## Ph.D. in Information Technology
## Thesis Defenses

**September 17th, 2024**
**at 9:00 a.m.**
**Room Alpha**

**Nicolas Matthias KESSLER** – XXXVI Cycle

**LINEAR MATRIX INEQUALITY\\CONDITIONS FOR GAIN-SCHEDULING AND MODEL PREDICTIVE CONTROL**

Supervisor: Prof. Lorenzo Mario Fagiano

**Abstract:**

This dissertation presents a novel approach to gain-scheduling model predictive control (MPC) for trajectory tracking on uncertain nonlinear systems, leveraging linear parameter-varying (LPV) models. A hierarchical scheme is developed, separating trajectory generation from stabilization using a 2-Degrees-of-Freedom (DoF) design. The focus of this thesis is the design of the feedback action, such that it guarantees tracking of the reference under bound satisfaction. A key innovation is the graph-based gain-scheduling variable, enabling modular feedback application for online decisions. Nonlinearities are taken into account by extending the resulting LPV model with a polytopic uncertainty.

Initially, a simple Linear Matrix Inequality (LMI) condition is proposed to address stabilizability and later extended to address performance in an MPC scheme. Subsequently, it yields a novel method for the systematic design of the terminal ingredients for an LTV MPC. The LTV MPC is then extended to a robust tube-MPC with constraint satisfaction.

Efficient offline solvability of the resulting LMI conditions is addressed via the Alternating Direction Method of Multipliers (ADMM) to enable memory-efficient, distributed optimization. The proposed LTV MPC scheme is computationally efficient online, because the optimal control problem is structured as a convex Quadratic Program (QP), that exploits its temporal evolution. Simulation on a Continuously Stirred Tank Reactor (CSTR) and hardware implementation on a CrazyFlie drone demonstrate the approach's capability to stabilize nonlinear systems under disturbances and constraints with limited computing resources. These advancements, combined with efficient offline LMI solving, promise broad applicability for safety-critical industrial systems.

**Jing XIE** – XXXVI Cycle

**MACHINE LEARNING METHODS FOR MODELING AND CONTROL OF DYNAMIC SYSTEMS**

Supervisor: Prof. Riccardo Scattolini

**Abstract:**

The thesis topic revolves around machine learning methods for system identification and model-based control design, with a specific emphasis on Recurrent Neural Network (RNN) models. The thesis comprises three main parts.

The first part delves into RNN model identification, addressing several key issues. Stability properties such as Input-to-State Stability (ISS) and incremental ISS are analyzed, and sufficient conditions are derived. These conditions can be enforced by adding a regularization term to the training cost. Additionally, the incorporation of physical information into RNN model design is explored to enhance interpretability and modeling performance. Furthermore, a lifelong learning method for model adaptation after dynamics drift is proposed.

In the second part of the thesis, the focus shifts to model-based control design. Two schemes are considered: Model Predictive Control (MPC) and Internal Model Control (IMC). A robust offset-free MPC tracking scheme is proposed for NNARX models, wherein an integrator and derivative action are added to the system model. Moreover, a Control Affine NNARX model is introduced, mirroring the input affine structure of the system dynamics. An IMC scheme leveraging CA-NNARX models is also proposed to expedite online computation.

The final part of the thesis is dedicated to industrial application. A tailored NNARX-based MPC algorithm is implemented for temperature control units manufactured by Tool-Temp AG. This application demonstrates the practical relevance and effectiveness of the developed control methodologies in real-world scenarios.

## PhD Committee

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