Drift Rejection for Long Range Capacitive Sensors and Optimization of Machine Learning Human Tracking

ScuDo Scuola di Dottorato – Doctoral School
WHAT YOU ARE, TAKES YOU FAR
XXXVI Cycle

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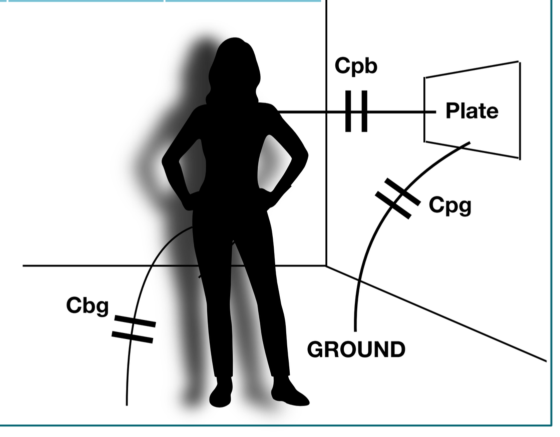
Research context and motivation

- Indoor Monitoring and Human Activity Recognition (HAR) are key-objectives for creating smart and safe space. Monitoring and learning daily routines of people allow the detection of diseases and the clever utilization of building resources, can bring benefits in assisted living for elderly people and increase building protection services.
- Environmental human sensors can be classified as active or passive, based on the interaction between human and sensor. The former involves wearable devices that transmit and/or receive signals, thus implying high deployment and maintenance costs and short device life, the latter includes remote and tagless sensors with low cost and privacy-aware.

Tagless solutions

	Infrared Sensors	Ultrasonic	Wi-Fi	Radar	ZigBee	UWB	Camera
Measurement Principle	TOA	TOA	RSSI/CSI/ AOA/TOA	TOA/AOA	RSSI/AOA/ TOA	TOA	Image proc.
Cost	Medium	High	Medium	Medium	Low	High	High
Covered area	20 m²	15 m²	100 m²	150 m²	3 m²	50 m²	100 m²

- Capacitive sensors operating in load mode use one single plate transducer and they measure the mutual capacitance between the plate and surrounding objects, thus also human body. They have low cost of installation compared to solution listed above and they don't collect confidential data.



Addressed research questions/problems

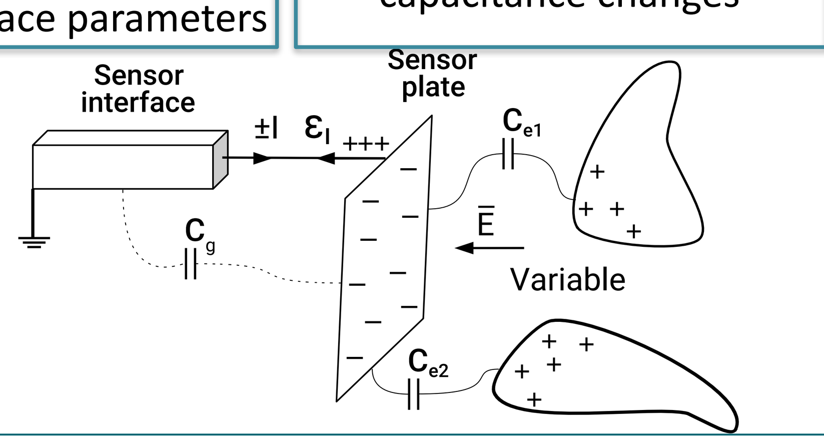
- Although capacitive sensors have many practical advantages for the end-user, they present some technical drawbacks and limitations. Environmental noise can affect measurement stability and accuracy, and this effect is more noticeable at long range where the capacitance variation is below 0,01 %.

Low frequency noise : measurement *drift*

High frequency noise : measurement *jitter*

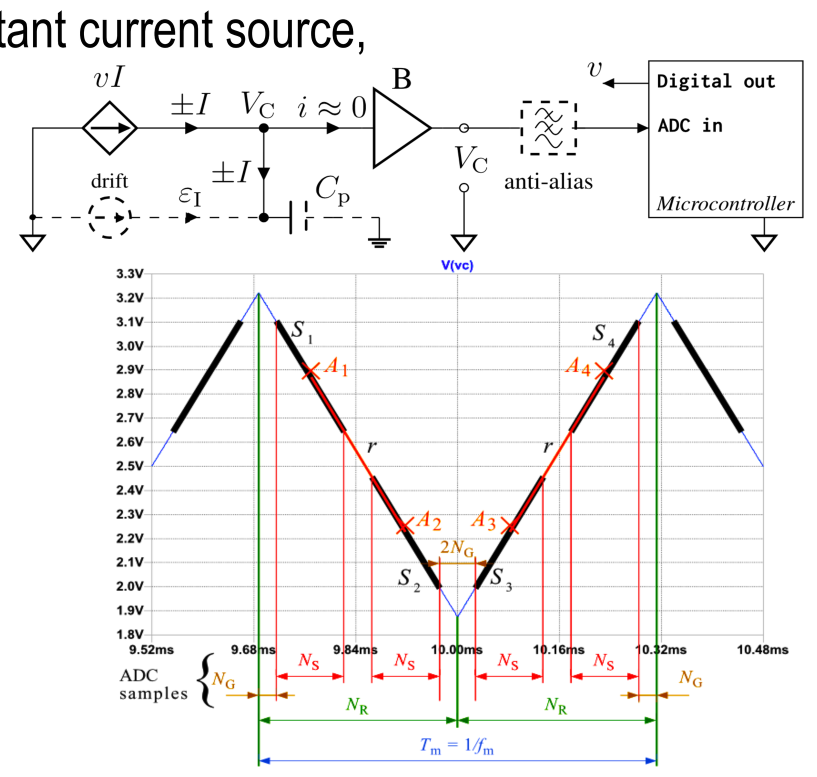
Environmental charge buildups: variation of sensor interface parameters

Variable air humidity: actual capacitance changes



Novel contributions

- We propose a slope modulation technique with differential measurement that can effectively reject noise from slow drifts while preserving the sensitivity.
The slope modulator repeatedly charge and discharge the mutual plate capacitance, as the period modulation interface, through a constant current source, but it uses fixed period oscillation and digital calculation of two adjacent ramps. The quasi-constant drift current changes the right and left slope, but the average slope is invariant to that, thus the plate capacitance is calculated by averaging the slope magnitudes.
- The integral measurement of ramps and the careful choice of ramp period and sampling frequency allows to use oversampling and decimation technique to lower the quantization noise.



Submitted and published works

- Subbicini, Giorgia; Lavagno, Luciano; and Lazarescu, Mihai; "*Drift Rejection Frontend for Single Plate Capacitive Sensors*", IEEE SENSORS JOURNAL, vol. 22, no. 16, 2022, pp. 16141-16149

Adopted methodologies

1 Analytic → 2 Simulation → 3 Experiment

1

Period $\left\{ T = T_r + T_f = \dfrac{2C_{plate}(V_{TH}-V_{TL})I}{(I^2 - \epsilon_i^2)} \right.$

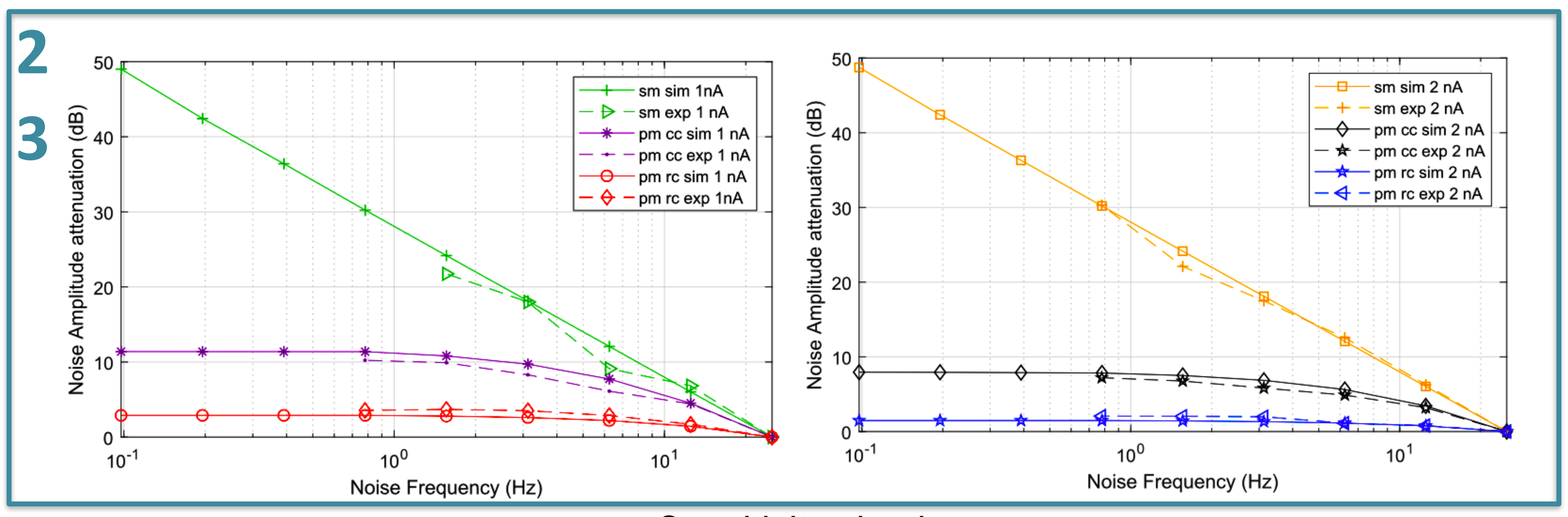
ϵ_i → Current induced by noise

Slope $\left\{ S_a = \dfrac{|S_r| + |S_f|}{2} = \dfrac{1}{2}\left(\dfrac{I + \cancel{\epsilon_i}}{C_{plate}} - \dfrac{-I + \cancel{\epsilon_i}}{C_{plate}}\right) = \dfrac{I}{C_{plate}} \right.$

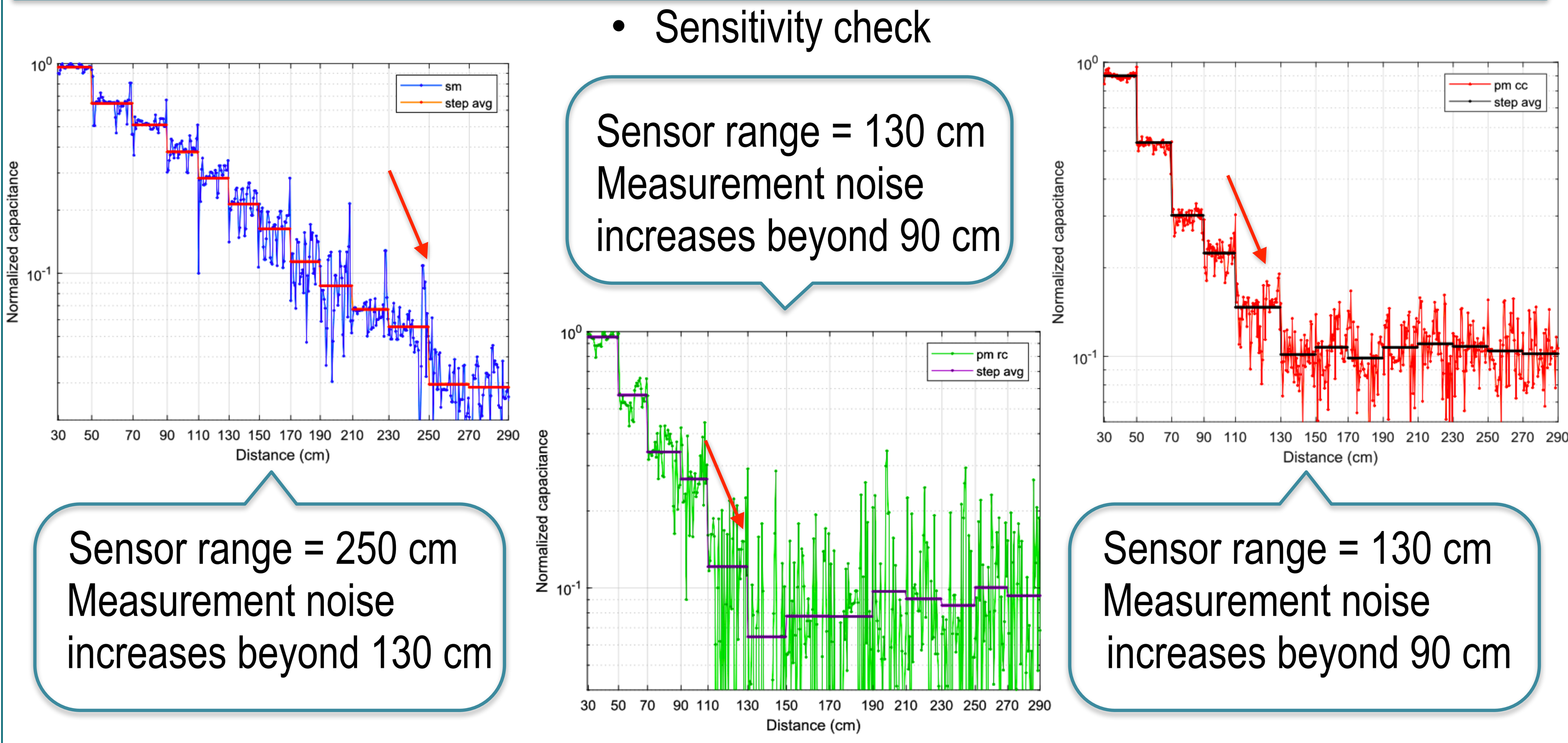
- Because mutual plate capacitance and relatively large voltage variations are hard to produce and control, the charge induction current is injected directly into the sensor plate node using a Howland voltage-controlled current generator.

2

3



- Sensitivity check



Future work

- The slope modulation frontend is compatible with antialiasing filters which can further reduce noise
- Use neural network, such as Multilayer Perceptron (MLP), 1D-Convolutional (CNN), and Long-Short Term Memory (LSTM) and perform design space exploration to improve accuracy with reasonable computational cost.
- Temporal Convolutional Network (TCN) design space exploration comparison with other time-series solutions.
- Extract readable, low-cost equations modeling the long-range mutual capacitance between human body and sensors using ML to reduce the complexity of ML model for inferring path.

List of attended classes

- 01UJBRV – Adversarial training of neural networks (3/6/2021, 15 h)
- 01QEZRV – Sviluppo e Gestione di Sistemi di acquisizione Dati (4/4/2022, 25 h)
- 01TVUQW – Embedded Electronic Systems for AI/ML (19/2/2021, 30 h)
- 01UIZRV – Microwave Sensing and Imaging for Innovative Applications in Health and Food Industry (22/3/2022, 20 h)
- 01MNFIU – Parallel and Distributed Computing (26/7/2021, 25 h)
- Coursera – Generative Deep Learning with TensorFlow (7/6/2021, 15 h)
- Coursera – Custom and Distributed Training with Tensorflow (19/5/2021, 15 h)
- Coursera – Advanced Computer Vision with TensorFlow (28/5/2021, 15 h)
- Coursera – Custom Models, Layers and Loss Functions with TensorFlow (12/5/2021, 15 h)
- PhD School – SIE, Electronics for IOT (5-7/7/2021, Trieste)
- Summer School – Cyber Physical Systems, from concepts to implementation (19-23/9/2022, Pula)