Ph.D Proposal 2025: Prescribed-time Control for Hybrid Distributed Parameter Systems

Supervisor:

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Project : ANR JCJC : PH-DIPSY.

Context and objectives

Many complex physical systems in fields such as transportation, traffic, energy, biology, and epidemiology, among others, are accurately described by Distributed Parameter Systems (DPS), whose state solution lies in an infinite-dimensional space. These mathematical models reveal intricate space-time phenomena and are typically formulated as Time-Delay Systems (TDS) and Partial Differential Equations (PDEs) in one or higher spatial dimensions—particularly hyperbolic and parabolic PDEs, which are essential for modeling hydraulic networks, traffic flow, gas pipelines, and more. The dynamic operation of such systems relies on integrating suitable control and estimation strategies that influence system behavior and guide it toward desired outcomes. For control and estimation design, two primary approaches to act on these systems can be highlighted: boundary and in-domain sensing and actuation. The design process often employs methods such as the Backstepping approach, Lyapunov techniques, and Modal decomposition.
Many DPS also exhibit discrete or hybrid phenomena, including impulsive dynamics, switching resets, and digital controller effects. While hybrid finite-dimensional systems (ODEs) have been extensively studied, hybrid DPS remain a significant challenge, requiring novel theoretical approaches.

The existing control and estimation algorithms typically ensure exponential or asymptotic convergence. However, finite-time stabilization and estimation are crucial when precise, time-constrained control is required. Prescribed-time convergence, achieved through time-varying feedback or state delays, has emerged as a powerful tool, enabling user-defined convergence times while reducing control effort.

Objective 1: Develop novel controllers and observers for DPS to achieve prescribed-time stability and estimation. The focus will be on linear and nonlinear hyperbolic and parabolic PDEs in one or higher dimensions, potentially including nonlocal terms and interactions with ODEs.
Objective 2: Address hybrid phenomena and digital realization in DPS. This includes:
i) Analyzing how switching behavior impacts DPS, formulating control problems, and studying stability and well-posedness in hybrid DPS settings.
ii) Developing robust digital realization frameworks, such as sampled-data, event-triggered control, and quantization, to address the hybrid characteristics introduced by sampling, scheduling, and quantization.

Objective 3: Achieve prescribed-time convergence for Hybrid DPS by building on tools like time-scaling transformations, intentional delays (time-varying delayed feedbacks), sampled-data, and state-dependent switching/gain scheduling.
Objective 4: Apply the theoretical results to real-world traffic flow control. It is worth noting that freeway traffic congestion control is a prominent example of DPS application. Hyperbolic PDEs, such as the Lighthill-Whitham-Richards (LWR) and Aw-Rascle-Zhang (ARZ) models, describe traffic density and velocity dynamics. Control strategies, including ramp metering and variable speed limits, aim to mitigate stop-and-go traffic. However, existing models often overlook hybrid phenomena, such as sudden driver behavior changes or traffic light regulation, necessitating the development of new models. Hence, we aim to develop a hybrid DPS model for traffic flow that incorporates switching phenomena, such as abrupt driver behavior changes and traffic light effects. The objective is to achieve faster convergence, mitigate congestion, and enhance traffic efficiency through advanced control strategies developed in the previous objectives, particularly to address stability and prescribed-time convergence in hybrid DPS.

Work plan

The first part of the thesis will be dedicated to a comprehensive literature review of the latest research on prescribed-time control of Hybrid Distributed Parameter Systems (DPS). This review will explore various tools and methodologies, including time-varying and non-smooth techniques, to achieve finite-time and prescribed-time convergence for Hybrid DPS. Additionally, it will examine traffic flow control problems, highlighting key challenges and recent advancements in the field.
The second part of the Ph.D. thesis will focus on achieving the outlined scientific objectives. This will involve developing novel control and estimation strategies, analyzing hybrid phenomena in DPS, and applying these theoretical advancements to real-world scenarios, particularly in traffic flow control. Progress will be systematically assessed through an annual report, which will include an evaluation by the doctoral school (CSI evaluation) and outline perspectives for the following years.

The candidate will be asked to regularly write technical reports including the review of the progress achieved and the perspectives for the next period. The research findings will be disseminated through presentations at international conferences and the publication of articles in top-tier journals.

Required Skills and Expertise

We are looking for a talented and highly motivated candidate with a solid background in applied mathematics and control theory.
The ideal candidate should be passionate about research, capable of both independent and collaborative work, and actively engaged in collective activities within the laboratory. Very good English skiils and advanced proficiency in scientific programming (Python, MATLAB) are essential.

Position details

Employment : Full-time, 3 years.
Location : Lille, France.
Starting Date: Between October and December 2025.

Application Information

Please send, in a single PDF, your detailed CV, motivation letter, transcripts of grades and contact details for one or two references to: Nicolas Espitia (nicolas.espitia-hoyos@univ-lille.fr).

Application Deadline: April 16, 2025.

Note: CRIStAL is subject to **“Zone à Régime Restrictif” (ZRR)**. Additional documents may be required for a security clearance by the **"France Sécurité Défense" (FSD).**

References

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