Politecnico di Torino
Dipartimento di Automatica e Informatica

PhD in Computer and Control Engineering
36th cycle

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Synthesis of Smart and Intelligent Sensor

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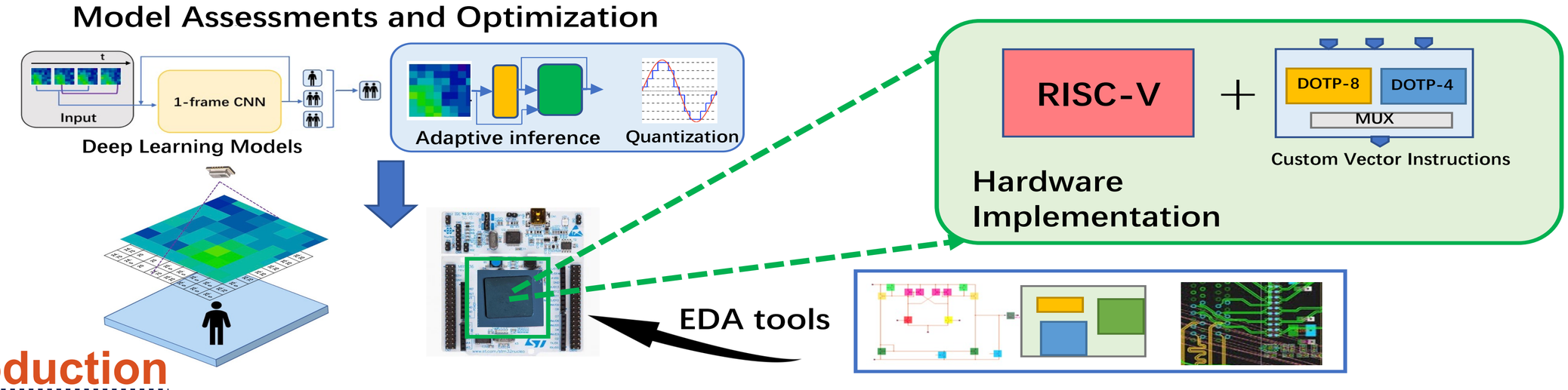


1. Introduction

The execution of Machine Learning (ML) / Deep Learning (DL) algorithms on Smart Sensors permits the extraction of valuable information from the physical world. However, ML involves compute-intensive kernels, posing challenges to the HW and SW design for these systems.

2. Goal

The goal of this thesis, sponsored by STMicroelectronics, is to conceive novel design solutions to implement efficient ML-equipped smart sensors, favoring energy saving.

3. Method

The work covers the whole vertical stack, from algorithm-level explorations, to hardware implementation, and design flow optimizations.

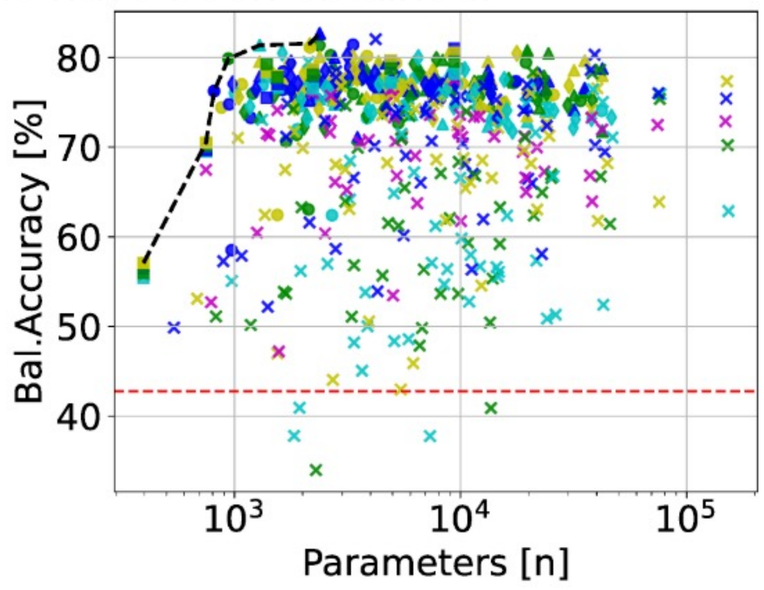
At the algorithm level, several efficient DL models such as compact Convolutional Neural Networks (CNNs) are studied for social distance monitoring and person counting applications based on multipixel IR sensors. Moreover, adaptive inference is applied to achieve energy saving [1,2].

Concerning HW implementation, a custom RISC-V core based on IBEX with sub-byte vector instruction set extensions has been realized to speed-up the execution of low-bit-width *quantized* ML models. Moreover, HW optimizations based on approximate computing have been applied to the I/O serial buses of smart sensors to further improve their energy efficiency [3].

Lastly, ML and modelling techniques to enhance the automation of an Analog Mixed-Signal (AMS) design flow, fundamental for smart sensors design, have been studied. Specifically, the study focused on AMS topology recognition to automatically derive placement constraints.

4. Results

The main current results refer to the explorations of efficient DL models. Thanks to the extensive architecture exploration, a rich set of Pareto-optimal solutions have been obtained.



Moreover, the best model can significantly outperform a state-of-the-art deterministic solution for IR person counting, with up to **+39%** accuracy. These results have been used as basis to drive the design of the customized RISC-V core, which have led to tapeout of a real smart sensor prototype **MAUPITI**. The deployment results show that MAUPITI, at the cost of 7% area overhead, achieving **17.9%** energy reduction comparing with IBEX.

Platform	Model Size [B]	Energy [µJ]
IBEX	4580	6.003
MAUPITI	5256	4.927

Concerning AMS topology recognition, a library-based approach has been evaluated, reaching a precision of **96%** on a large industrial netlist.

5. References

1. Chen Xie et al, “Privacy-preserving Social Distance Monitoring on Microcontrollers with Low-Resolution Infrared Sensors and CNNs”, IEEE ISCAS 2022.
2. Chen Xie et al., ”Efficient Deep Learning Models for Privacy-preserving People Counting on Low-resolution Infrared Arrays”. IEEE INTERNET OF THINGS JOURNAL. 2023.
3. Chen Xie et al, "ACME: An Energy-Efficient Approximate Bus Encoding for I2C,” IEEE/ACM ISLPED 2021.