# Synthesis of Smart and Intelligent Sensors

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## Abstract

As the crucial intermediary between the real world and Information Communication Technology (ICT) infrastructures, smart and intelligent sensors play a vital role in extracting valuable information for a variety of tasks from human activity recognition, and people counting, to hand gesture recognition, etc., depending on the type of smart sensors.

The process involves translating raw physical data into electrical signals, and performing data analysis and processing to fulfill specific requirements. With advances in machine learning (ML) and deep learning (DL) algorithms in recent decades, the intelligence of smart sensors has undergone significant development. However, it poses challenges due to the memory and computation-intensive nature inherent in ML/DL models. Moreover, the sensing process involves the transmission of large amounts of data, which consume a significant portion of the energy budget, far beyond the availability of battery-operated smart sensors at the edge.

This Ph.D. thesis aims to devise innovative design solutions for efficient ML architectures, prioritizing energy conservation. This involves exploring novel implementation strategies and advanced tools to synthesize and optimize heterogeneous designs targeting smart sensors, especially where the digital and analog domains intersect. The research encompasses various aspects of the design hierarchy, including front-end tasks such as automatic design and optimization of new architectures, as well as back-end tasks such as circuit-level design techniques for area, power, and optimization of digital-in-analog components. These research endeavors are conducted in close collaboration with STMicroelectronics.

This thesis undertakes a comprehensive exploration of the optimization of smart sensor designs; the techniques involved can be categorized into three main aspects: **i) algorithm level**, **ii) hardware level**, and **iii)** the deployment of **advanced EDA tools**, targeting each phase in the design flow. All research activities are integrated with practical applications in smart sensor design. In particular, ML models deployed in smart sensors are optimized through multiple techniques, including **quantization** and **adaptive inference**, while specific hardware features are studied to efficiently support

such models, including **a custom CPU** and efficient **approximate computing** for I2C buses. In addition, **topology recognition** in layout placement automation targeting complex analog-mixed signal (AMS) IC design for smart sensors is studied.

The experiments in this thesis are performed on extensive datasets, and running on real-world devices, including both academic open-source platforms and commercial ones. Particularly, a **real smart sensor prototype** was realized, and the experimental results demonstrated the effectiveness of the proposed optimization techniques.