Fostering Opportunities Towards Slovak Excellence in Advanced Control for Smart Industries

D3.2. Report on the 1st and 2nd summer schools and on Academia meets industry seminar series

Date by 30.09.2024
v.1

Project: 101079342 — FrontSeat —HORIZON-WIDERA-2021-ACCESS-03

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DELIVERABLE INFORMATION

Work package	WP3
Task	Task T3.3: Seminars with industrial participation Task T3.4: Summer schools
Due date	30.09.2024
Submission date	27.09.2024
Deliverable lead	University of Pisa
Version	v.1
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Dissemination Level	PUB - Public

Abstract	The project aims at increasing the research and academic prospects of the Slovak University of Technology in Bratislava, Slovakia (STUBA) and at initiating the evolution of STUBA into a modern, reputed excellent institution that performs high-quality research in advanced automatic control, educates top-quality scholars and industrial practitioners, and is successful in active dissemination and exploitation of its research and innovation efforts. For this purpose, STUBA teams up with two renowned research groups in automatic control from Ruhr University Bochum, Germany (RUB) and Pisa University, Italy (UNIPI). The specific goals of the action are to reinforce the collaboration with the two research groups from Western Europe, to intensify research in advanced automatic control, to open up new collaboration channels through academic and industrial networking, to train excellent young/senior researchers and project managers, and to effectively disseminate and exploit the research results of STUBA. The unique features of the project are: - Adoption/amendment of internal research project-related rules and procedures and develop project management toolbox, - Research efforts aiming at the continued creation of high-quality research results and software tools, - Establishment of a series of guest scientific and academic lectures, - Exchanges and training of project managers and research (junior and senior) personnel, - Organization of conferences and invited sessions, seminars with industry, and annual summer schools, - Preparation and implementation of a new PhD curriculum at STUBA, - Establishment of an academic-industrial research and innovation cluster.
Keywords	Control theory and optimization; Sensor networks, embedded systems, hardware platforms;

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	Embedded systems; Monitoring and control systems; Embedded systems in automation and control.

Document Revision History

Version	Date	Description of change	List of contributors

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PARTNERS

The consortium of FrontSeat consists of 3 partners, as presented here below.

STUBA

Slovak University of Technology in Bratislava

RUB

Ruhr University Bochum

UNIPI

University of Pisa

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EXECUTIVE SUMMARY

This document constitutes Deliverable 3.2 “Report on the 1st and the 2nd Summer School and on “Academia meets industry” seminars“ of the FrontSeat Project, funded by the European Union’s Horizon Europe research and innovation programme under the action number 101079342. The purpose of this deliverable is to present the results of 2 Summer Schools – 1st one that took place in September 2023 in STUBA and 2nd one that took place in September 2024 in UNIPI, and of the series of seminars “Academia meets Industry”, that were organised by STUBA during the project implementation.

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ABBREVIATIONS

Abbreviation	Expanded Version
MPC	Model Predictive Control
MPT3	Multi-Parametric Toolbox

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1ST SUMMER SCHOOL IN STUBA

Short introduction and objectives of the activity

The aim of this five-day FrontSeat Summer School on "Embedded Optimal Control" organized at the Slovak University of Technology in Bratislava (STUBA) was to provide participants with both theoretical insights and hands-on experience in advanced methods and tools for embedded optimal control. The program covered state-of-the-art approaches to formulating and solving optimal control problems, including real-time model predictive control and data-driven alternatives using machine learning, with a focus on implementation on embedded hardware. The course featured technical lectures followed by dedicated workshops with computer exercises. Additionally, a session on presentation skills was included. In the end of the course, students worked on an application problem (self-chosen) by exploiting various methods and algorithms discussed within the summer school.

Recruitment and admission

The FrontSeat Summer School on "Embedded Optimal Control" was organized by Ing. Juraj Holaza, PhD. and doc. Ing. Martin Gulan, PhD. between 11-15 September 2023 in Slovak University of Technology in Bratislava (STUBA).

Students were invited to the summer school via an intensive propagation campaign that started from early 2023. The main focus of the campaign was mainly to make the summer school visible on various social networks (see e.g. Instagram, Facebook) and on several scientific conferences (such as PC23 and IFAC world congress 2023), by distributing flyers, via our poster, and official dedicated web page. Altogether, we have booked all our opened seats with 19 participants from four European countries ranging from graduate students to early-career researchers.

To provide a high-quality program, renown scientists from academia and industry were invited to participate in the summer school. Table ***1*** lists the key speakers along with brief descriptions of their field of expertise. Notably, each speaker was accompanied by top students or colleagues to enhance the interactive nature of the workshops. While the names of these assistants are not listed to streamline the document, we extend our gratitude for their support.

Key Speaker	Description
prof. Ing. Michal Kvasnica, PhD.	Profesor at STUBA in Bratislava. Recognized expert in the field of predictive control.
prof. Ing. Gergely Takács, PhD.	Senior research engineer at Garret Motion. Recognized expert in the field of real-time embedded control.
doc. Ing. MSc. Martin Klaučo, PhD.	Deputy of Institute of Information Engineering, Automation, and Mathematics (UIAM) for research at STUBA in Bratislava. Recognized expert in the field of AI.
Ing. Marco Vaccari, PhD.	Assistant Professor at University of Pisa (Pisa, Toscana, Italia). Recognized expert in the field of process modeling/simulation/optimization.
Mgr. Martin Ždímal	Lecturer of English/Slovak languages with 18-year experience. Trainer of soft/hard skills.

Table 1: List of key speakers

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Description of the program

The program was scheduled across five days where English was used as the main language. To make the best estimate of the difficulty level of the programme, a survey was conducted to get information from all attending students about their confidence in the control theory, programming skills, etc. This information was subsequently provided to all key speakers that adequality tailored their lectures and workshops. The final program is shown in .

<table>
<tr><th></th><th>Mo 11.9.</th><th>Tu 12.9.</th><th>We 13.9.</th><th>Th 14.9.</th><th>Fr 15.9.</th></tr>
<tr><td>9:00 – 10:00</td><td>Registration</td><td rowspan="2">Introduction to MPC Code</td><td>Introduction to Embedded Control Hardware / Introduction to AutomationShield</td><td rowspan="4">Soft Skills Presentation</td><td rowspan="4">Project Presentation</td></tr>
<tr><td>10:00 – 11:00</td><td rowspan="2">Introduction to Optimal Control / Introduction to MPT3</td><td rowspan="2">AutomationShield Workshop</td></tr>
<tr><td>11:15 – 12:00</td><td>MPC Code Workshop</td></tr>
<tr><td>12:00 – 13:00</td><td>Lunch</td><td>Lunch</td><td>Lunch</td><td>Lunch</td><td>Lunch</td></tr>
<tr><td>13:00 - 14:00</td><td rowspan="2">MPT3 Workshop</td><td>Introduction to Machine Learning</td><td>Project Assignment</td><td rowspan="2">Project Work</td><td rowspan="2"></td></tr>
<tr><td>14:15 – 17:00</td><td>Machine Learning Workshop</td><td>Social Program</td></tr>
</table>

Table 2: Schedule of the summer school

The program started with a smooth registration process, during which all participants received a gift bag containing essential items that were later utilized in both lectures and workshops. The eco-bag included notebook, coffee cup, and pen with the FrontSeat logo (see Figure 1). This was followed by a welcoming presentation, where the program and organizational personnel were formally introduced.

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Figure 1: Invitation bag for all participants of the summer school

Introduction to optimal control and MPT3

The lecture and workshop on optimal control and Multi-Parametric Toolbox (MPT3) was led by prof. Ing. Michal Kvasnica, PhD. (Figure 2). The session was designed to equip attendees with the necessary skills to implement and customize MPC algorithms for various control applications.

The lecture began with an overview of the theoretical foundations of optimisation and model predictive control (MPC), emphasizing its relevance and application in modern control systems. Subsequently, importance of a fast prototyping of this control strategy was stressed out to enable easy tunning and deployment of the MPC to the real system. MPT3 toolbox was introduced as a very suitable candidate to satisfy this need. Specifically, MPT3 is an open source, MATLAB-based toolbox for parametric optimization, computational geometry and model predictive control. With a simple interface, MPT3 allows users to design complex feedback controllers within typing a few lines of code.

The workshop covered the key aspects of MPC design, including the formulation of control objectives, constraints, and optimization problems. First, the basic optimisation problems were exercised by formulating simple optimisation problems. Secondly, foundation of simple MPC strategies were developed and verified via MPT3. Finally, a more challenging tasks were adopted and simulated during the course.

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Figure 2: Introduction to optimal control and MPT3 by Prof. Michal Kvasnica.

Introduction to MPC Code

The workshop was dedicated to a multipurpose, easy-to-use code for Model Predictive Control (MPC) design, analysis and simulation called *MPC-code* that is developed by Marco Vaccari at the Department of Civil and Industrial Engineering of University of Pisa under supervision of Prof. Gabriele Pannocchia. MPC Code is distributed under the LGPL license, meaning the code can be used royalty-free even in commercial applications. Unlike MPT3 toolbox, which is using MATLAB programming language, MPC-code is has been implemented in Python.

The lecture and workshop, led by Ing. Marco Vaccari, PhD., focused on providing participants with the essential skills to implement and tailor MPC algorithms for a range of control applications (Figure 3). The lecture covered the fundamental elements of MPC design and their formulation in the *MPC-code* framework. The workshop featured case studies demonstrating the application of the *MPC-code* to common industrial control problems. These examples were chosen to highlight the flexibility and robustness of the MPC framework in handling complex dynamic systems. Additionally, participants were encouraged to experiment with the code, exploring different configurations and tuning parameters to observe their effects on system performance.

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Figure 3: Introduction to MPC Code by Dr. Marco Vaccari.

Introduction to Machine Learning

The lecture and workshop, led by doc. Ing. MSc. Martin Klaučo, PhD. (Figure 4), aimed to provide participants with practical experience in applying advanced machine learning tools within the context of control theory. The session specifically explored methods to enhance the efficiency of Model Predictive Control (MPC). Participants received a comprehensive introduction to machine learning case studies, focusing on the selection of suitable architectures and data preparation strategies. The workshop then presented cutting-edge MPC-mimicking techniques designed to generate approximate explicit control laws, along with guidelines for developing general controllers modelled as neural networks with stability assurances. Case studies and examples were customized to address common challenges and processes within this field. The workshop provided participants with hands-on experience in experiment preparation and coding exercises.

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Figure 4: Introduction to Machine Learning by Assoc. Prof. Martin Klaučo.

Introduction to Embedded Control and Automation Shield

The course, led by prof. Ing. Gergely Takács, PhD. (Figure 5), included an in-depth lecture covering both the theoretical foundations of embedded control, which is integral to the design and implementation of embedded systems, and an introduction to the AutomationShield project. Participants were introduced to the principles and challenges of embedded control, providing a strong theoretical background that was essential for understanding and working with the AutomationShield platform. This lecture served as a crucial foundation for the practical applications explored later in the workshop.

The workshop targeted embedding these advanced control methods into a simplified control environment, where participants engaged with the AeroShield—an experimental platform that is part of the broader AutomationShield project. The AeroShield, a key component of this workshop, served as the controlled process, allowing students to apply theoretical knowledge to a tangible, real-world system. Participants were guided through the process of implementing control algorithms on the Arduino, gaining hands-on experience with the challenges and nuances of embedded control systems. The workshop successfully bridged the gap between theoretical control concepts and their practical implementation, providing participants with valuable skills in embedded control systems.

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Figure 5: Introduction to Embedded Control and AutomationShield by Prof. Gergely Takács.

Soft skill

As the summer school was dedicated to graduate students to early-career researchers it was of a paramount importance to address and improve, besides the technical knowledge, also communication skills. This course was led by a lector Mgr. Martin Ždímal who was providing such trainings for almost two decades (Figure 6).

The lecture and workshop targeted on developing essential soft skills for effectively presenting research and project results to a broader audience. The session aimed to equip participants with the communication techniques and strategies necessary to convey simple/complex ideas clearly and engagingly to diverse stakeholders, including non-specialists. Participants were introduced to best practices for structuring presentations, tailoring messages to different audiences, and using visual aids to enhance comprehension.

During the workshop, students were encouraged to prepare a short presentation about a topic that was close to them and present it to their colleagues. Besides having only a few minutes to prepare speech, students have experienced the transition from a listener to a speaker. By the end of the session, participants had gained practical tools and insights for presenting their work in a manner that resonates with a broad audience, ultimately increasing the impact and reach of their research.

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Figure 6: Soft skill course by Mgr. Martin Ždímal.

Social program

The social program is primarily targeted to enhance the students' networking activities. Therefore, the social program was divided into two main parts. The first part consisted of a scenic trip to Devin and Bratislava castles, followed by an excursion to the attractive Bratislava downtown area. To enhance the experience, transportation to all three points of interest was provided by a tourist train that picked up students directly from the university. A local guide, fluent in all four languages, shared historical and architectural insights throughout the journey. The second part of the social program took place at a local restaurant, where dinner was served. Besides of nice views and the meal, students were able to bond and get to know each other even better, forming valuable connections for their future careers.

Figure 7: Social program.

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Final project assignment

The final project served as a crucial component of the course, designed to verify and consolidate the knowledge students had acquired throughout the program. With limited time and resources, students were tasked with solving a specific problem and presenting their solutions to their peers. This assignment not only tested their technical skills but also integrated the soft skills learned during the course, such as teamwork and effective communication.

Participants were divided into several independent groups. Following a brief brainstorming session, each group chose a specific control problem to work on and to propose a solution to. The groups were given half a day to develop their solutions, with lecturers available for consultation as needed. On the last day of the summer school, the groups presented their projects to a four-member committee composed of lecturers and organizers. The committee moderated the presentations, providing feedback through questions and comments.

The quality of the projects was impressive, particularly given the time constraints, demonstrating both a high level of technical understanding and strong communication skills. Ultimately, all projects were successfully defended, reflecting the effectiveness of the course in preparing students for real-world challenges.

Figure 8: Certificates of achievement presented to summer school graduates.

Lunches and coffee breaks

Throughout the duration of the summer school, lunches and coffee breaks played an essential role in maintaining a comfortable and productive environment for the participants. Lunches were provided daily in the university canteen, offering students the convenience of booking their meals a day in advance to accommodate diverse dietary preferences and ensure satisfaction for everyone.

In addition to the lunches, coffee breaks were scheduled twice a day, providing students with much-needed refreshment and an opportunity to recharge between sessions. These breaks not only kept participants energized and ready to absorb new knowledge but also served as informal networking opportunities where students could connect and discuss ideas in a relaxed setting.

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Overall, the well-organized lunch and coffee breaks contributed significantly to the overall experience, fostering both productivity and camaraderie among the participants.

Final student feedback

The final feedback was received via a Google formular from students. The survey addressed several criteria across lectures, workshops, and organization. The results of the survey are shown in Table ***3***.

Criterion	**Lectures (0%- none, 100% very)**	**Workshops (0%- none, 100% very)**
The difficulty level	49.7%	51.9%
The level of added value	69.1%	71.6%
The level of attractiveness	74.2%	73.3%
The level of organisation	80.0%	
Rating of the social program	93.3%	
Overall rate of the summer school	86.7%	

Table 3: Evaluation of the feedback from the participants.

Finally, all lecture and workshop materials can be found on Google drive where one can also watch recorded lectures or to look at captured photos during the entire summer school. The summarizing report of the FrontSeat Summer school on Embedded Optimal Control can be found on the official FrontSeat blog.

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2ND SUMMER SCHOOL IN UNIPI

Short introduction and objectives of the activity

The aim of this five-day FrontSeat Summer School on "Optimazion-based Control Systems: Theory and Application" organized at the University of Pisa (UNIPI) and coordinated by Prof. Gabriele Pannocchia was to provide participants with both theoretical insights and practical experience in advanced methods and tools for optimization-based control. The program covered the basis of numerical optimization, state-of-the-art approaches to formulating and solving optimal control problems, model predictive control design, from linear to nonlinear type, passing through off-set free formulation and moving-horizon estimation, and finally data-driven modeling techniques of traditional and machine-learning methods. The course featured technical lectures followed by dedicated workshops with computer exercises using open-source software. At the end of the course, students worked on small self-chosen projects by exploiting the various methods and algorithms discussed within the lessons.

Recruitment and admission

The FrontSeat Summer School on "Optimazion-based Control Systems: Theory and Application " took place between 9-13 September 2024 at the Department of Civil and Industrial Engineering of the University of Pisa (Italy). The event was led by Prof. Gabriele Pannocchia, who organized the program by selecting topics and inviting lecturers. The two researchers of the UNIPI group, Dr. Riccardo Bacci di Capaci and Dr. Marco Vaccari, took care of all logistic aspects from the recruitment and promotion to the schedule definition and the social program.

Students were invited to the Summer School via a propagation campaign in early 2024. The main focus was to make the summer school visible on social networks (e.g., LinkedIn, Facebook) and during the proceeding of scientific conferences (such as ADCHEM2024) by distributing flyers, via our poster and the official dedicated web page. Altogether, we have booked all our open seats with 22 participants from 8 European countries ranging from Master's to PhD students and early-career researchers (Figure 9).

To provide a high-quality program, 7 renowned scientists from academia were invited to participate in the summer school. Table ***1*** lists the key speakers and brief descriptions of their expertise.

Key Speaker	Description
Prof. Moritz Diehl	Professor at University of Freiburg. Recognized expert in optimization and predictive control.
Prof. Martin Mönnigmann	Professor at Ruhr-Universität Bochum. Recognized expert optimization and predictive control.
Prof. Gabriele Pannocchia	Professor at University of Pisa. Recognized expert in optimization and predictive control.
Dr. Karol Kiś	Assistant Professor at STUBA in Bratislava. Recognized expert in process modeling and simulation.
Dr. Riccardo Bacci di Capaci	Assistant Professor at University of Pisa. Recognized expert process modeling and simulation.
Dr. Marco Vaccari	Assistant Professor at University of Pisa. Recognized expert in simulation and optimization.

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Jonathan Frey	PhD student at University of Freiburg. Recognized expert in optimization and CasADi, maintainer of software acados.

Table 4: List of key speakers

Figure 9. 2024 FrontSeat Summer School participants.

The program at a glance

The program was scheduled across five days where English was used as the main language. To make the best estimate of the program difficulty level, a preliminary survey was conducted to get information from all attending students about their confidence in the control theory, programming skills, etc. The final program is shown in Table 5.

	Mo 9.9.	**Tu 10.9.**	**We 11.9.**	**Th 12.9.**	**Fr 13.9.**
9:00-9:45	Welcome speech & Motivations on optimization-based control	Nonlinear MPC	Systems identification: traditional data-driven methods	Project Work	Project Presentation
9:45-10:30	Optimization basics	Offset-free MPC			
11:00-11:45	Linear MPC & QP	Numerical integration and direct optimal control methods	Systems identification: Neural Networks and Machine Learning		
11:45-12:30	Nonlinear optimization				Final discussion & wrap-up
12:30-14:00	Lunch	Lunch	Lunch	Lunch	Lunch
14:00-15:00	Introduction to CasADi	Moving Horizon Estimation	Workshop 3.1: SIPPY tool	Project Work	
15:15-16:00	Workshop 1.1: Generic NLP	Workshop 2.1: MPCcode	Workshop 3.1: NN with Pytorch		
16:00-17:00	Workshop 1.2: Linear MPC & QP	Workshop 2.2: acados	Project Assignment	Social Program	

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Table 5: Schedule of the summer school

The program started with a smooth registration process, during which all participants received essential items later utilized in both lectures and workshops.

Detailed description of the program

Introduction

The event was opened by a welcome speech (Figure 10) delivered by the 2024 FrontSeat Summer School coordinator Prof. Gabriele Pannocchia (UNIPI). After a brief introduction, the program and organizational personnel were formally introduced, and the professor outlined the motivations for optimization-based control. Control issues and objectives of multivariable systems were outlined, so that the need for model-based advanced control strategies was explained.

Figure 10. Welcome speech by Prof. Gabriele Pannocchia.

Optimization and Model Predictive Control

Our special guest, Prof. Moritz Diehl (University of Freiburg), a renowned expert in the field of optimal control and MPC, delivered three interesting lectures during the first two days: “Optimization basics” (Figure 11) and “Nonlinear optimization” on Day 1 and “Numerical integration and direct optimal control methods” on Day 2. He also supervised the Workshops on Day1 and Day2.

Within his lecture on “Optimization basics”, Prof. Diehl outlined the basic definitions for optimization problems, such as physical set, global and local minimizers, convex sets, convex functions, and convexity. Then, the Professor presented a comprehensive classification for optimization problems and related numerical algorithms, spanning from linear (LP), quadratic (QP), and nonlinear programming (NLP) to mathematical programming with complementarity constraints, mixed-integer nonlinear programming, and continuous-time optimal control.

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Finally, direct optimal control methods and nonlinear MPC were presented as widely spread examples of NLPs, and instrumental for the implementation of optimization-based control systems.

Figure 11. Optimization basics by Prof. Moritz Diehl.

Also, Prof. Martin Mönnigmann (Ruhr-Universität Bochum, RUB), FrontSeat coordinator for RUB, contributed to the core program. As a recognized expert in the field of optimal control and MPC, he delivered two engaging lectures: “Linear MPC and QP” (Figure 12) on Day 1 and “Nonlinear MPC” on Day 2.

In his “Linear MPC and QP” lecture, Prof. Mönnigmann recalled balance and ordinary differential equations (ODEs) as the core of dynamic models, stressing how even simple systems result in nonlinear ODEs. Then, the Professor showed that a large class of problems can be modeled with linear time-invariant (LTI) systems and relative extensions. In contrast, discrete-time models are the basis for digital control systems and microcontrollers, so suitable discretization methods are required to convert continuous LTIs into discrete LTIs. Linear MPC (LMPC) was later introduced, by stating the general formulation and discussing the necessary transformations from the original infinite horizon problem to the practical finite horizon problem. Finally, the transformation of a general LMPC problem into a quadratic program using block matrices was extensively discussed.

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Figure 12. Linear MPC and QP by Prof. Martin Mönnigmann.

Finally, Prof. Gabriele Pannocchia (UNIPI), completed the rich program of the first two days and, as a recognized expert in the field of optimal control and MPC, his captivating lectures were on: "Linear state estimation & offset-free MPC" (Figure 13) and "Moving Horizon Estimation" on Day 2.

In his lecture on "Linear state estimation & offset-free MPC", Prof. Pannocchia introduced state estimation in MPC explaining the relative objectives and challenges. Later, linear optimal state estimation was discussed, starting with the well-known Kalman filter, arriving at the steady-state Kalman filter and Luenberger observer, and finally presenting the duality between optimal control and optimal estimation. Later, the critical issue of system uncertainties (such as systems subject to external disturbances and/or model/plant mismatch) was introduced, and the offset-free MPC was presented as a key solution. The lecturer continues with a detailed presentation of offset-free MPC formulations, in linear and nonlinear structures, by stressing industrial and academic design principles, in terms of the disturbance model and consequent augmented model, and the relative three basic blocks, as observer, target calculation, and finite horizon optimal control problem. Finally, the main advantages over other traditional – non-offset-free - MPC formulations were illustrated with numerical examples.

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Figure 13. Linear state estimation & offset-free MPC by Prof. Gabriele Pannocchia.

Jonathan Frey, PhD student at University of Freiburg, an expert in the field of optimization and CasADi and acados, delivered a lecture on "Introduction to CasADi and acados" and organized the Workshops on Day1 - generic NLP - and Day2 – acados (Figure 14).

Figure 14. Workshops on *acados* by Jonathan Frey.

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Assistant Professor Marco Vaccari (UNIPI), an expert in the field of process simulation, optimization, and MPC, delivered a lecture on "Introduction to MPCCode" and organized the Workshops on Day 1 - linear MPC/QP - and Day 2 – MPCcode (Figure 15).

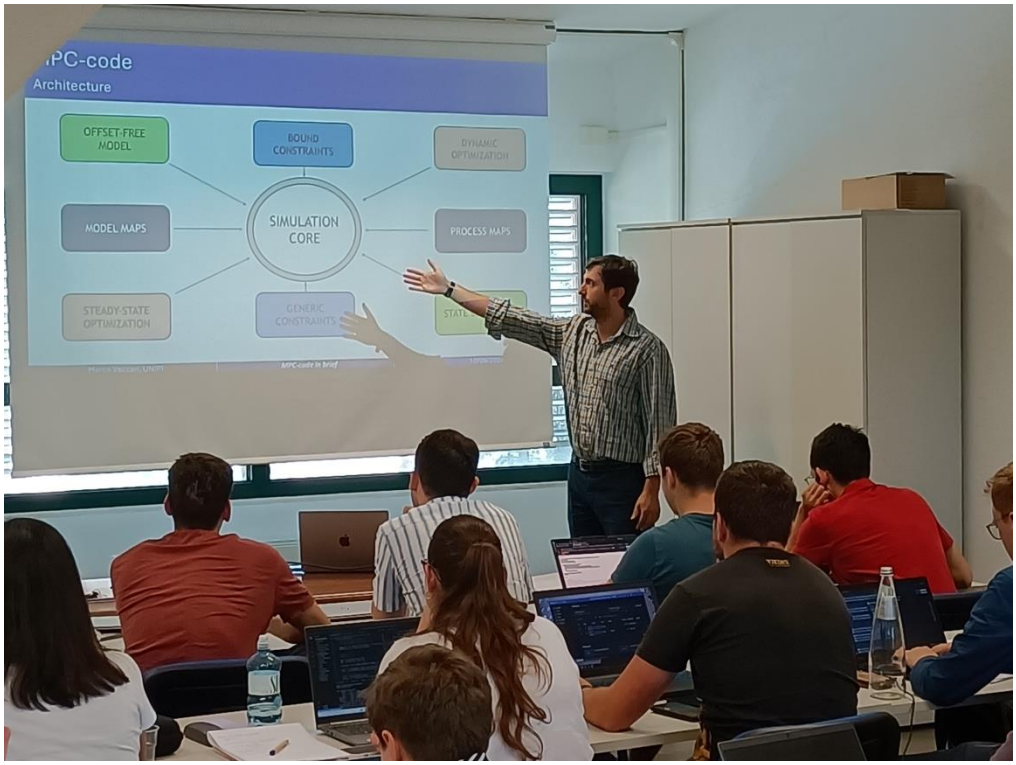

Figure 15. Workshop on *MPCcode* by Dr. Marco Vaccari.

MPCcode is implemented in Python and distributed under the LGPL license, meaning the code can be used royalty-free even in commercial applications. The lecture and workshop of Dr. Vaccari focused on providing participants with the essential skills to implement and tailor MPC algorithms. The brief lecture covered the fundamental elements of MPC design and their formulation in the *MPC-code* framework. The workshop featured case studies demonstrating the application of the *MPC-code* to a common industrial control problem. The example chosen highlighted the flexibility and robustness of the MPC framework in handling complex dynamic systems. Additionally, participants were encouraged to experiment with the code, exploring different configurations and tuning parameters to observe their effects on system performance.

Modelling

Assistant Professor Riccardo Bacci di Capaci (UNIPI), an expert in the field of process modelling and simulation, delivered a lecture on "Systems identification: traditional data-driven methods" (Figure 16) and organized the relative Workshops on Day 3 – SIPPY tool.

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Figure 16. Systems identification: traditional data-driven methods by Dr. Riccardo Bacci di Capaci.

In his lecture on "Systems identification: traditional data-driven methods", Dr. Riccardo Bacci di Capaci started by introducing the objectives, ingredients, and phases of data-driven system identification procedure. Later, the lecturer presented a comprehensive classification of identification methods for dynamic input/output linear models, from the conventional approaches (Finite Impulse Response – FIR and AutoRegressive with eXogenous – ARX models) to advanced techniques based on the prediction error, such as AutoRegressive with Moving Average and eXogenous input (ARMAX) models. In addition, the difference between conventional and advanced input design approaches was discussed, introducing the concept of informative signals for a suitable model definition and stressing the pros and cons of open-loop and closed-loop data collection. After hints on nonlinear models and NLP for system identification, the lecture introduced subspace methods, of classical and parsimonious type, for direct identification of linear state-space models. Finally, the definition of information criteria and the concept of model validation were presented as useful tools for model performance optimization and testing.

Dr. Karol Kiš (STUBA), completed the program of Day 3, and as an expert in the field of process modelling and simulation, delivered a lecture on "Systems Identification with Machine Learning" (Figure 17). He also organized the relative Workshops on Day 3 – Neural Networks with Pytorch.

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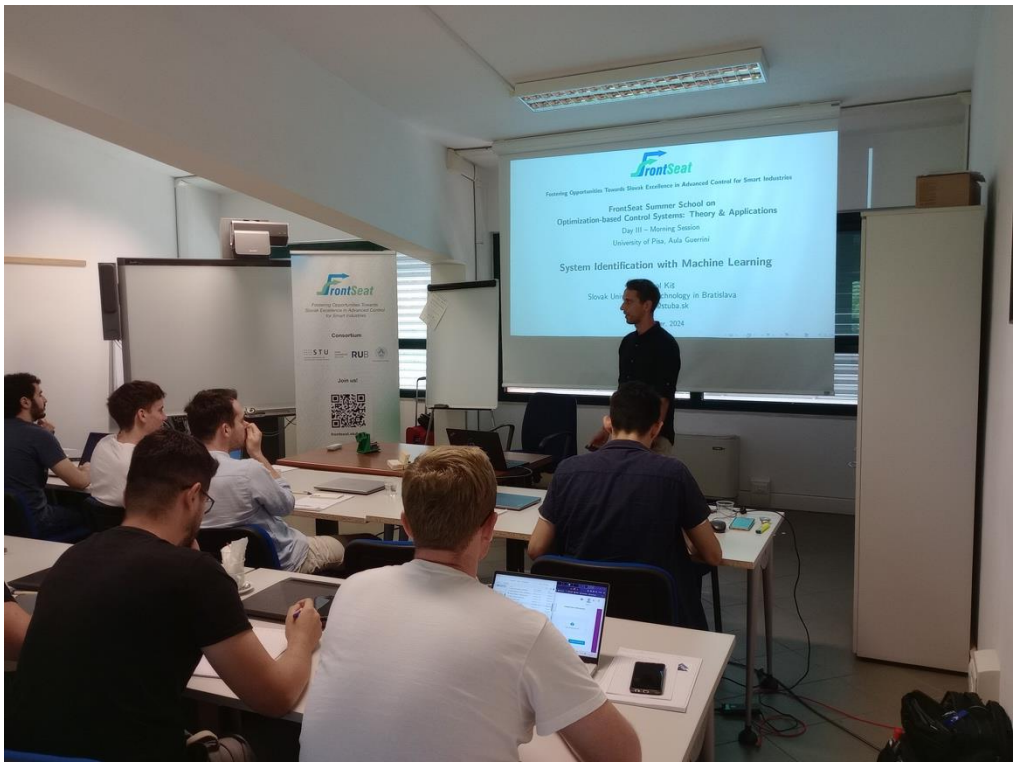

Figure 17. Systems Identification with Machine Learning by Dr. Karol Kiš.

In his lecture on "Systems Identification with Machine Learning", Dr. Karol Kiš recalled the difference between major classes (white/grey/black) of dynamic models for system identification. After an introduction to the history and distinction between artificial intelligence, machine learning, and neural networks, the various approaches for model training (supervised, unsupervised, and reinforcement learning) were defined. Then, the focus was on Neural Networks (NN), defining the main features and parameters, such as perceptron, activation functions, layers, loss functions, gradient descent methods, learning rate, classes of optimizer, and levels of performance. Later, two established NN-based approaches for system identification were extensively presented: the Neural State-Space Models and the Neural ODE. Finally, the Differentiable Predictive Control was introduced as an example of an NN-based predictive controller.

From the end of Day 3, students worked on small projects, exploiting the methods and software learned and used during the course. Students were free to compose the project team and select their application problem (Figure 18), but Prof. Pannocchia and Prof. Diehl outlined some hints and prototypes of projects.

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Figure 18. The project works: the assignment phase.

During Day 4 students worked in 6 small groups (3/4 people each) and real-time supervision was provided by the teachers so that the sessions allowed constructive discussions, feedback, and the exchange of innovative ideas (Figure 19).

Figure 19. The projects: teamworking moments.

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Finally, on Day 5 students presented their research projects focused on optimization-based control. In particular, the 6 projects concerned: i) spacecraft attitude control, ii) Van Der Vusse reactor control; iii) active suspension control and estimation; iv) attitude control and estimation of UAVs; v); bioreactor control and estimation; vi) path follower car-like vehicle control and estimation. Teachers listened to students with interest, appreciating the efforts made and the result achieved, and providing fruitful feedback and suggestions for the future (Figure 20).

Figure 20. The projects: final presentations.

At the end, all attendees received a certificate of participation upon completion of the summer school, recognizing their dedication to advancing the field of optimal control (Figure 21).

Figure 21. Certificates of achievement presented to summer school graduates.

Social Program

Moreover, the 2024 FrontSeat Summer School fostered an environment for networking and teamwork. In addition to the academic program, students enjoyed the millennial culture and history of Pisa through an engaging social program comprised of a guided tour of the famous Piazza dei Miracoli and the Leaning Tower (Figure 22) and a pleasant social dinner in a typical Osteria within the city centre (Figure 23).

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Figure 22. Social Program: visiting Piazza dei Miracoli and the Leaning Tower of Pisa.

Figure 23. Social Program: enjoying the social dinner.

Lunches and coffee breaks

Throughout the 2024 FrontSeat summer school, lunches and coffee breaks were essential in maintaining a comfortable and productive environment for the participants. Meals were provided just next to the room for lectures and workshops, accommodating diverse dietary

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preferences and ensuring satisfaction for everyone. In addition to the lunches, coffee breaks were scheduled twice a day, providing students with much-needed refreshments and an opportunity to recharge between sessions. These breaks not only kept participants energized and ready to absorb new knowledge but also served as informal networking opportunities where students and teachers could connect and discuss ideas in a relaxed setting.

Overall, the well-organized lunch and coffee breaks contributed significantly to the experience, fostering both productivity and friendship among the participants.

Final student feedback

The final feedback of the 2024 FrontSeat summer school was received via a Google form filled out by the students just after the event term. The survey addressed several criteria across lectures, workshops, and organization. The overall results of this survey are shown in Table 6.

Criterion	Lectures	Workshops
The difficulty level (0% - too easy; 100% - too difficult)	58.0	55.7
The level of attractiveness (0% - no interest; 100% - great)	81.8	72.7
The level of added value learned (0% - no useful; 100% - very useful)	87.5	75.0
The level of organisation (0 – 100%)	94.3	
Rating of the social program (0 – 100%)	95.5	
Rating of the social dinner (0 – 100%)	92.0	
Overall rate of the summer school (0 – 100%)	90.9	

Table 6: Evaluation of the feedback from the participants.

Among student indications, the project work session proved a bit stressful due to the limited time assigned and the rich schedule (e.g., having the social program and dinner both on Day 4 just before the project presentation did not reveal the best choice), but also results as a great full-immersion experience in optimization-based control systems.

Finally, all lecture and workshop materials can be found on One Drive where one can also look at the captured photos during the entire 2024 Summer School. A cover note of the FrontSeat Summer School on Optimization-based Control can be found on the official FrontSeat: https://frontseat.stuba.sk/summer-school-on-optimization-based-control-systems-theory-applications/

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"ACADEMIA MEETS INDUSTRY" SEMINARS

Short introduction and objectives of the activity

The goal of this activity is to create a closer connection between STUBA workplaces in the field of cybernetics and the private environment, including industry. For this, the FrontSeat Industrial Council was established, which has 6 academic members (individual institutes) and representatives from 19 different Industry partners. These seminars have a dedicated section on the project website: https://frontseat.stuba.sk/academia-meets-industry/

Objectives of the the Industrial Council:

1. Act as an advisory body in the field of research, development, innovation and education in the field of cybernetics,

2. Deepen communication between STUBA and partner companies, enterprises and institutions in Slovakia and abroad in the field of cybernetics,

3. To help shape the profile of a cybernetics graduate at STUBA so that it meets the requirements of practice,

4. Create conditions for the two-way transfer of knowledge between STUBA and enterprises with an orientation towards the development of STUBA as well as partner enterprises in the field of cybernetics,

5. Improve the employment opportunities of STUBA graduates in the field of cybernetics,

6. Enable the transfer of the results of STUBA's scientific research activities into practice in the field of cybernetics,

7. To create positive awareness of pedagogical and scientific-research activities at STUBA in the field of cybernetics.

Meetings

Academia meets Industry #1

Figure 24: First meeting "Academia meets Industry"

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The first meeting took place on February 28, 2023 in Bratislava (STUBA). During the meeting the members of the newly formed "FrontSeat Industry Council for Cybernetics" were announce and were given appointment decrees. The meeting was focused on getting to know each other and hearing the first ideas and thoughts on how this cooperation could work. The most important part of the meeting was the discussion. The industrial partners presented their approach to the cooperation and raised valuable questions. Practices and good and bad experiences were discussed. In the end, the Council agreed to prepare some more clear vision of needs from the part of the industry, so the STUBA could easier understand what kind of students, with what skills, they could suggest. Council agreed to meet at least 2-times per year in an informal setting, to stimulate more active discussion. Full article with photos can be found here: https://frontseat.stuba.sk/academia-meets-industry-1/

Academia meets Industry #2

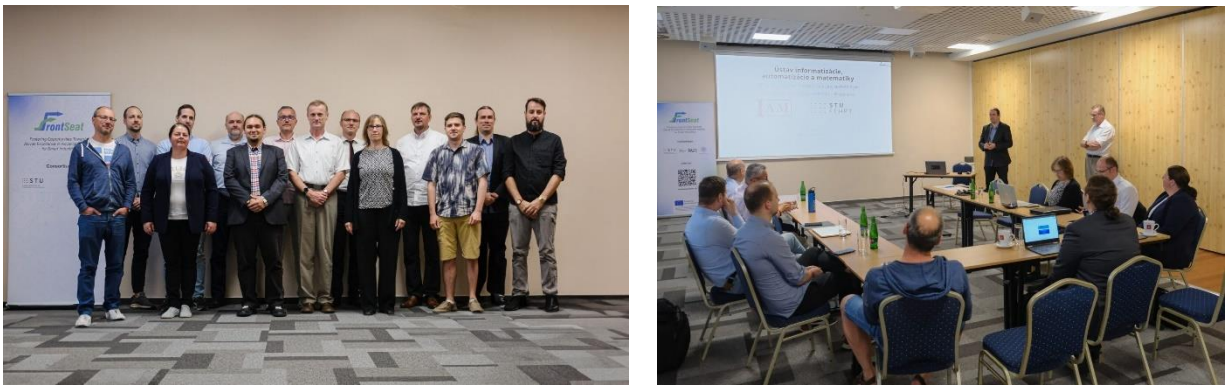

Figure 25, 26: Second meeting of "Academia meets Industry"

The second meeting took place on 15.6.-16.6. 2023 in Patince, Slovakia. The second "Academia Meets Industry" seminar picked up on the initial meeting held in February, and after the official opening started with short presentations of the participating institutes from five faculties of the Slovak University of Technology in Bratislava, given by their representatives, namely Prof. Fikar, Prof. Vrábel, Prof. Rosinová, Prof. Duchoň, and Dr. Juhás. In addition to introducing the workplace, its personnel, and study programs, the presentations focused on current research activities and selected examples of cooperation with industry. They were intertwined with stimulating discussion and questions raised by the industrial partners representing seven companies: Ing. Peter Beňo, PhD. (Photoneo), Ing. František Jantoška (Schunk), Ing. Hynek Procházka, PhD. (Prosystemy), Ing. Ondrej Kolimár (SmartBase), Ing. Daniel Zverko (IQLOGY), Ing. Zuzana Kovaríková (VÚEZ), Ing. Pavol Buček, PhD. (ŽP VVC).

During the meeting Ing. Zuzana Kovaríková of VÚEZ, a.s. presented their cooperation with the Institute of Robotics and Cybernetics in terms of joint R&D projects, co-supervised bachelor, master, and dissertation theses, and a particular success story that resulted in a robotic workplace for intelligent welding of small-scale production. The discussion initiated several ways of cooperation and mutual support, for example by involving the students in applied research projects of the companies via final theses, co-funding the laboratories, providing specific technologies, and promoting each other in general.

Full article with photos can be found: https://frontseat.stuba.sk/academia-meets-industry-2/

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Academia meets Industry #3

Figure 27: Third "Academia meets Industry" meeting

The main motive of the meeting was for the industry partners to present their companies and activities and, in particular, to offer the selected research idea as topics of final theses for university students. The presentations were given, in order of appearance, by Ing. Rudolf Trautenberger (Spolchemie), Ing. Hynek Procházka, PhD. (Prosystemy), Ing. Michal Kopček, PhD. (SKARTEK), Ing. Pavol Buček, PhD. (ŽP VVC), Ing. Marián Šrámek (Micro-Epsilon Inspection), Ing. Marián Filka (Siemens), Ing. Richard Janáč (SOVA Digital), Ing. Peter Beňo, PhD. (Photoneo), Ing. František Jantoška (SCHUNK Intec), Ing. Zuzana Kovaríková (VUEZ), and Ing. Jaroslav Filo (S-D-A). The proposed topics of final theses were collected and are now distributed to 6 institutes at 4 faculties of STUBA, where they are to be offered to interested supervisors and students themselves.

The presentations were followed by a stimulative discussion aimed at identifying ways how to further boost the dialogue between academia and industry.

Specific diploma theses were defined, which academic workplaces in cooperation with companies will present to students. The next meeting will be focused on evaluating the assignment of diploma theses and setting up further cooperation - for example, the question of establishing a cluster. It should take place in October 2024.

Full article with photos can be found: https://frontseat.stuba.sk/academia-meets-industry-3/

Results and outcomes

- 42 diploma theses submitted by companies;
- Developed cooperation with industry and a more significant influence of industry on pedagogy at individual institutes;

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- Better acquaintance with companies and the academy in the cybernetics portfolio.

Future collaboration after the project

During the upcoming meeting, potential future collaboration will be explored. Key points of consideration include the regular assignment of diploma theses by Industry partners, which will strengthen the connection between academic research and industry needs. This consistent collaboration will provide students with valuable real-world experience, while companies will benefit from fresh perspectives and innovative solutions to current challenges.

In addition, we will formalize cooperation within research projects by aligning research goals with industry objectives, both parties can leverage their respective strengths, resulting in mutual benefits such as technological advancements, increased competitiveness, and expanded research opportunities. This cooperation will also open doors for interdisciplinary projects, fostering innovation across sectors.

To ensure the sustainability of these partnerships beyond the lifespan of the project, creation of a structured framework, such as a dedicated cluster or consortium will be created. This framework will serve as a platform for ongoing collaboration, enabling participants to continue sharing resources, knowledge, and expertise even after the completion of the projects. It will also facilitate the expansion of the network to include additional partners, thereby enhancing the scope and impact of future joint initiatives.

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