

Fundamental field: Engineering Sciences  
Specialisation: Systems Engineering

# **HABILITATION THESIS**

## **-abstract-**

**Interdisciplinary Research for Dependable Cyber-Physical  
Systems: The Use of IoT and Deep Learning**

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The habilitation thesis is structured in a logical and coherent manner, aiming both to present the author's professional and scientific trajectory and to highlight the original contributions in the field of dependable cyber-physical systems. The organization of the chapters reflects a natural progression from the general conceptual framework to specific applications and future directions of development.

## Introduction

The introductory chapter outlines the theoretical framework and the motivation of the research, positioning cyber-physical systems (CPS) within the context of contemporary digital transformation. The roles of the Internet of Things, deep learning, and embedded technologies in the development of dependable CPS are discussed, along with the major challenges related to reliability, security, resilience, and real-time operation. The introduction establishes the objectives of the thesis, the interdisciplinary nature of the research, and the overarching vision that guides the scientific work presented.

## Chapter 1 – Synthesis of Scientific, Professional, and Academic Achievements

This chapter provides an overview of the author's academic and professional career. It presents teaching activities, involvement in university management, supervision of bachelor's and master's theses, as well as national and international collaborations. Furthermore, the research activity is synthesized, including the projects coordinated or participated in by the author, the scientific publications, and their impact, as evidenced by scientometric indicators.

### **1. Scientific results and academical activity**

The research activity is materialized through a substantial portfolio of scientific publications, comprising more than 70 articles, which includes:

- articles published in international journals indexed in Web of Science, some of which are classified in the Q1 and Q2 quartiles, demonstrating the quality and impact of the research;
- papers published in the proceedings of prestigious international conferences, particularly in the IEEE domain, focusing on intelligent systems, deep learning, and cyber-physical systems;

- articles indexed in international databases, supporting the wide dissemination of the obtained results.

The publications address both theoretical aspects and practical applications, such as:

- architectures of intelligent cyber-physical systems;
- the use of deep learning techniques in medical and industrial applications;
- reliability and resilience of distributed systems;
- predictive maintenance and advanced data analysis.

These results confirm the thematic continuity of the research, the originality of the contributions, and the author's ability to integrate emerging technologies into functional solutions.

## **2. Books, Book Chapters, and Editorial Contributions**

This section also highlights the author's contributions to the development of academic and editorial materials, materialized through:

- the publication of six books in the fields of intelligent systems, data processing, and software applications;
- contributions and teaching materials used in the university-level educational process.

These works reflect the author's ability to synthesize advanced knowledge and to adapt it both for the scientific community and for the education of students and early-stage researchers.

## **3. Professional Results and Participation in Research Projects**

From a professional perspective, the synthesis emphasizes the author's active involvement in:

- national and international research projects, as a member or as a person responsible for scientific activities;
- interdisciplinary collaborations with academic and industrial partners;
- technology transfer activities and experimental validation of the proposed solutions.

Participation in these projects has led to the development of case studies and demonstrative applications, strengthening the link between fundamental research and applied research.

## **4. Teaching Activity and Taught Courses**

An essential component of Chapter 1 is the presentation of the teaching activity carried out at the Technical University of Cluj-Napoca. The author has consistently delivered courses at both undergraduate and master's levels in fields such as:

- Automation, Applied Informatics, and Intelligent Systems;
- Systems Engineering.

The teaching activity is characterized by:

- continuous updating of course content in line with technological developments;
- integration of the author's own research results into lecture and laboratory materials;
- supervision of bachelor's and master's theses on advanced topics, many of which have scientific or applied outcomes.

## **5. Academic Impact and Human Resource Development**

The synthesis of achievements highlights the author's contribution to the development of highly qualified human resources through:

- supervision of students in research activities;
- supervision of students in practical training activities;
- supervision of bachelor's theses;
- supervision of master's theses;
- involvement in academic committees and institutional activities;
- support for the development of a research and innovation culture among students.

## **Chapter 2 – Contributions to Medical Cyber-Physical Systems**

This chapter is dedicated to CPS applications in the medical domain, a field that is critical in terms of safety and reliability. It presents medical CPS architectures, Cloud–Fog–Edge solutions, and mechanisms for increasing the reliability of data exchange and processing. The contributions include the development of intelligent models for medical image analysis, physiological parameter monitoring, pathology classification, and clinical decision support, with an emphasis on experimental validation and practical applicability.

### **2.1. Contributions to Advanced Medical Image Analysis and Pathology Classification**

This subsection presents original contributions to the development and application of advanced medical image processing algorithms, with a focus on artificial intelligence and machine learning–based methods. Solutions for the automatic detection and classification of pathologies are discussed, demonstrating significant improvements in the accuracy of computer-aided diagnosis.

### **2.2. Contributions to the Development of Intelligent Devices for Medical Monitoring**

This section addresses the design and implementation of intelligent devices integrated into medical cyber-physical systems. Solutions for continuous monitoring of physiological parameters, interoperability with digital platforms, and increased reliability of healthcare support systems are highlighted.

### **2.3. Contributions to Demographic Attribute Classification and Facial Expression Analysis**

This subsection addresses innovative methods for automated human face analysis, including the recognition of demographic attributes and facial expressions. The contributions are relevant both to medical applications and to intelligent human-machine interaction systems.

### **2.4. Contributions to Data Analysis and Predictive Maintenance**

This section highlights the use of CPS and AI for complex data analysis and the development of predictive maintenance models, with applications in medical and industrial systems. Clear benefits are demonstrated in terms of risk reduction and optimization of operational processes.

## **Chapter 3 - Contributions to CPS and the Internet of Things (IoT)**

This chapter addresses the integration of IoT infrastructures into CPS ecosystems, highlighting the role of distributed sensors, secure communications, and distributed processing. Concrete applications are presented in air quality monitoring, assistance for vulnerable individuals, smart agriculture, smart homes, and remote control. The emphasis is placed on scalable architectures and the reliability of IoT systems in real-world environments.

### **3.1. Contributions to Air Quality Monitoring and Early Risk Detection**

This subsection presents distributed IoT systems for environmental monitoring, with a focus on air quality and early identification of health risks. Scalable architectures and real-time data analysis methods are described.

### **3.2. Contributions to Human Activity Monitoring and Assistance for Vulnerable Individuals**

This section addresses the development of CPS solutions for human activity recognition and support for vulnerable individuals, using intelligent sensors and machine learning algorithms. The social and ethical implications of these applications are emphasized.

### **3.3. Contributions to the Development of IoT Infrastructures for Smart Agriculture, Smart Homes, and Remote Control**

This subsection describes integrated IoT solutions for resource optimization in agriculture, home automation, and remote system control. The contributions highlight the energy efficiency and adaptability of the proposed infrastructures.

## **Chapter 4 - Contributions to the Reliability of Cyber-Physical Systems (CPS)**

This chapter provides a systematic analysis of reliability issues in CPS, addressing both theoretical aspects and practical case studies. Methods for evaluating and enhancing reliability are presented for environmental monitoring systems, medical IoT systems, mechatronic systems and assistive robots, hardware platforms with limited resources, as well as advanced driver assistance systems and autonomous vehicles. The contributions target both the architectural and the algorithmic levels of CPS, demonstrating how artificial

intelligence, IoT, and embedded systems technologies can be integrated to ensure correct and predictable system operation in real-world environments characterized by uncertainty and severe resource constraints.

#### **4.1. Reliability of Environmental and Safety Monitoring Systems**

This subsection analyzes CPS solutions dedicated to environmental and public safety monitoring, where measurement accuracy and operational continuity are critical. Distributed architectures based on IoT sensors and edge nodes are presented, capable of detecting performance degradation and maintaining system functionality in the presence of faults or extreme environmental conditions. The contributions highlight methods of functional redundancy, intelligent data filtering, and real-time anomaly detection.

#### **4.2. Reliability in Medical IoT Systems**

This subsection addresses reliability issues in IoT-based medical systems, where errors may have direct consequences for patient safety. Fault-tolerance mechanisms, biomedical data validation strategies, and methods for ensuring communication integrity are analyzed. The contributions demonstrate how Cloud-Fog-Edge architectures and explainable AI models can increase trust in connected medical systems.

#### **4.3. Reliability of Mechatronic Systems and Assistive Robots**

This section is dedicated to mechatronic CPS and assistive robots, where direct interaction with users imposes strict safety and robustness requirements. Reliability evaluation models based on continuous system state monitoring and context-aware behavioral adaptation are presented. The contributions support the development of safe collaborative and assistive robots operating in dynamic environments.

#### **4.4. Reliability of Hardware Systems and Assistive Devices**

This subsection addresses the reliability of hardware components and assistive devices, with emphasis on constraints imposed by energy resources, component wear, and variability in operating conditions. Methods for early fault diagnosis and strategies for extending operational lifetime are analyzed.

#### **4.5. Reliability of Resource-Constrained Platforms**

This section focuses on challenges specific to embedded and edge platforms characterized by limited computational and memory resources. The contributions emphasize AI algorithm optimization, deterministic execution, and energy consumption reduction, while maintaining CPS performance and stability.

#### **4.6. Reliability of Driver Assistance Systems and Autonomous Vehicles**

This subsection analyzes CPS used in advanced driver assistance systems (ADAS) and autonomous vehicles. Mechanisms for sensor redundancy, data fusion, and risk assessment are discussed, demonstrating the critical role of reliability in real-time autonomous decision-making.

## **Chapter 5 - Contributions to CPS and Intelligent Transportation**

This chapter is dedicated to CPS applications in intelligent transportation systems. Solutions for driving behavior monitoring, ADAS, autonomous vehicles, and V2V/V2I cooperation are discussed, with an emphasis on safety, performance, and operational reliability. The author's contributions focus on the integration of sensors, deep learning-based perception algorithms, and adaptive control mechanisms for traffic optimization and risk reduction. The research demonstrates the potential of CPS to transform transportation into a safe, predictable, and energy-efficient system.

## **Chapter 6 - Contributions to CPS and Deep Learning**

This chapter presents the use of deep learning techniques within CPS. The types of neural networks employed (CNN, LSTM, generative networks, reinforcement learning) are analyzed, along with advanced applications in computer vision, classification, and intelligent optimization, as well as challenges related to deploying these models in real-world and embedded systems.

### **6.1. Types of Deep Learning Networks Used**

This subsection presents the main deep learning architectures used in the research, including CNN, LSTM, GRU, hybrid CNN-RNN models, and transformer-based networks. The advantages of each architecture are discussed in relation to CPS applications.

### **6.2. Contributions to Deep Learning and Advanced Applications**

This section highlights original contributions to the application of deep learning for complex data analysis, anomaly detection, and advanced classification. Experimental results demonstrating improved performance and robustness in real-world applications are presented.

### **6.3. Generative Networks and Advanced Computer Vision**

This subsection addresses the use of generative networks (GANs) and advanced computer vision techniques for data augmentation, simulation, and visual analysis in CPS. The contributions support the development of systems capable of operating under limited data conditions.

### **6.4. Reinforcement Learning and Intelligent Optimization**

This section analyzes the use of reinforcement learning for adaptive control and optimization in CPS, demonstrating the potential of these methods in autonomous and self-adaptive systems.

## **Chapter 7 - Contributions to CPS and Predictive Maintenance**

This chapter addresses the integration of predictive maintenance into industrial CPS ecosystems. AI-based solutions are presented for monitoring industrial air compressors,

early fault diagnosis, and estimation of the remaining useful life (RUL) of Li-ion batteries, as well as CPS architectures supporting proactive maintenance decisions.

#### **7.1. AI Solutions for Monitoring Industrial Air Compressors**

This subsection describes AI models for industrial signal analysis and early fault detection in compressors, demonstrating reduced downtime.

#### **7.2. Early Diagnosis of Li-Ion Battery Health State**

This section addresses data-driven diagnostic methods based on electrical signals and deep learning models, relevant to energy systems and industrial CPS.

#### **7.3. Remaining Useful Life (RUL) Estimation of Li-Ion Batteries**

This subsection focuses on RUL estimation using LSTM, GRU, and hybrid architectures, highlighting prediction accuracy under real operating conditions.

#### **7.4. Integration of Predictive Maintenance into Industrial CPS Ecosystems**

The final subsection discusses the full integration of predictive maintenance into CPS ecosystems, demonstrating the economic and operational benefits of these approaches.

### **Chapter 8 – Final Remarks**

This chapter synthesizes the main results obtained throughout the previous chapters and highlights the transversal contributions of the research. The lessons learned, limitations of the proposed approaches, and their implications for the future development of dependable CPS are emphasized.

### **Career Development and Future Plans**

This section presents the author's vision for the future development of teaching and research activities. It details plans for scientific career progression, the alignment of educational activities with research, and institutional and community engagement. The chapter outlines strategic directions for professional, academic, and scientific development in the post-habilitation period, with the objective of consolidating the author's academic position and developing a nationally and internationally competitive research activity. The proposed plans are grounded in the experience accumulated to date, the results obtained in the field of dependable cyber-physical systems, and emerging trends in artificial intelligence, the Internet of Things, and distributed intelligent systems.

The overarching vision of career development is oriented toward establishing the author as an academic and scientific leader in the field of intelligent cyber-physical systems, with a focus on integrating deep learning, IoT infrastructures, and embedded technologies into applications critical to society. This evolution presupposes a balanced approach between

teaching excellence, research performance, and active involvement in institutional and community life.

### **a) Plan for the Development of Educational Activities**

The development of educational activities will focus on continuously adapting the teaching process to labor market requirements, rapid technological evolution, and the specific needs of students in Automation, Applied Informatics, and Intelligent Systems. The main objective is to train graduates with strong, interdisciplinary competencies, capable of designing, implementing, and evaluating intelligent and dependable cyber-physical systems.

In this regard, the following are envisaged:

- continuous updating of course content through the integration of the latest research results in AI, deep learning, edge computing, and CPS;
- expanded use of active, student-centered teaching methods, including project-based learning, industrial case studies, and digital simulations;
- development of modern laboratories integrating IoT platforms, embedded systems, and advanced software tools for data analysis and artificial intelligence.

An important objective is the initiation and consolidation of new undergraduate and master's courses and modules dedicated to emerging topics such as:

- dependable cyber-physical systems;
- artificial intelligence for embedded systems;
- predictive maintenance and data-driven industrial analytics;
- security and reliability in IoT and CPS.

In addition, increased involvement in supervising bachelor's, master's, and doctoral theses is envisaged, with an emphasis on applied and interdisciplinary research topics leading to disseminable results in the form of scientific publications or functional prototypes.

### **b) Plan for the Development of the Scientific Career**

The development of the scientific career will be oriented toward consolidating a coherent and internationally visible research agenda focused on the design and evaluation of intelligent and dependable cyber-physical systems. The main research directions include:

- integration of explainable deep learning (XAI) methods into critical CPS;
- development of Cloud–Fog–Edge architectures for medical and industrial systems;
- application of federated and distributed learning in heterogeneous IoT environments;
- enhancement of CPS reliability and resilience through self-monitoring and self-adaptation mechanisms;
- advanced predictive maintenance for industrial and energy infrastructures.

A strategic objective is the coordination and acquisition of national and international research projects (PN, PNRR, Horizon Europe) as project director or principal investigator, as well as the expansion of existing collaborations with universities and research centers in Europe, Asia, and Australia.

Publishing results in top-tier Web of Science–indexed journals and active participation in IEEE and IFAC international conferences will remain priorities, with an emphasis on scientific quality and impact. In parallel, involvement in editorial and peer-review activities for international journals and conferences is envisaged, contributing to enhanced academic visibility.

### **c) Alignment of Teaching Activities with Scientific Research**

A central pillar of the professional development plan is strengthening the synergy between teaching and research activities. Direct integration of scientific results into the educational process is envisaged, enabling students to access up-to-date topics and cutting-edge technologies.

This alignment will be achieved through:

- involving students in ongoing research projects;
- using real data and research-developed prototypes as support for laboratory and project activities;
- developing graduation theses leading to joint student–faculty publications;
- promoting a research culture and critical thinking from the undergraduate level onward.

This approach contributes to the training of a new generation of engineers and researchers capable of addressing complex problems and actively contributing to the development of emerging technologies.

### **d) Institutional and Community Engagement**

The career development plan includes active and responsible involvement in the institutional life of the Technical University of Cluj-Napoca and in the academic and professional community. Continuous participation in academic leadership structures, committees, and decision-making bodies is envisaged, contributing to the strategic development of the faculty and the university.

Additionally, the plan includes:

- strengthening relationships with industry and the IT sector through educational partnerships and joint projects;

- participation in science outreach activities and promotion of STEM fields among pupils and students;
- involvement in lifelong learning initiatives, continuing education courses, and open educational resources (OER, MOOCs);
- support for the academic community through mentoring activities and supervision of early-career researchers.

## **Final Conclusions**

The final chapter provides an integrative synthesis of the entire thesis, highlighting its overall contribution to the field of dependable cyber-physical systems. General conclusions are formulated, the scientific and applied impact of the research is assessed, and strategic directions for post-habilitation development are outlined.

The habilitation thesis synthesizes and critically evaluates the scientific, professional, and academic activity carried out over recent years, with a central focus on the research, development, and application of intelligent and dependable cyber-physical systems (CPS) integrated with artificial intelligence technologies, the Internet of Things, and embedded systems. The presented contributions demonstrate a coherent, mature scientific trajectory oriented toward complex problems that are relevant from both theoretical and applied perspectives.

From an academic standpoint, the thesis reflects a strong integration of research and teaching activities, materialized through the development of modern courses, supervision of graduation theses, and the involvement of students in applied research projects. This synergy contributes to the training of a new generation of specialists capable of addressing current technological challenges.

Overall, the habilitation thesis demonstrates the author's ability to initiate, lead, and develop original and relevant research directions, to coordinate complex academic activities, and to actively contribute to the development of the scientific community. The results obtained confirm the scientific and professional maturity required to assume the role of doctoral supervisor and to consolidate a research school in the field of intelligent and dependable cyber-physical systems.

The future research directions outlined in the thesis ensure the continuity and further development of this activity, providing the premises for significant contributions to scientific progress and to the societal impact of emerging technologies.