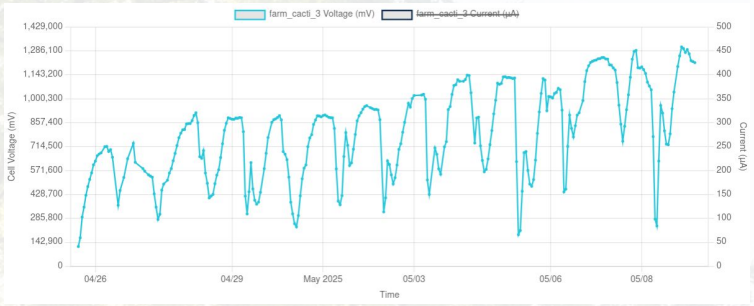
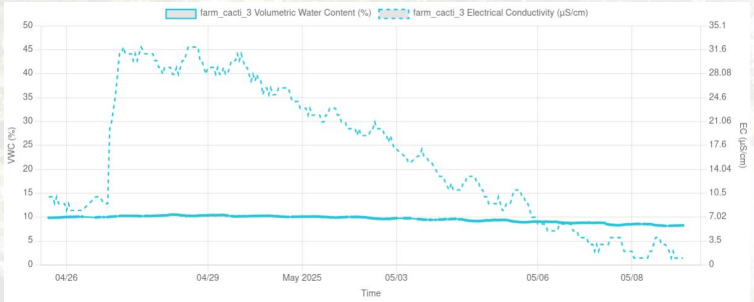
Use case: Energy harvesting from cacti





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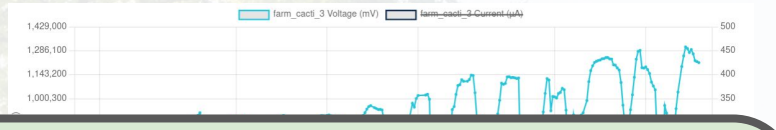
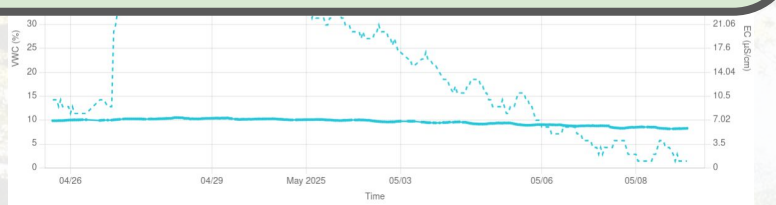


Takeaway: Co-Design guides pragmatic, usable features while avoiding feature creep and speculative engineering effort.



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Success of ENTS

Open source ecosystem

Designing for extensibility

Partnerships with domain experts

Metric	Hardware	Firmware	Visualization
Internal Contributors	6	7	10
External Contributors	0	2	5
Commits	404	1259	1158
Forks	0	4	18

Contributors from:

- Google summer of code
- Undergraduates
- Collaborators

Future Work

Tock

“An embedded operating system designed for running multiple concurrent, mutually distrustful applications on low-memory and low-power microcontrollers.” [1]

[1] Tock, “Tock Embedded Operating System,” Tock Embedded Operating System. Accessed: Jul. 01, 2025. [Online]. Available: https://www.tockos.org/

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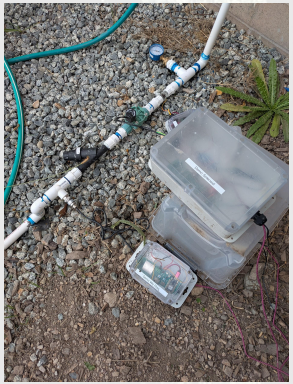
Future Work

Tock

Security in WSNs.

Supporting additional applications.



[1] Tock, “Tock Embedded Operating System,” Tock Embedded Operating System. Accessed: Jul. 01, 2025. [Online]. Available: https://www.tockos.org/

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Where to find us

- Josephson Lab Website
  https://sensors.soe.ucsc.edu/
- John Madden (Me)
  https://www.jmadden173.com/
- Stephen Taylor (Co-author)
  https://stevegtaylor.github.io/
- Live Data
  https://dirtviz.jlab.ucsc.edu/

Project Repos

Paper Link