Predictive Design, Performance and Robustness Analysis of R2R Nitrate Sensor

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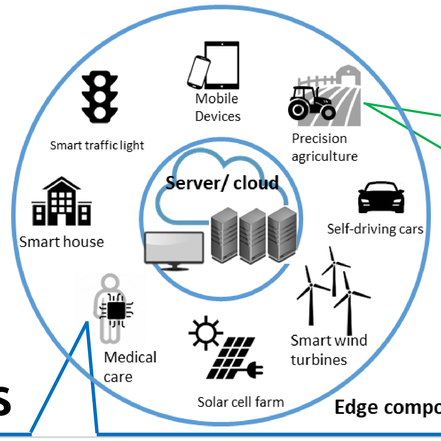
WHIN
WABASH HEARTLAND INNOVATION NETWORK

I. Motivation

Why IoT ?

- Edge computing vs. cloud computing
- Interconnection
- Integration with nanotechnology



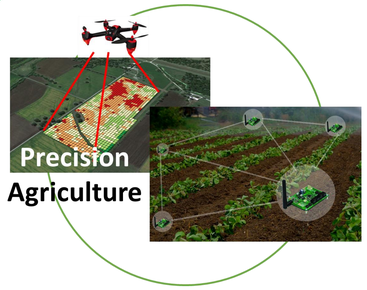
II. Previous Works

Various sensor models based on theory of device physics

Potentiometric (V)	Amperometric (I)	Impedance (Z)	Force (F)
MOSFET-based	Enzymatic	Droplet-based	MEMS-based
Thin film-based	Non-enzymatic		

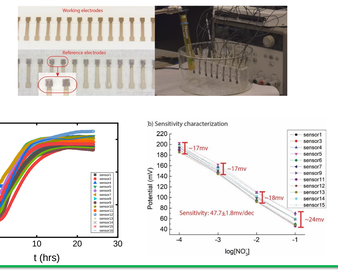
- Our group has rich experience in modeling of various sensors

III. Key Research Contributions

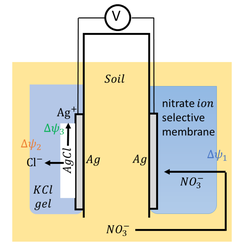


Soil nitrate sensing

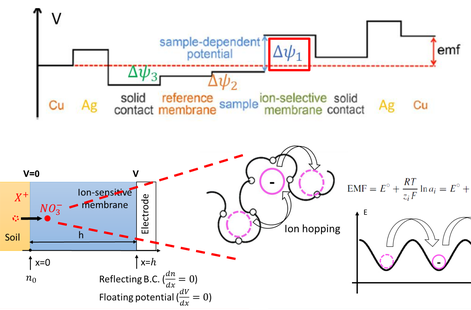
Thin-film printable nitrate sensor



Model



The principle of electro-chemical potential



Predictive physical-based model

Drift-diffusion Eq. $\frac{\partial n(x,t)}{\partial t} = \frac{\partial}{\partial x}\left(\mu n(x,t)\frac{\partial \psi(x,t)}{\partial x} + D\frac{\partial n(x,t)}{\partial x}\right)$

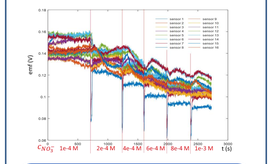
Poisson's Equation $\frac{\partial^2 \psi(x,t)}{\partial x^2} = -\frac{q \cdot n(x,t)}{\kappa \epsilon_0}$

Input: nitrate concentration n_0
Design parameters:
- Membrane thickness: h
- Membrane material property: D, κ

Environment parameters:
- Temperature: T
- Relative humidity (affect both D and κ)

Output: electrical potential across the membrane $\Delta\psi$

Real-time time-dependent variabilities among sensors

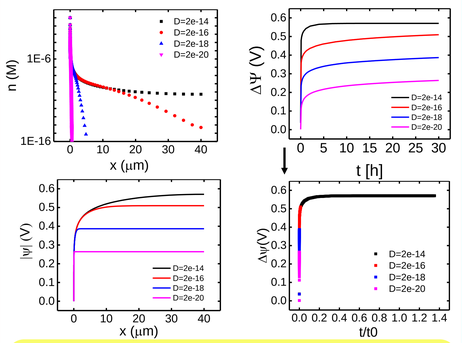


Source of the variations:
- Johnson–Nyquist noise (thermal agitation of electrons, water molecules, etc.)
- Mechanical vibrations
- Variations from fabrication (membrane thickness, bubbles, material variations, roughness, active area)

- How to optimize the design ?

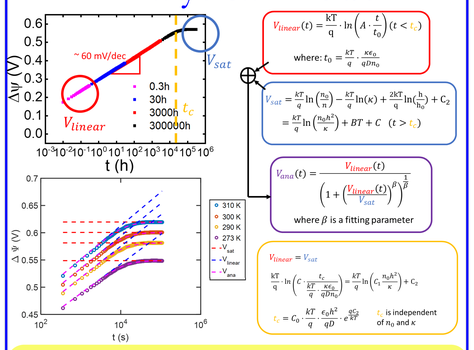
An end-to-end fundamental understanding

Numerical model



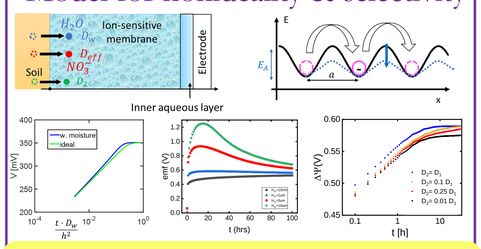
- The first numerical modeling of transient response of nitrate sensors suggests universal response

Analytical model



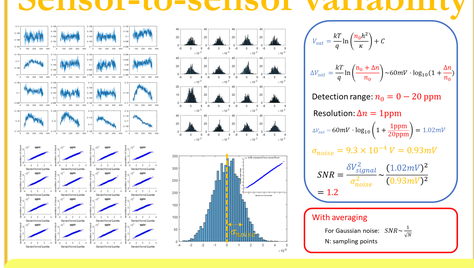
- Compact model provides analytical expressions and reduce computational complexity for system level integration

Model for nonideality & selectivity



- Moisture accelerates transient response
- Inner aqueous layer leads to voltage overshoot
- Selectivity comes from diffusivity difference

Sensor-to-sensor variability



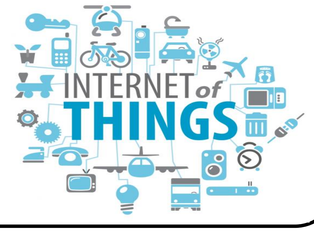
- Statistical analysis reduces SNR by averaging over higher sampling frequency

Collaborators:

PURDUE UNIVERSITY Discovery Park
ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
Northwestern University
Agricultural & Biological ENGINEERING

IV. Impact of Our Research

- Developed fundamental physics-based numerical/analytical models of thin-film based nitrate sensor
- Our work will enable sensor to IoT system level integration



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