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Spiking Physics-Informed Neural Network for Electromagnetic Robust Sensing (SPINNERS)

Réseau neuronal impulsionnel informé par la physique pour la détection électromagnétique robuste (SPINNERS)

Context: The fusion of Artificial Intelligence (AI) and IoT devices has enabled the development of context-aware systems, enhancing the potential of these devices to perform real-time processing, communication, and decision-making. As IoT networks expand, however, they face critical challenges related to data transmission bottlenecks, reliability, energy consumption, and computational complexity. A prominent solution is the development of electromagnetic field sensing (EFS) technologies within IoT networks, which could unveil novel communication schemes. Thus, neuromorphic circuitry could be used to detect and distinguish wideband RF signals for purposes such as environment positioning and network identification.

The implementation of Spiking Neural Networks (SNNs) is often performed on neuromorphic processors such as Truenorth, SpiNNaker, and Loihi. These solutions fully exploit the sparsity of events and offer remarkable computational efficiency. Until now, power consumption is still between milli and microWatts for digital solutions, while analog ones achieve nanoWatts (Shrestha, 2022). Recent literature has validated a library of electronic neurons using bio-inspired models known as neuromorphic circuits (Rioufol, 2023).

To bring AI to the edge of IoT sensing, Cassidy et al. (2008,) have been the first to propose a neuromorphic impulsive radio introducing a distributed wireless cortex capability by a neuromorphic digital solution (i.e., FPGA) and discrete RF components. However, the power consumption challenge remained to enable AI edge IoT sensing. Jouni et al. (2025) have proposed a neuromorphic-enhanced wake-up radio (WuR). Ferreira et al. (2025) have proposed a neuromorphic spiking radio using noise-optimized electronic neurons inspired by revisited neuromorphic circuitry in (Rioufol, 2023). Results have presented the best energy consumption per synaptic operation (Eeff ≈ 10.0 fJ/SOP) and a competitive area trade-off (104.7 µm2/neuron). However, neural network learning remains limited since synaptic weights are hardcoded in transistor widths and lengths.

Memristive devices introduce stochasticity and non-linearity into synaptic updates, analog circuits are affected by noise and transistor mismatch. Designing learning rules that remain stable, bounded, and effective under these conditions is a major challenge. While spike-timing-dependent plasticity and related bio-inspired mechanisms are attractive due to their locality and low overhead, their interaction with noisy and drifting devices can lead to instability if not carefully bounded. The use of memristive synapses offers significant advances in terms of non-volatility, on-line learning (Daddinounou and Vatajelu, 2024), and energy efficiency (Khuu, 2023), compared to conventional synaptic circuits. Besides, memristor devices are aligned with the requirements of context-aware SNN learning algorithms, and suitable for neuromorphic circuits interconnections (Daddinounou, 2024).

In conclusion, SNNs provide a promising alternative for ultra-low-power and compact designs, although at the cost of slower operation and training complexity. The choice between these architectures presents a major trade-off in edge AI system design. Besides SNNs offer compelling advantages for sustainable electronics and bio-inspired applications. Computing (ie. neuromorphic circuits) and memory (ie. memristors) for SNNs are located within the same node, which requires a paradigm shift from von Neumann to neuromorphic computing. Indeed, SNNs should require a specific problem (ie. EFS) solutions. Frugal AI methods and physics-informed datasets are promising, since current general NN architectures lack SNNs (Ferreira, 2025a). Building fault-tolerant and energy-efficient edge AI solutions for IoT devices is a challenge in the state-of-the-art.

Objective: SPINNERS' project focuses on developing a robust neuromorphic radio based on neuromorphic circuits and memristive devices. Such a solution brings low-power, real-time processing directly to a reliable edge AI solution for IoT applications. Key objectives include:

i. Designing energy-efficient spiking neural network with on-line learning capabilities, ensuring fault tolerance, and improving device security.
ii. Integrating EFS into neuromorphic circuitry, being a solution to enhance context-aware reliable communications in IoT.
iii. Developing learning rules that remain convergent while preserving adaptability and energy efficiency.

Keywords: energy efficiency, reliability, neuromorphic circuits, memristors, IoT.

Project Supervision: Project supervision is held by CROMA and TIMA labs. CROMA laboratory is represented by Pietro M. FERREIRA (marisfep@univ-smb.fr), Full Professor at Université de Savoie Mont Blanc. His research interests are design methodologies and microwave instrumentation techniques for ultra-low power integrated circuits in harsh environments. Recent projects aim the Internet of Things industry considering IA edge and reliability. TIMA laboratory is represented by Ioana VATAJELU (ioana.vatajelu@univ-grenoble-alpes.fr), CRCN CNRS. Her research interests are in design and design-for-dependability of beyond-CMOS neuromorphic circuits.

Candidate will be formed according to the criteria of EEATS Doctoral School, but also through personalized guidance specific to the tools and scientific methods of the research topic. Practical activities and real-world scenarios are planned, including scientific writing, communication and public speaking, result quality, time management, and research project management

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SPINNERS is a PhD research project funded by MIAI Cluster IA Chair entitled “Energy-Efficient, Context-Aware Neuromorphic Systems for Resilient Smart IoT (ECO-Neuro)”. SPINNERS shall cover scientific challenges described in WP1 and WP2 of MIAI Chair. SPINNERS benefits of operation investments such as SNN fabrication in integrated circuit technology. To this end, SPINNERS is strongly connected to platforms for computer-aided design from CIME and integrated circuit fabrication on CIME-P. Besides, fabricated SNN shall be measured on equipment from OPENRA platform.

Candidate Profile: The candidate profile required for the project is a young professional pursing a master’s degree in Eletrical or Electronics Engineering, interested in the scientific field of embedded electronics, microwave, and AI. He/She must be motivated, passionate about research in a multidisciplinary field and an organized person using scientific methods. He/She must justify good academic tracks in maths and applied physics; an experience in design flow; linguistic competence in English (B2 written and spoken); linguistic competence in French is a plus.

Intellectual Property: Being fundamental scientific research, this subject is not attached to any industrial project. Intellectual property will be promoted through scientific communications favoring the open science policy of the French government.

Bibliography: Jouni et al. (2025) 10.1109/TCASAI.2025.3571021; Ferreira et al. (2025) 10.1109/MDAT.2025.3547974; Ferreira et al (2025a) 10.3389/fnins.2025.1676570; Daddinounou and Vatajelu (2024) 10.3389/fnins.2024.1387339; Daddinounou et al. (2024) 10.1109/ACCESS.2024.3411519; Rioufol (2023)10.1109/SBCCI60457.2023.10261961; Khuu (2023) 10.1088/1361-6463/ad1016; (Shrestha, 2022) 10.1109/MCAS.2022.3166331;