# PROPOSITION DE SUJET DE THÈSE

**Intitulé : Formal Verification of Quantized Neural Networks on Embedded Platforms**

Référence : **TIS-DTIS-2026-28**
*(à rappeler dans toute correspondance)*

| **Début de la thèse : octobre 2026** | **Date limite de candidature :** |
|---|---|

**Mots clés**

neural networks, formal verification, quantization, embedded systems

**Profil et compétences recherchées**

knowledge in several topics among: neural networks, formal verification, computer hardware, computer arithmetics

**Présentation du projet doctoral, contexte et objectif**

## Context

The use of neural networks in safety-critical embedded systems is increasing across domains such as avionics, drones, automotive, and space. Neural networks are used to replace large decision tables (e.g., **ACAS-Xu**), to process visual signals for safe landing (**vision-based landing with LARD dataset**), or to make real-time decisions during emergency procedures (**UAV emergency landing**). These applications share strong constraints: limited memory, power, and latency on embedded platforms (CPU, DSP, FPGA, ASIC), strict safety requirements, and the need for predictable, certifiable behavior to comply with standards such as DO-178C/DO-254 or ISO 26262.

## Problem Statement

Deploying neural networks in safety-critical systems faces three main challenges:

1. **Hardware constraints**: embedded platforms have limited computational resources and energy budgets.
2. **Safety assurance**: it is crucial to formally guarantee that networks never produce unsafe outputs.
3. **Certification and predictability**: implementations must be deterministic, with bounded execution times, to meet certification standards.
   Current approaches in neural network quantization often overlook formal verification and predictable implementation, creating a gap between efficient models and certifiable embedded deployment.

## Objectives

The main goal of this thesis is to develop a **methodology for co-design of quantization, formal verification, and predictable embedded implementation** of neural networks for safety-critical applications.
Specific objectives include:

- Design quantization methods based on static analysis and formal guarantees on the outputs. The quantization relies on safe conversion from higher-precision arithmetic (floating-point) to resource efficient fixed-point integer arithmetic based on integers. This approach facilitates reducing memory and computation while remaining verification friendly.
- Apply formal verification techniques (SMT, MILP, abstract interpretation) to guarantee safety properties for quantized networks.
- Deploy neural networks on embedded platforms (CPU, DSP, FPGA) in a deterministic and certifiable manner. This can include optimizing the design of such platforms to leverage

parallelism, pipelining, resources specific to the platform, etc.

- Validate the methodology on multiple use cases: ACAS-Xu, vision-based landing, and/or UAV emergency landing, demonstrating its generality.

**Methodology**

- **State-of-the-art study**: review quantization methods, formal verification approaches, and embedded deployment strategies.
- **Quantization development**: create "verification-aware" quantization methods inspired by Winandy et al. [1].
- **Formal verification**: extend SMT-based verification for quantized networks [2].
- **Embedded deployment**: implement networks on CPUs, DSPs, and FPGAs, leveraging methodsvinspired by Guérignon's [3] or Winandy et al. [4] FPGA techniques,FPGA techniques [3] to ensure deterministic execution.
- **Experimental validation**: assess memory usage, latency, energy, safety, and predictability across three use cases (ACAS-Xu, LARD, UAV emergency landing).

**Expected Results**

- New quantization methods compatible with formal verification and certification.
- Verification tools for quantized neural networks in embedded environments.
- Demonstration of predictable, certifiable neural network implementations on embedded platforms.
- A methodological framework and guidelines applicable to other safety-critical domains such as automotive, aerospace, or space systems.

**References**

[1] Dorra Ben Khalifa, Matthieu Martel. Efficient Implementation of Neural Networks Usual Layers on Fixed-Point Architectures. LCTES2024: 12-22
[2] Wang et al. (2023). *Formal specification and SMT verification of quantized neural network for autonomous vehicles*.
[3] Guérignon, C. (2021). *Implementation of quantized neural networks on FPGA: methods and applications*. PhD Thesis.
[4] Winandy, Dion, Manni, Garoche et al. (2025). *Automated Fixed-Point Precision Optimization for FPGA Synthesis*. IEEE Open Journal of Circuits and Systems, vol. 6.

**Collaborations envisagées**

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