Report on the 2020/21 Nano-IoT Research Community

Presentation To
NNCI Annual Meeting
November, 2021
Mark Allen/MANTH

National Nanotechnology Coordinated Infrastructure

NNCI's Research Community Efforts

- Research Communities (RCs) are subsets of the 16 sites that make up the NSF sponsored National Nanotechnology Coordinated Infrastructure (NNCI) network
- RCs complement the roles of other organizations within the NNCI, concentrating on a focused research topic in order to:
  - Advance collaboration
  - Position our sites to better accommodate emerging needs
  - Better understand future trends
- There are many ways RCs can self-organize to achieve these goals. The Nano-IoT RC members plan to hold and/or participate in annual, day-long symposia that will rotate among the RC community sites.
  - The major goal of each symposium is to summarize, inform, and exchange the work of NNCI users
  - New ideas to be introduced through invited external speakers

What is the Nano-Enabled Internet of Things?

It is our conjecture that many devices and applications for the Internet-of-Things will be enabled by nanotechnology

- The IoT ‘things’ may in many cases comprise small-scale structures, sensors, and actuators (MEMS)
- The IoT ‘things’ may need to process and collect data, requiring on-board electronics
- The IoT ‘things’ will need to communicate with the Internet, requiring communication protocols in multiple bands exploiting a diversity of modalities

publicdomainvectors.org

The Nano-IoT Research Community Vision

Our vision is that the ubiquitous sensing potential of the Nano-Enabled Internet of Things (Nano-IoT)* will:

- provide the input necessary for data mining/big data processing to understand complex system behavior
- augment the interaction environment in future workplaces
- be the transducers that can monitor living things from agriculture to medicine
- catalyze the convergence of researchers from many intellectual backgrounds

*One of our presenters suggested we could consider renaming this research community IoNT – the 'internet of nano things'. This is different, because the Things may not be nano, even if they are enabled by nano — but the acronym sure sounds a lot better.

Nano-IoT encompasses several of the themes of the NSF Ten Big Ideas, including:

- Future of Work
- Growing Convergence Research
- Understanding the Rules of Life
- Harnessing the Data Revolution

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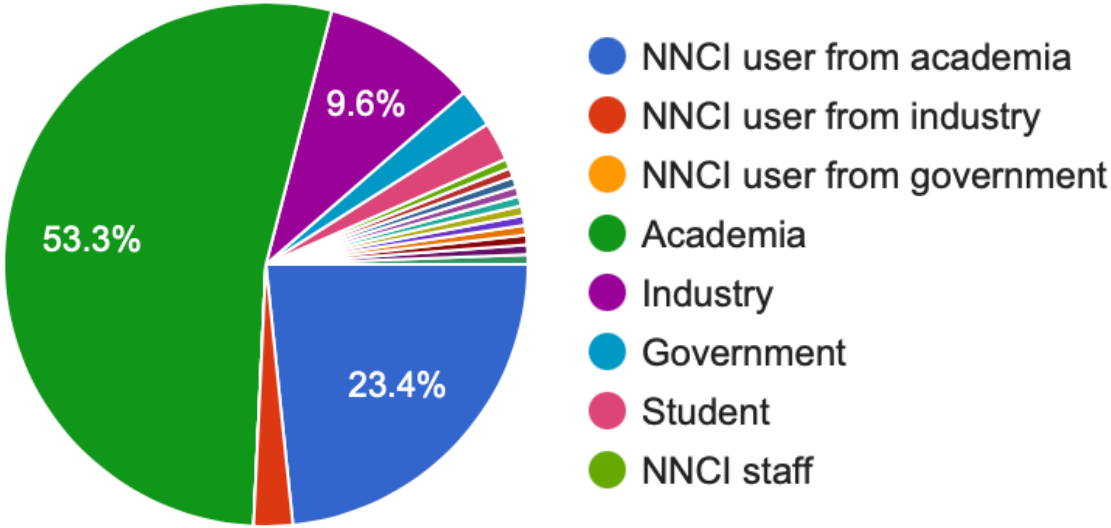
Meeting Structure and Attendee Statistics

- All-Virtual Symposium
- Presentations Followed By Q&A
- 160 unique registrants
  - ~78 from Penn
  - ~34 from other RC sites
  - ~9 from other NNCI sites
  - ~39 external
- Total of 65 unique attendees signed in throughout the day; typically 30 attendees for any given presentation
- ~80% of feedback respondents rated the content with a 4 or 5 (out of 5)



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Speakers

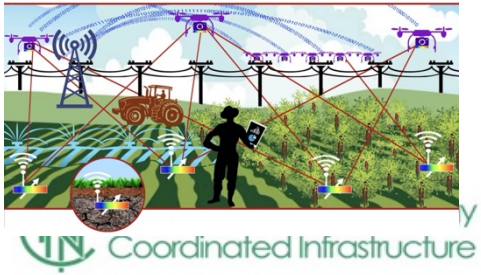
9:30 AM	Welcome
	IoT4Ag,
9:45 AM	Cherie Kagan, UPenn
	Impact of Autonomy on Transformative Transportation and Logistics,
10:25 AM	Kaydon Stanzione, Logistiwerx
	Irrigate? Ask the tree! Implantable MEMS to measure plant hydration,
10:50 AM	Michael Santiago, FloraPulse
11:15 AM	Break
	Enabling IoNT: Internet of Things Infrastructure,
11:30 AM	Rick O'Brien, SemperCon
11:55 AM	***CNF Site Overview***, Christopher Ober, Cornell
12:20 PM	***SENIC Site Overview***, Oliver Brand, Georgia Tech
12:45 PM	Lunch Break
1:30 PM	***MANTH Site Overview***, Mark Allen UPenn
1:55 PM	***NNF Site Overview***, Christian Binek, U Nebraska, Lincoln
2:20 PM	***KY-Multiscale Site Overview***, Kevin Walsh, U Louisville
2:45 PM	Concluding Remarks

Cherie Kagan, Director of the IoT4Ag NSF Engineering Research Center, University of Pennsylvania, ***IoT4Ag***

Kaydon Stanzione, CEO, Logistiwerx, ***Impact of Autonomy on Transformative Transportation and Logistics***

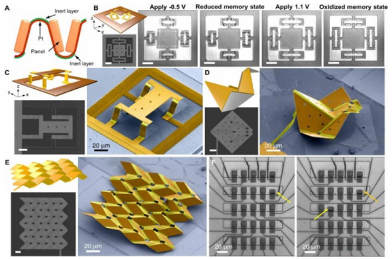
Michael Santiago, CEO, FloraPulse, ***Irrigate? Ask the tree! Implantable MEMS to measure plant hydration***

Richard O'Brien, President, SemperCon, ***Enabling IoNT: Internet of Things Infrastructure***



NanoIOT for Life

Low-power microrobotics

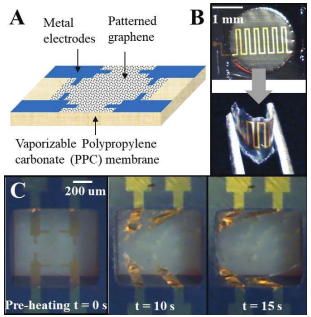


Q. Liu, W. Wang, M. F. Reynolds, M. C. Cao, M. Z. Miskin, T. A. Arias, D. A. Muller, P. L. McEuen, I. Cohen, *Sci. Robot.* **6**, eabe6663 (2021)

Honey Bee Flight Tracking

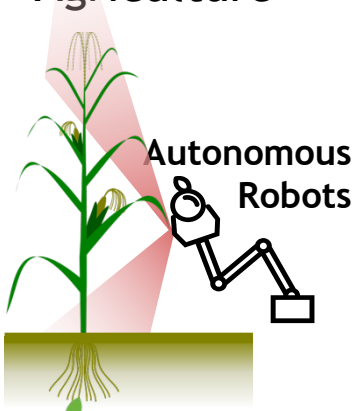
D. M. Palmer and A. C. Molnar, IEEE Transactions on Systems and SYSTEMS—II: Express Briefs, 68(5), May 2021

Eco-friendly vaporizable sensor



V. Gund and A. Lal, 2021 IEEE 34th International Conference on Micro Electro Mechanical Systems (MEMS); DOI: 10.1109/MEMS51782.2021.9375341

New STC on Digital Agriculture



cropps
Center for Research on Programmable Plant Systems

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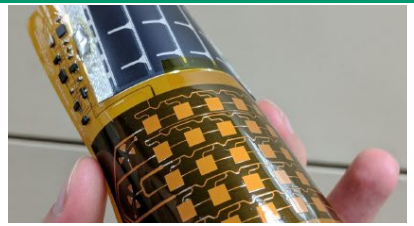
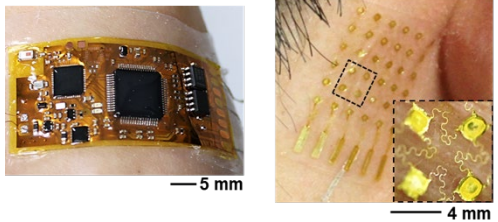
SENIC – Nano-Enabled IoT Research Examples

Structural Health Monitoring
Prof. Manos Tentzeris



IEEE Microwave Mag. 21 (2020) 87
Scientific Reports 11 (2021) 636

Wearable Flexible Electronics
Prof. Hong Yeo



Nature Communications 11:3450 (2020)
Nature Machine Intelligence 1, 412 (2019)

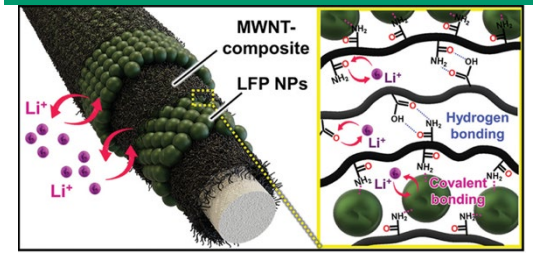
Wearable Sensing Systems
Prof. Farrokh Ayazi

Scientific Reports 11 (2021) 13427
npi Digital Medicine 3 (2020) 19

Chemical Sensing Systems
Profs. P. Hesketh & O. Brand

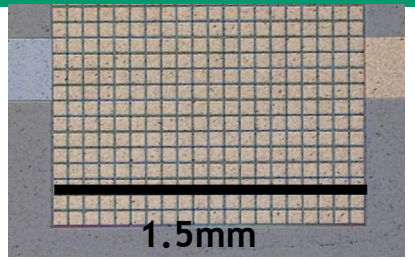
Lab Chip 17 (2017) 2323
IEEE Sensors Conf. (2019) 1-4

Flexible Energy Storage Devices
Prof. Seung Woo Lee



Adv. Energy Mater. 2101631 (2021)

MEMS-Based Power Transfer
Prof. Levent Degertekin



Smart Mat. and Struct. 30 (2021) 045024

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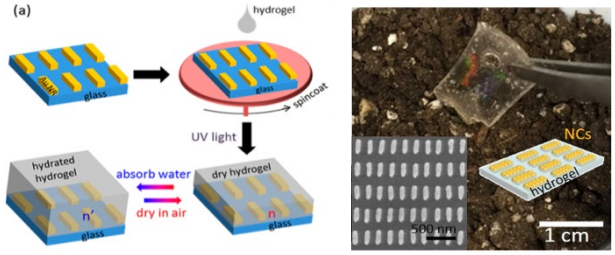
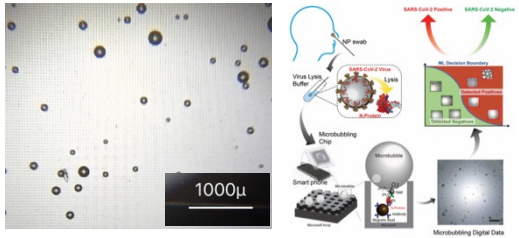
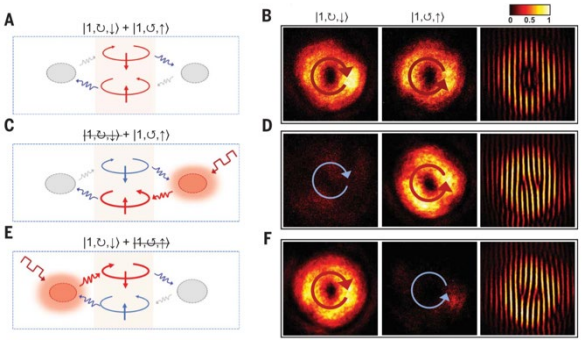
MANTH – Nano-IoT Selected Research



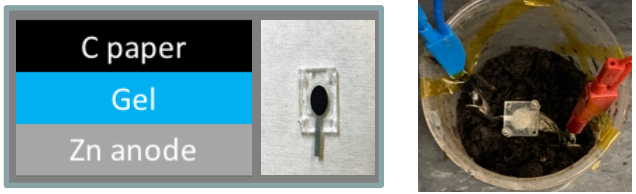
Agricultural sensors for: nutrients, pathogens, soil pH, …
Kagan et al., Proc. 2021 IEEE MEMS Conference



CoVID-19 Sensors with Smartphone Readout
Wang P. et al., Clin Chem. Aug 2021



Vortical laser emitters
L. Feng et al., Science, 760-763 (2020).



Biodegradable Air Batteries
Venkatesh et al., Proc. Transducers 2021

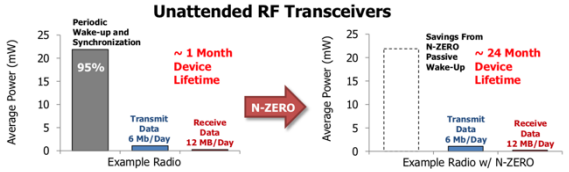


Figure 2. Reference transceiver lifetime without (left) and with an N-ZERO wake-up (right) for an existing mesh network radio when network traffic is sparse [1]. N-ZERO systems do not drain the battery for scheduled wake-up and synchronization.

Olsson III, R. H. et al., "Zero and Near Zero Power Intelligent Microsystems." Journal of Physics Conference Series. Vol. 1407. No. 1. 2019.

Startups: **InnaMed** is developing a smart, at-home blood testing device for the early detection of deterioration and automation of therapy in chronically ill patients.

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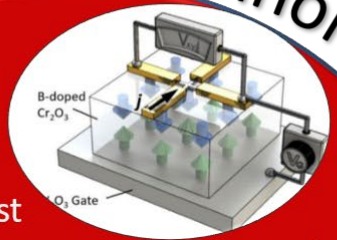
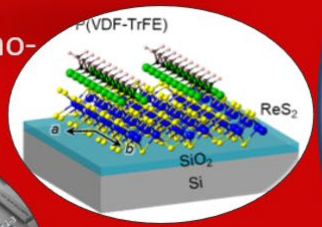
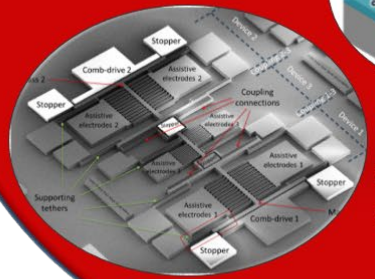
Nano-enabled IoT at NNF in a Nutshell

Information Technology



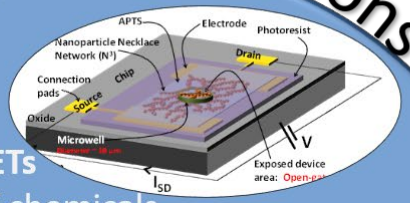
Ultra-low power
- ultra-fast **Antiferromagnetic spintronics**
- Flexible Nano-**electronics**





MEMS
as physical computing units

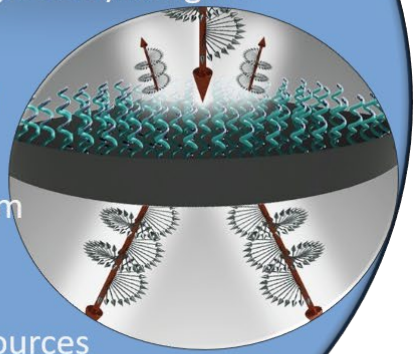
Sensing applications



Open gate FETs
-detection of chemicals
- interfacing with single cells/living FET

Nanophotonic

Chirality
- -sensing chiral molecules
- -chiral quantum optics



-single photon sources for quantum communication

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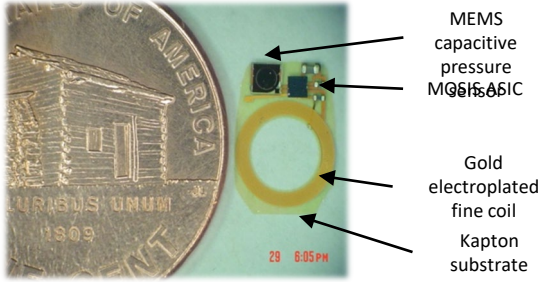
Nebraska Nanoscale Facility

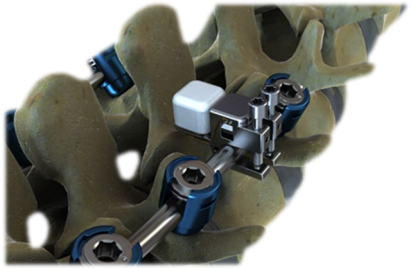
NSF

KY Multiscale – Nano-enabled IoT Research

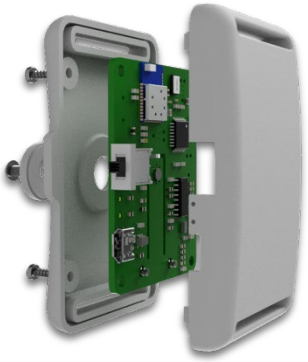
Wireless IoT Eye Pressure Sensor for Glaucoma Prevention



Wireless IoT Strain Sensor System for Spinal Fusion Monitoring

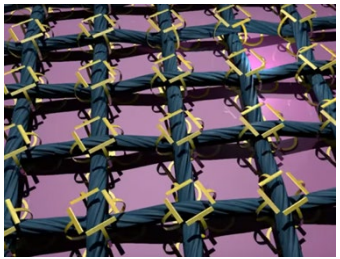


Wireless IoT Tocodynamometer for the Detection of Braxton Hicks "False Labor"

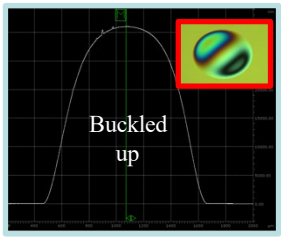


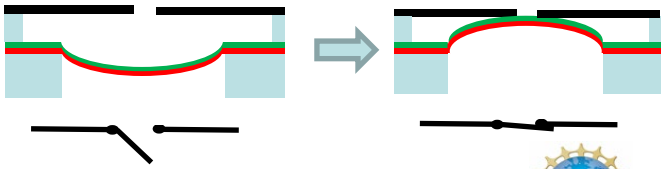
Sensorized IoT Rocking Chair for Pediatric Spinal Cord Injury Therapy

Transferring MEMS Devices to Fabric with Strain-Engineered Grippers



No Electrical Power Event Driven Bistable MEMS Sensors





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Lessons Learned and Next Steps

- According to survey feedback, this format (invited speakers to illustrate emerging research areas in nano-IoT, followed by site reports) worked well.
- The virtual meeting format allowed more participation from multiple sites
  - Perhaps consider a hybrid format for the next RC meeting
- Consider a panel discussion for helping to define future research directions and funding opportunities in the Nano-IoT area
- Cornell has offered to host next year's Nano-IoT RC symposium meeting