Summer Research Program

LGPM (Process and Materials Engineering Lab) - Paris-Saclay campus

https://lgpm.centralesupelec.fr/

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Scientific area: Methane production from biomasses

Subject: Validation of routine analyses employed in following anaerobic digestion for methane production.

Activities:

- Literature search
- Total acidity measurement by titration
- Total NH3 measurements by colourimetric kits
- Free NH3 measurements by colourimetric kits
- Dry weight measurements
- Preparation of samples for HPLC analysis

Photonics Chair – Metz campus

http://www.chairphotonics.eu/en/

[redacted]

Biotechnology Chair – Pomacle campus

http://www.chaire-biotechnologie.centralesupelec.fr/en

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Biomaterials: production and characterization of biosourced materials as means to replace traditional materials in plastic industries, from wrapping to construction, therefore contributing to sustainable development.

GeePS (Electric and Electronic Engineering Lab of Paris-Saclay) – Paris-Saclay campus

https://www.geeps.centralesupelec.fr/index.php?page=home

[redacted]

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- Innovative materials for terahertz imaging
- Fast and low consumption devices for terahertz imaging

[redacted]

[redacted]

Choose one of 3 options:

- Smart Framework on AI Cloud to Edge Synthesis (SF-AI)
- Spiking-MEMS: a neuromorphic interface for open-loop MEMS sensing
- Biological Instrumentation using Microwave Integrated Circuits (BioMIC)

(see below)

Laboratoire Génie électrique et électronique de Paris
Université Paris-Saclay, CentraleSupélec, CNRS, 91192, Gif-sur-Yvette, France.
Sorbonne Université, CNRS, 75252, Paris, France.

Smart Framework on IA Cloud to Edge Synthesis (SF-IA)

Framework de Synthèse : Intelligence Artificielle du Cloud au Matériel

Context: Computer engineering is currently based on binary programming with a Von Neumann architecture (Schuman, 2017), while CMOS technology faces limitations in energy consumption and circuit density. A new hardware design is emerging by drawing analogies between biology and silicon electronic circuits to integrate bioengineering-inspired models, allowing the creation of real-time computing circuits for robotics, data processing, and classification applications. Flexibility, surface area, energy efficiency, and reliability are the primary challenges addressed by such biomimetic electronic circuits.

For the implementation of a neuromorphic or bio-inspired computer, based on bio-inspired neurons from the cortex of the brain (Izhikevich, 2003), advances have already been published in the state of the art. Most works focus on the software layer, such as convolutional neural networks, Big Data, and learning algorithms. However, very few results are presented on the hardware layer. V. Rangan et al. (2010) and subsequent scientific works explore the nonlinear behaviors of cortex neurons. These works are often established using the Morris-Lecar models (1981). This commonly accepted model presents a nonlinear integration of leakage current and an impulse expressed through real exponentials. In CMOS technology, such behavior is obtained in weak inversion. Moreover, transistors operating in this regime also have the advantage of being low power consumption and biocompatible in terms of supply voltages (around 200 mV). The drawbacks of such a biomimetic approach are the limitations of mathematical models explaining quantum physics in transistors, posing a challenge that slows down the development of hardware neural networks compared to artificial intelligence in the Cloud.

I. Sourikopoulos et al. (2017) innovated by designing an electronic neuron (eNeuron) with a biomimetic version and a simplified version. In 2018, our research team embarked on this topic with a candidate in the Research Track at CentraleSupélec, and this project was followed last year by a Research Track and a PhD candidate. Together, we demonstrated the feasibility of spike-based neural networks with hardware implementation for IoT applications consuming approximately 1 nW (Ferreira 2019, 2020, Soupizet, 2022, and Jouni, 2022). Subsequently, the feasibility of deep learning in analog neural networks was studied. The results of PLS simulations highlight a trade-off between energy efficiency and deep learning capabilities when using these neurons.

Objective: The **SF-IA** project aims to bridge the gap between software AI and the analog neural network, a framework for synthesizing a hardware neural network based on transistors. The hardware neural network must be capable of solving the problem of electromagnetic wave source localization during communication between Intelligent Connected Objects (edge-AI). Our proposal involves implementing bio-inspired identification (vision/audition) of communicated waves in a wide band (1 to 6 GHz, such as WiFi). The scientific challenge is to find the best compromise between **(a)** adapting the component values of a hardware network to follow the simple equations of a digital network (MatLab/TensorFlow modeling), **(b)** developing a simplified model representing transistor defects to train a digital network, and **(c)** demonstrating an artificial intelligence solution with a consumption of a few nano-Watts.

Keywords: artificial intelligence, spiking neural networks, electronic neurons, bio-inspired, IoT.

Research Team: In GeePs laboratory at CentraleSupelec, **t**he SF-IA project is under the supervision of Pietro MARIS FERREIRA, Associate Professor at CentraleSupélec, University Paris-Saclay. The candidate will work as part of a team in a unique framework in collaboration with the PhD candidate, a student from the Research Track in the second year, three researchers from GeePs affiliated with Sorbonne University, and an international collaboration in progress.

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Spiking-MEMS : a neuromorphic interface for open-loop MEMS sensing

Spiking-MEMS: Architecture neuromorphique avec capteur MEMS en boucle ouverte

Context: The goal of reproducing the somatosensory system dynamics of humans is generally pursued by electronic signal acquisition architectures called bio-inspired or neuromorphic. For the implementation of a neuromorphic or bio-inspired architecture, the research conducted aims at a hardware implementation of cortex brain neurons according to their biological and mathematical models (Izhikevich, 2003). Advances have already been published in the state of the art, highlighting the trade-offs in computational complexity and fidelity to the bio-inspired model of these electronic neurons: eNeurons (Schuman, 2017).

Human touch is one of the first and most important senses developed. Artificial tactile sensors are based on piezoelectric transduction. Solutions in this direction are proposed in the literature, such as the neuromorphic event-based sensor through capacitive instrumentation of tactile forces (Janotte, 2022). However, pressure or acceleration sensors like MEMS are the most used in electronic devices. The most widespread architectures for acquiring these signals are the MEMS sensor in open loop or closed loop (Juillard, 2018).

A new hardware design is emerging by analogy between biology and silicon electronic circuits to integrate bioengineering-inspired models for designing real-time computing circuits for robotics, data processing, and classification applications. Flexibility, surface, energy efficiency, and reliability are the primary challenges addressed by such biomimetic electronic circuits. Most works focus on the software layer, such as convolutional neural networks, Big Data, and learning algorithms. However, very few results are presented on the hardware layer. V. Rangan et al. (2010) and subsequent scientific works explore the nonlinear behaviors of cortex neurons. These works are often established using the Morris-Lecar models (1981).

This commonly accepted model presents a nonlinear integration of leakage current, and an impulse expressed through real exponentials. In CMOS technology, such behavior is obtained in weak inversion. Moreover, transistors operating in this regime also have the advantage of low power consumption and biocompatibility in terms of supply voltages (around 200 mV). The drawbacks of such a biomimetic approach are the limitations of mathematical models explaining quantum physics in transistors.

The research team has already proposed the design of eNeurons (Ferreira, 2019) and neuromorphic architectures for audio signal acquisition (Ferreira, 2020). Recently, advances in spike-based neural networks (Soupizet, 2022) and a neuromorphic radio receiver (Jouni, 2022) have been implemented. Furthermore, the design and characterization of resonant MEMS sensors have been validated (Prache, 2018). The limitations of MEMS sensors in open or closed loops have also been highlighted (Juillard, 2018). To our knowledge, a neuromorphic MEMS sensor interface has never been studied.

Objective: The **Spiking-MEMS** project aims to study the feasibility of a hardware neural network for the interface of MEMS sensors in an open loop. The neuromorphic architecture must be capable of instrumenting and solving problems from the literature with artificial intelligence for a consumption of a few nano-Watts. The challenge is (a) to ensure the resolution of the sensors, (b) to process physical quantities instrumented with artificial intelligence, and (c) to demonstrate a hardware solution with a consumption of a few nano-Watts.

Keywords: artificial intelligence, spiking neural networks, non-linear oscillators, MEMS, sensor interface.

Research Team: In GeePs laboratory at CentraleSupelec, the Spiking-MEMS project is under the direction of Pietro MARIS FERREIRA, Associate Professor (HDR) at CentraleSupélec, Université Paris-Saclay, and co-supervised by Jerome JUILLARD. The candidate will work as part of a team in a unique framework in collaboration with PhD candidates, post-docs, and M1/M2 interns from GeePs.

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Biological Instrumentation using Microwave Integrated Circuits (BioMIC)

Instrumentation Biologique par l'Instrumentation Intégré Microonde

Context: The detection and identification of pathogens still relies on conventional microbiological techniques. These methods are generally expensive, as samples can only be used once. They require highly skilled personnel and take time (Rydosz, 2016). Conventional methods are only used for laboratory tests, limiting their common application, such as in a medical office. In contrast to the classical approach, microwave dielectric spectroscopy techniques can provide real-time observations of materials and biological environments, extracting rich information about their electrical properties without altering the measurement environment. Its popularity stems from its simplicity, ease of use, non-invasiveness, and real-time capabilities. Moreover, these integrated instrumentation devices can explore the advantages of Silicon, including low cost, portability, and reconfigurability.

In the agricultural, food, and pharmaceutical sectors, it is possible to estimate the quality, moisture content, and degree of fermentation of cereals and drugs by monitoring the trend of permittivity variation over time (Abegaonkar, 1999). In chemistry, the quantitative estimation of the dielectric properties of polymers, gelatin, and reagents can provide valuable information about the composition and structure of these chemicals (Daw, 2006). In human health and biology, the measurement of dielectric constant has proven its importance since (Pethig, 1987). It can be used for the detection and isolation of single cells (Grenier, 2013), monitoring the blood glucose levels of diabetic patients (Xiao, 2017), and studying the relaxation of dissolved proteins (Basey-Fisher, 2011). Other known applications include, but are not limited to, moisture and gas concentration detection (Withayachumnankul, 2012), determining the composition of a liquid (Chen, 2012). Thus, measuring the dielectric properties of biological materials has demonstrated its ability to provide crucial information for the research of new materials, bioprocesses, and biomedical applications.

Objective: The **BioMIC** project aims to make improvements to the fully integrated reflectometer based on interferometry. BioMIC expands the ambitions of the team's previous projects in the field of biological instrumentation towards a demonstrator that would be capable of characterizing the gamma relaxations of macromolecules in the Ku-band. To achieve this, BioMIC must address: (a) the reconfiguration of the fully integrated IBR's $\boldsymbol{f_{nil}}$; (b) the limitation in accuracy and high impedance measurement resolution.

Keywords: biological instrumentation, microwave reflectometer, bioprocesses, interferometry.

Research Team: In GeePs laboratory at CentraleSupelec, BioMIC project is under the supervision of Pietro MARIS FERREIRA, Associate Professor at CentraleSupélec, Université Paris-Saclay. This project will be in cooperation with Filipa LOPES, head of the Bioprocess team at LGPM (CentraleSupélec), a researcher in the field of innovative, sustainable, and competitive bioprocesses, and the fight against biofilms. It also involves collaboration with Hakiem Talleb and Hamid KOKABI, experts in biomedical instrumentation at Sorbonne University.