Activity Report 2022

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Activity Report 2022

AUTOMATIC CONTROL | LUND UNIVERSITY

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Activity Report 2022

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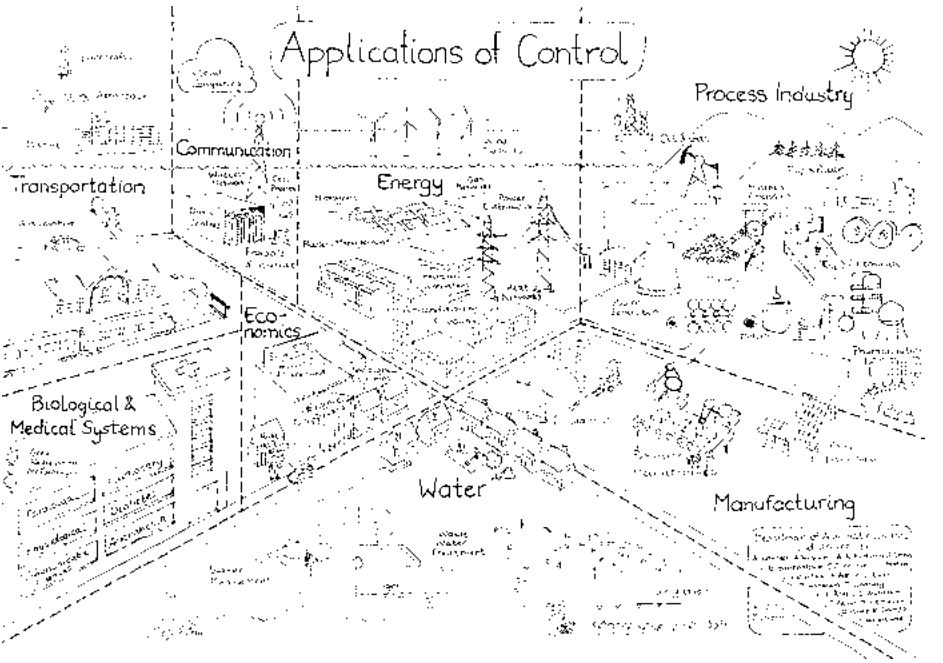
Content

Introduction

A summary of the activities at the Department of Automatic Control, Lund University during the period January 1 to December 31, 2022


Applications of Control
Process Industry
Communication
Transportation
Energy
Eco-
nomics
Biological &
Medical Systems
Water
Manufacturing

AUTOMATIC CONTROL HIGHLIGHTS OF 2022

This report covers the activities at the Department of Automatic Control during 2022. We can summarise the year in numbers as follows:

The economy showed a turnover for 2022 of 67,1 MSEK, an increase of 4,3 MSEK since the previous year. More about financial figures is found in the chapter *Economy*.

The department now has 58 members (excluding guests), divided into the following categories: 5 professors, 1 senior professor, 1 guest professor, 1 adjunct professor, 9 associate professors, 5 research engineers, 4 administrators, 4 postdocs, 3 researchers, 25 PhD students and 3 industrial PhD students (this includes part-time positions). This year four new PhD students and two postdocs were admitted to the department. We also welcomed two new associate professors in Robotics. Read more about this in the chapters *Education/Personnel*.

Tore Hägglund retired in August but is still working part-time for the department, mainly with the planning of moving back to the M-building in May 2023.

During 2022, the department gave seventeen different courses and 1 087 students passed, 49 students presented their masters' theses at the department. Six PhD courses were also given.

Eight PhD theses were defended and two licentiate theses were presented during 2022. The total number of PhDs graduated from the department is now 140. The number of WASP-funded PhDs and postdocs at the department have slightly decreased and is now 11, including two industrial PhD students and two postdocs. Some of our other PhD students are also "WASP affiliated", which means that they can take courses offered within the WASP Graduate School programme. Read more about this in the chapter *Education*.

During the year our *Industry Club* had its first event in March, where round-table discussions divided into our three research branches, as well as the introduction of our latest robot "SPOT" took place. Read more in the chapter *External Contacts*.

An ELLIIT focus period workshop, with the title *Data-driven modelling and learning for cancer immunotherapy* was held in Lund, May 4-6. Young researchers had the opportunity to spend some time in connection to the workshop. In October the first ELLIIT Tech Talk was released, followed by another twelve episodes.

In May an alumn mingle party was held - many of them have not met for a long time, so it was much appreciated - the next time might be when we are back in the M-building again.

This year the Swedish Automatic Control meeting took place in Luleå, June 7-10, having been postponed for 2 years because of the pandemic. Next time it will take place in Lund in 2025.

The euRobotics week is now well established and took place during three days in late November. New for this year was the participation of the Cognition RoboticsLab under the umbrella of AI Lund.

Research within Lund University and the Faculty of Engineering has been divided into profile areas, whereas the department is involved in several of the faculty profile areas. Another way to make our research areas more visible, has been to produce a number of short films introducing both Automatic Control in general and also a number of specific research areas, like "Large Scale Applications", "Optimization Research", "Industry Standards" and "Medical Applications". Many of our colleagues have become "film stars".

The pandemic is over and we have been able to welcome several new colleagues, and have had a the number of visiting guests, primarily during the fall.

Looking into the future, the new funding and our newly started projects will open up interesting challenges for the years to come. The field of Automatic Control is centrally placed in the rapidly developing field of AI, Machine Learning and its applications. We have an interesting time ahead of us.

Monika Rasmusson and Kristian Soltesz

Education

Education at undergraduate and graduate level including dissertations 2022

UNDERGRADUATE STUDIES

The engineering education at LTH, the engineering faculty of Lund Univeristy, follows the central European system with five-year programs leading up to the university degree civilingenjör, with the international title MSc in engineering.

Automatic control courses are taught as part of the engineering curricula in Engineering Physics (F), Electrical Engineering (E), Computer Engineering (D), Mechanical Engineering (M), Information and Communication Engineering (C), Environmental Engineering (W), Engineering Mathematics (Pi), Industrial Management and Engineering (I), Biotechnology (B), Engineering Nanoscience (N), Chemical Engineering (K), and Biomedical Engineering (BME). Our advanced courses are included in more than fifteen of the master-level specializations in the various programs.

During 2022, there were 1 394 course registrations and 1 087 passed grades were awarded, which corresponds to 181 full-year equivalents. The table on the next page, lists our undergraduate courses, along with the number of students who passed each course. Some of our courses have become so popular that we unfortunately had to restrict the number of students, due to lack of staff resources. 49 students completed their master's thesis projects, and a total of 34 theses were presented. A list of the master's theses is given in the *Publications and Seminars* chapter.

The two-year international master programme *Machine Learning Systems and Control* was started with 12 students in 2020 and a second batch of 18 students were admitted in 2021. The programme is managed by Mikael Nilsson at the mathematics department and Bo Bernhardsson. In 2022 a third batch of 22 students were admitted, which is a slight increase.

Most of our lectures have now been recorded and we have also developed new formats of teaching which are worthy to maintain also in the future, when we now have returned to a more normal post-pandemic situation.

Many of the courses now have course material available via a Canvas page open to the public. You can find these pages through our education web page.

TOTAL NUMBER OF STUDENTS WHO PASSED OUR COURSES 2022

Automatic Control, Basic Course
(FRTF05 Reglerteknik) 516
Systems Engineering
(FRTF10 Systemteknik) 47
Control Theory
(FRTF15 Reglerteori) 13
Applied Robotics
(FRTF20 Tillämpad robotteknik) 40
Introduction to Machine Learning, Systems and Control
(FRTF25 Introduktion till maskininlärning, system och reglering) 23
Physiological Models and Computations
(FRTF01 Fysiologiska modeller och beräkningar) 43
Nonlinear Control and Servo Systems
(FRTN05 Olinjär reglering och servosystem) 3
Real-Time Systems
(FRTN01 Realtidssystem) 52
Automatic Process Control
(FRTN25 Processreglering) 29
Network Dynamics
(FRTN30 Nätverksdynamik) 35
Project in Automatic Control
(FRTN40 Projekt i reglerteknik) 24
Mathematical Modeling, Advanced Course
(FRTN45 Matematisk modellering, fortsättningskurs) 36
Optimization for Learning
(FRTN50 Optimering för maskininlärning) 32
Automatic Control, Advanced course
(FRTN55 Reglerteknik, fortsättningskurs) 47
Real-Time Systems
(FRTN60 Realtidssystem) 3
Modeling and Learning from Data
(FRTN65 Modellering och inlärning från data) 47
Project in Systems, Control and Machine Learning
(FRTN70 Projekt i system, reglering och maskininlärning) 7
Learning-Based Control
(FRTN75 Inlärningsbaserad reglering) 40
Engineering Work Training
(FRTF97 Ingenjörsinriktad yrkesträning) 5
Degree Project in Automatic Control
(FRTM01 Examensarbete i reglerteknik) 45

GRADUATE STUDIES

The PhD education consists of four years of studies, but since most students have 20% of department duties, the nominal time for the PhD education is 5 years. In the Swedish system there is also a possibility to do a half-time thesis called a "licentiate". The general syllabus for PhD studies in Automatic Control states that the course requirement for a PhD degree is 90 credits, while the thesis scope is 150 credits.

In 2022 eight doctoral theses were defended by Martin Heyden, Taouba Jouini, Alexandre Martins, Tommi Berner, Johan Ruuskanen, Martin Morin, Hamed Sadeghi and Claudio Mandrioli. Two licentiate theses were presented by Christian Rosdahl and Olle Kjellqvist. During the year we have admitted Lara Laban, Luka Bakovic, Marko Guberina, Julia Adlercreutz and Alba Gurpegui Ramón as new PhD students. Fredrik Bagge Carlson, a former PhD graduate from the department and currently research scientist with JuliaHub, held a PhD course in Scientific programming using the Julia language, where the students learnt and practiced bleeding edge techniques for efficient scientific programming techniques. Charlotta Johnsson was involved as a Guest speaker in the PhD course *Innovation and Value Creation in Research*, September 2022. Charlotta Johnsson was also involved as a guest speaker in the course *Complex Automation*, May 2022.

The following PhD courses were given at the department in 2022:

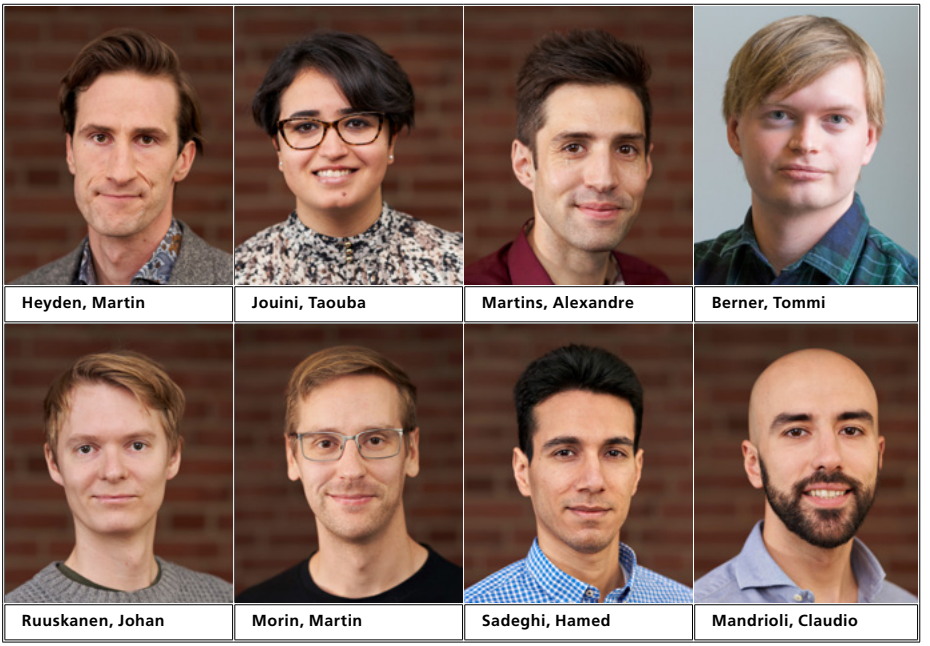
- *Feedback control theory;* Richard Pates
- *Julia for scientific programming;* Fredrik Bagge Carlsson
- *FRT260F Real-Time Operating Systems;* Anton Cervin
- *Linear Systems;* Venkatraman Renganathan
- *Modeling - from Physics to Languages and Software;* Karl Johan Åström
- *Statistical Data and Learning Visualisation - a data-driven tour through the cancer immunity state base;* Bo Bernhardsson, Magnus Fontes and Gérard Besson

There are also several PhD courses organised within the WASP Graduate School programme, available for both WASP graduate and affiliated students. WASP Graduate School students are required to take WASP courses corresponding to at least 27 credits, including the mandatory course and at least 2 out of the 3 foundational courses. See below offered courses:

Mandatory courses	*Legal, Ethical and Societal Aspects of AI and Autonomous Systems*
Foundational courses	*Autonomous Systems*
	AI and Machine Learing
	Software Engineering and Cloud Computing
Elective courses	*Deep Learning for Natural Language Processing*
	Deep Learning
	Graphical Models, Bayesian Learning and Statistical Relational Learning
	Interaction, Collaboration and Visualization
	Learning Feature Representations
	Learning Theory
	Reinforcement Learning
	Scalable Data Science and Distributed Machine Learning
	Topological Data analysis
	WASP project course
Introductory courses	*Introduction to logic for AI*
	Mathematics for Machine Learning

DOCTORAL DISSERTATIONS

This year there were eight PhD students defending their thesis. The abstracts are presented below.



Heyden, Martin	Jouini, Taouba	Martins, Alexandre	Berner, Tommi
Ruuskanen, Johan	Morin, Martin	Sadeghi, Hamed	Mandrioli, Claudio

ON THE CONTROL OF TRANSPORTATION NETWORKS WITH DELAYS

Heyden, Martin

ISBN 978-91-8039-118-4

In this thesis, a general model for transportation on directed tree graphs is studied. The nodes in the graph correspond to different storage locations, and the edges describe between which storage locations transportation is possible. The transportation is assumed to be subject to delay. Furthermore, nodes at the top of the network are allowed to produce more of the studied quantity. As an example, this setup can model an irrigation network, consisting of several pools that are connected via gates. The gates allow water to be transported from the upstream to the downstream pool. Each pool can be described by a node, and the edges describe which pools are connected by a gate. The production corresponds to taking water out from a reservoir and into a pool.

A common approach for control of large-scale networks is to stabilize the system around the optimal equilibrium point. However, as the operating conditions of the network change, the optimal equilibrium point will also change. In this thesis, the dynamic performance of the network is optimized, where the cost associated with deviations from the nominal levels is minimized. The transportation variations are not penalized, as it is assumed that this cost is negligible (for example, in the case of irrigation networks, gravity is responsible for the movement).

The optimal controller is shown to be highly structured, without imposing any structural constraints on the controller that normally limit performance. This structure allows for a simple and efficient implementation. The optimal transportation assignments can be calculated by a sweep through the graph, starting in the nodes without children, and iterating upwards. This implies that each gate in an irrigation network only needs to receive information from the gates downstream and send information to the gates upstream.

Even stronger results are derived for string graphs. Firstly, it is shown how to give optimal feed-forward for planned disturbances. These planned disturbances could for example be farmers taking water out of an irrigation network. This requires minor modifications to the aforementioned controller structure, where the information about the planned disturbances can be communicated by a sweep through the graph. Secondly, it is shown how to allow for production in every node. This requires two sweeps, with one going in the upstream direction and one going in the downstream direction. These sweeps can be done in parallel, and thus the implementation time is unaffected. The resulting controller is applied to a more realistic simulation model for irrigation networks, where it outperforms a simple P controller in response to both step changes and disturbance rejection. For disturbance rejection of low-pass filtered disturbances, the performance is close to the theoretical maximum attained using a centralized controller with a perfect model.

The optimal control problem is also studied from a localized perspective, where each node tries to maximize its own utility. To coordinate, each node is presented with a price for having a certain level at each time point. It is shown how to calculate prices so that that the nodes' optimal levels align with the socially optimal levels. These prices can also be calculated by a sweep through the graph.

NETWORK SYNCHRONIZATION AND CONTROL BASED ON INVERSE OPTIMALITY : A STUDY OF INVERTER-BASED POWER GENERATION

Jouini, Taouba

ISBN 978-91-8039-089-7

This thesis dwells upon the synthesis of system-theoretical tools to understand and control the behavior of nonlinear networked systems. This work is at the crossroads of three topics: synchronization in coupled high-order oscillators, inverse optimal control and the application of inverter-based power systems. The control and stability of power systems leverages the theoretical results obtained for synchronization in coupled high-order oscillators and inverse optimal control.

First, we study the dynamics of coupled high-order nonlinear oscillators. These are characterized by their rotational invariance, meaning that their dynamics remain unchanged following a static shift of their angles. We provide sufficient conditions for local frequency synchronization based on both direct, indirect Lyapunov methods and center manifold theory.

Second, we study inverse optimal control problems, embedded in networked settings. In this framework, we depart from a given stabilizing control law, with an associated control Lyapunov function and reverse engineer the cost functional to guarantee the optimality of the controller. In this way, inverse optimal control generates a whole family of optimal controllers corresponding to different cost functions. This provides analytically explicit and numerically feasible solutions in closed-form. This approach circumvents the complexity of solving partial differential equations descending from dynamic programming and Bellman's principle of optimality. We show this to be the case also in the presence of disturbances in the dynamics and the cost. In networks, the controller obtained from inverse optimal control has a topological structure (e.g., it is distributed) and thus feasible for implementation. The tuning is analogous to that of linear quadratic regulators.

Third, motivated by the pressing changes witnessed by the electrical grid toward renewable energy generation, we consider power system stability and control as the main application of this thesis. In particular, we apply our theoretical findings to study a network of power electronic inverters. We first propose a controller we term the matching controller, a control strategy that, based on DC voltage measurements, endows the inverters with an oscillatory behavior at a common desired frequency. In closed-loop with the matching control, inverters can be considered as nonlinear oscillators. Our study of the dynamics of nonlinear oscillator network provides feasible physical conditions that ask for damping on DC- and AC-side of each converter, that are sufficient for system-wide frequency synchronization.

Furthermore, we showcase the usefulness of inverse optimal control for inverter-based generation at two different settings to synthesize robust angle controllers with respect to common disturbances in the grid and provable stability guarantees. All the controllers proposed in this thesis, provide the electrical grid with important services, namely power support whenever needed, as well as power sharing among all inverters.

RESOURCE MANAGEMENT IN DISTRIBUTED CAMERA SYSTEMS

Martins, Alexandre

ISBN 978-91-8039-187-0

The aim of this work is to investigate different methods to solve the problem of allocating the correct amount of resources (network bandwidth and storage space) to video camera systems. Here we explore the intersection between two research areas: automatic control and game theory. Camera systems are a good example of the emergence of the Internet of Things (IoT) and its impact on our daily lives and the environment. We aim to improve today's systems, shift from resources over-provisioning to allocate dynamically resources where they are needed the most. We optimize the storage and bandwidth allocation of camera systems to limit the impact on the environment as well as provide the best visual quality attainable with the resource limitations. This thesis is written as a collection of papers. It begins by introducing the problem with today's camera systems, and continues with background information about resource allocation, automatic control and game theory. The third chapter describes the models of the considered systems, their limitations and challenges. It then continues by providing more background on the automatic control and game theory techniques used in the proposed solutions. Finally, the proposed solutions are provided in five papers.

Paper I proposes an approach to estimate the amount of data needed by surveillance cameras given camera and scenario parameters. This model is used for calculating the quasi Worst-Case Transmission Times of videos over a network. Papers II and III apply control concepts to camera network storage and bandwidth assignment. They provide simple, yet elegant solutions to the allocation of these resources in distributed camera systems. Paper IV combines pricing theory with control techniques to force the video quality of camera systems to converge to a common value based solely on the compression parameter of the provided videos. Paper V uses the VCG auction mechanism to solve the storage space allocation problem in competitive camera systems. It allows for a better system-wide visual quality than a simple split allocation given the limited system knowledge, trust and resource constraints

MODELING AND CONTROL FOR IMPROVED PREDICTABILITY OF CLOUD APPLICATIONS

Berner, Tommi

ISBN 978-91-8039-234-1

Cloud computing has emerged as a key technology in the latest decade and continues to be applied to manage the computing needs of new domains. As a result, the requirements on predictable behavior in the cloud increase, thus the hosted applications need to be recognized as both fault-tolerant and responsive even under difficult conditions.

In this thesis, new modeling methods and decision-making strategies are presented with the goal of increasing the predictability of cloud applications. The methods can be divided into two tracks, using concepts from control theory and queuing theory respectively. The control-theoretical method track utilizes the concept of graceful degradation as an enabling actuator. In the context of server control, a novel dynamic model for queue lengths is proposed, as well as a cascaded structure for response time control. Additionally, interactions between decision-making strategies at different layers in the cloud infrastructure are discussed, including an interpretation of the popular Join-Shortest-Queue (JSQ) load-balancing strategy as a queue length controller.

The queuing-theoretical track utilizes the concept of request cloning to increase the predictability of applications replicated across multiple servers. A criterion for synchronized service is formalized, which enables a dramatic simplification of modeling of applications subject to cloning, without requiring any further assumptions on neither queuing disciplines nor on the statistical distributions involved. Furthermore, model error bounds are derived for server systems that break the synchronized service criterion. It is shown that imperfections that can arise during implementation, only slightly affect the accuracy of the model. Finally, an intuitive explanation is given for why the popular JSQ load-balancing strategy acts as a service synchronizer, that allows for accurate, approximate modeling of the complicated scenario of unrestricted request cloning across replicated servers where the JSQ strategy is used for load-balancing.

While there are differences in the modeling approaches between the two separate method tracks, they both share common properties that run throughout the thesis. First, the majority of the involved techniques revolve around finding design choices that enable simplification, without limiting the applicability of the solutions. Second, many of the strategies presented in the thesis apply concepts and structures traditionally used in different domains, which often requires the problems to be viewed from a slightly different angle. The proposed models and methods from both tracks are evaluated in a simulated cloud environment, composed of a discrete-event simulator implemented in a request-by-request fashion, independent of the proposed methods in this thesis.

DYNAMICAL MODELING OF CLOUD APPLICATIONS FOR RUNTIME PERFORMANCE MANAGEMENT

Ruuskanen, Johan

ISBN 978-91-8039-394-2

Cloud computing has quickly grown to become an essential component in many modern-day software applications. It allows consumers, such as a provider of some web service, to quickly and on demand obtain the necessary computational resources to run their applications. It is desirable for these service providers to keep the running cost of their cloud application low while adhering to various performance constraints. This is made difficult due to the dynamics imposed by, e.g., resource contentions or changing arrival rate of users, and the fact that there exist multiple ways

of influencing the performance of a running cloud application. To facilitate decision making in this environment, performance models can be introduced that relate the workload and different actions to important performance metrics.

In this thesis, such performance models of cloud applications are studied. In particular, we focus on modeling using queueing theory and on the fluid model for approximating the often intractable dynamics of the queue lengths. First, existing results on how the fluid model can be obtained from the mean-field approximation of a closed queueing network are simplified and extended to allow for mixed networks. The queues are allowed to follow the processor sharing or delay disciplines, and can have multiple classes with phase-type service times. An improvement to this fluid model is then presented to increase accuracy when the \emph{system size}, i.e., number of servers, initial population, and arrival rate, is small. Furthermore, a closed-form approximation of the response time CDF is presented. The methods are tested in a series of simulation experiments and shown to be accurate.

This mean-field fluid model is then used to derive a general fluid model for microservices with interservice delays. The model is shown to be completely extractable at runtime in a distributed fashion. It is further evaluated on a simple microservice application and found to accurately predict important performance metrics in most cases. Furthermore, a method is devised to reduce the cost of a running application by tuning load balancing parameters between replicas. The method is built on gradient stepping by applying automatic differentiation to the fluid model. This allows for arbitrarily defined cost functions and constraints, most notably including different response time percentiles. The method is tested on a simple application distributed over multiple computing clusters and is shown to reduce costs while adhering to percentile constraints.

Finally, modeling of request cloning is studied using the novel concept of synchronized service. This allows certain forms of cloning over servers, each modeled with a single queue, to be equivalently expressed as one single queue. The concept is very general regarding the involved queueing discipline and distributions, but instead introduces new, less realistic assumptions. How the equivalent queue model is affected by relaxing these assumptions is studied considering the processor sharing discipline, and an extension to enable modeling of speculative execution is made. In a simulation campaign, it is shown that these relaxations only has a minor effect in certain cases.

FIXED POINT ITERATIONS FOR FINITE SUM MONOTONE INCLUSIONS

Morin, Martin

ISBN 978-91-8039-410-9

This thesis studies two families of methods for finding zeros of finite sums of monotone operators, the first being variance-reduced stochastic gradient (VRSG) methods. This is a large family of algorithms that use random sampling to improve the convergence rate compared to more traditional approaches. We examine the optimal sampling distributions and their interaction with the epoch length. Specifically, we show that in methods like SAGA, where the epoch length is directly tied to the random sampling, the optimal sampling becomes more complex compared to for instance L-SVRG, where the epoch length can be chosen independently. We also show that biased VRSG estimates in the style of SAG are sensitive to the problem setting. More precisely, a significantly larger step-size can be used when the monotone operators are cocoercive gradients compared to when they just are cocoercive. This is noteworthy since the standard gradient descent is not affected by this change and the fact that the sensitivity to the problem assumption vanishes when the estimates are unbiased. The second set of methods we examine are deterministic operator splitting methods and we focus on

frameworks for constructing and analyzing such splitting methods. One such framework is based on what we call nonlinear resolvents and we present a novel way of ensuring convergence of iterations of nonlinear resolvents by the means of a momentum term. This approach leads in many cases to cheaper per-iteration cost compared to a previously established projection approach. The framework covers many existing methods and we provide a new primal-dual method that uses an extra resolvent step as well as a general approach for adding momentum to any special case of our nonlinear resolvent method. We use a similar concept to the nonlinear resolvent to derive a representation of the entire class of frugal splitting operators, which are splitting operators that use exactly one direct or resolvent evaluation of each operator of the monotone inclusion problem. The representation reveals several new results regarding lifting numbers, existence of solution maps, and parallelizability of the forward/backward evaluations. We show that the minimal lifting is n – 1 – f where n is the number of monotone operators and f is the number of direct evaluations in the splitting. A new convergent and parallelizable frugal splitting operator with minimal lifting is also presented.

EFFICIENT AND FLEXIBLE FIRST-ORDER OPTIMIZATION ALGORITHMS

Sadeghi, Hamed

ISBN 978-91-8039-467-3

Optimization problems occur in many areas in science and engineering. When the optimization problem at hand is of large-scale, the computational cost of the optimization algorithm is a main concern. First-order optimization algorithms—in which updates are performed using only gradient or subgradient of the objective function—have low per-iteration computational cost, which make them suitable for tackling large-scale optimization problems. Even though the per-iteration computational cost of these methods is reasonably low, the number of iterations needed for finding a solution—especially if medium or high accuracy is needed—can in practice be very high; as a result, the overall computational cost of using these methods would still be high.

This thesis focuses on one of the most widely used first-order optimization algorithms, namely, the forward–backward splitting algorithm, and attempts to improve its performance. To that end, this thesis proposes novel first-order optimization algorithms which all are built upon the forward–backward method. An important feature of the proposed methods is their flexibility. Using the flexibility of the proposed algorithms along with the safeguarding notion, this thesis provides a framework through which many new and efficient optimization algorithms can be developed.

To improve efficiency of the forward–backward algorithm, two main approaches are taken in this thesis. In the first one, a technique is proposed to adjust the point at which the forward–backward operator is evaluated. This is done through including additive terms—which are called deviations—in the input argument of the forward– backward operator. The deviations then, in order to have a convergent algorithm, have to satisfy a safeguard condition at each iteration. Incorporating deviations provides great flexibility to the algorithm and paves the way for designing new and improved forward–backward-based methods. A few instances of employing this flexibility to derive new algorithms are presented in the thesis.

In the second proposed approach, a globally (and potentially slow) convergent algorithm can be combined with a fast and locally convergent one to form an efficient optimization scheme. The role of the globally convergent method is to ensure convergence of the overall scheme. The fast local algorithm's role is to speed up the convergence; this is done by switching from the globally convergent algorithm to the local one whenever it is safe, i.e., when a safeguard condition is satisfied. This approach, which allows for combining different global and local algorithms within its framework, can result in fast and globally convergent optimization schemes

CONTROL-THEORETICAL PERSPECTIVE IN FEEDBACK-BASED SYSTEMS TESTING

Mandrioli, Claudio

ISBN 978-91-8039-433-8

Self-Adaptive Systems (SAS) and Cyber-Physical Systems (CPS) have received significant attention in recent computer engineering research. This is due to their ability to improve the level of autonomy of engineering artefacts. In both cases, this autonomy increase is achieved through feedback. Feedback is the iteration of sensing and actuation to respectively acquire knowledge about the current state of said artefacts and steer them toward a desired state or behaviour. In this thesis we discuss the challenges that the introduction of feedback poses on the verification and validation process for such systems, more specifically, on their testing. We highlight three types of new challenges with respect to traditional software testing: alteration of testing input and output definition, and intertwining of components with different nature. Said challenges affect the ways we can define different elements of the testing process: coverage criteria, testing set-ups, test-case generation strategies, and oracles in the testing process. This thesis consists of a collection of three papers and contributes to the definition of each of the mentioned testing elements. In terms of coverage criteria for SAS, Paper I proposes the casting of the testing problem, to a semi-infinite optimisation problem. This allows to leverage the Scenario Theory from the field of robust control, and provide a worst-case probabilistic bound on a given performance metric of the system under test. For what concerns the definition of testing set-ups for control-based CPS, Paper II investigates the implications of the use of different abstractions (i.e., the use of implemented or emulated components) on the significance of the testing. The paper provides evidence that confutes the common assumption present in previous literature on the existence of a hierarchy among commonly used testing set-ups. Finally, regarding the test-case generation and oracle definition, Paper III defines the problem of stress testing control-based CPS software. We contribute to the generation and identification of stress test cases for such software by proposing a novel test case parametrisation. Leveraging the proposed parametrisation we define metamorphic relations on the expected behaviour of the system under test. We use said relations for the development of stress testing approach and sanity checks on the testing results.

LICENTIATE DISSERTATIONS

This year there were two PhD students presenting their licentiate thesis. The abstracts are presented below.

Rosdahl, Christian

Kjellqvist, Olle

LEARNING-BASED CONTROLLER DESIGN WITH APPLICATION TO A CHILLER PROCESS

Rosdahl, Christian

In this thesis, we present and study a few approaches for constructing controllers for uncertain systems, using a combination of classical control theory and modern machine learning methods. The thesis can be divided into two subtopics. The first, which is the focus of the first two papers, is dual control. The second, which is the focus of the third and last paper, is multiple-input multiple-output (MIMO) control of a chiller process.

In dual control, the goal is to construct controllers for uncertain systems that in expectation minimize some cost over a certain time horizon. To achieve this, the controller must take into account the dual goals of accumulating more information about the process, by applying some probing input, and using the available information for controlling the system. This is referred to as the exploration-exploitation trade-off. Although optimal dual controllers in theory can be computed by solving a functional equation, this is usually intractable in practice, with only some simple special cases as exceptions. Therefore, it is interesting to examine methods for approximating optimal dual control. In the first paper, we take the approach of approximating the value function, which is the solution of the functional equation that can be used to deduce the optimal control, by using artificial neural networks. In the second paper, neural networks are used to represent and estimate hyperstates, which contain information about the conditional probability distributions of the system uncertainties. The optimal dual controller is a function of the hyperstate, and hence it should be useful to have a representation of this quantity when constructing an approximately optimal dual controller. The hyperstate transition model is used in combination with a reinforcement learning algorithm for constructing a dual controller from stochastic simulations of a system model that includes models of the system uncertainties.

In the third paper, we suggest a simple reinforcement learning method that can be used to construct a decoupling matrix that allows MIMO control of a chiller process. Compared to the commonly used single-input single-output (SISO) structures, these controllers can decrease the variations in some system signals. This makes it possible to run the system at operating points closer to some constraints, which in turn can enable more energy-efficient operation.

ON CONTROL AND ESTIMATION OF LARGE AND UNCERTAIN SYSTEMS

Kjellqvist, Olle

This thesis contains an introduction and six papers about the control and estimation of large and uncertain systems.

The first paper poses and solves a deterministic version of the multiple-model estimation problem for finite sets of linear systems. The estimate is an interpolation of Kalman filter estimates. It achieves a provided energy gain bound from disturbances to the point-wise estimation error, given that the gain bound is feasible.

The second paper shows how to compute upper and lower bounds for the smallest feasible gain bound. The bounds are computed via Riccati recursions.

The third paper proves that it is sufficient to consider observer-based feedback in output-feedback control of linear systems with uncertain parameters, where the uncertain parameters belong to a finite set. The paper also contains an example of a discrete-time integrator with unknown gain.

The fourth paper argues that the current methods for analyzing the robustness of large systems with structured uncertainty do not distinguish between sparse and dense perturbations and proposes a new robustness measure that captures sparsity. The paper also thoroughly analyzes this new measure. In particular, it proposes an upper bound that is amenable to distributed computation and valuable for control design.

The fifth paper solves the problem of localized state-feedback L2 control with communication delay for large discrete-time systems. The synthesis procedure can be performed for each node in parallel. The paper combines the localized state-feedback controller with a localized Kalman filter to synthesize a localized output feedback controller that stabilizes the closed-loop subject to communication constraints.

The sixth paper concerns optimal linear-quadratic team-decision problems where the team does not have access to the model. Instead, the players must learn optimal policies by interacting with the environment. The paper contains algorithms and regret bounds for the first- and zeroth-order information feedback.

Research

This chapter presents our excellence centers and describes our three main research branches and their ongoing projects

LUND UNIVERSITY AND FACULTY OF ENGINEERING PROFILE AREAS

During 2022 both Lund University and its Faculty of Engineering (LTH) concluded an open call for profile areas. Constellations of senior researchers submitted proposals of research areas in which the university/faculty are particularly strong and visible. Upon review and ranking, the profile areas enlisted below were established. We are happy that the breadth of theoretic foundation combined with versatility of applications have led to a presence of the Automatic Control department in the proposal and/or steering group of several Profile Areas, the ones marked (AC).

Lund University profile areas - They are all based on excellent research, with a distinct profile compared to what is done at other universities in Sweden or abroad. They all have ambitious plans for the future. They can show great collaboration with external partners and they have extensive connections to present education complemented with plans for new courses. Typical for the five profile areas is that several faculties are involved. Below a short description of each profile area.

HUMAN RIGHTS

Human Rights in a Polarised World - The field of Human Rights addresses challenges related to growing inequality gaps between rich and poor, refugee and migration movements, health, the climate crisis, conflicts and new technologies.

LIGHT AND MATERIALS

The profile area will harness recent fundamental research advances in measuring and controlling light and materials.

NATURAL AND ARTIFICIAL COGNITION (AC)

The profile area extends our understanding of behavioral patterns of natural and artificial systems and develops new artificial cognitive abilities in software and systems.

NATURE-BASED FUTURE SOLUTIONS

This area focuses on ecosystem-based approaches to handle biodiversity loss and climate change, and how the intertwined crises can be linked to sustainable societal development.

PROACTIVE AGEING

Focuses particularly on cognitive functions and musculoskeletal health as prerequisites for activity and participation.

Faculty of Engineering profile areas - These Profile Areas are the Faculty's strong and interdisciplinary research subjects formed in theme areas – to contribute to solutions in society's best interests. LTH's seven areas work in close collaboration with public authorities, companies, other research teams and society as a whole in order to use shared resources and knowledge to improve people's living conditions and find solutions to global problems. The Department of Automatic Control (AC) is involved in three out of seven of the profile areas. Below a short description of each area.

AEROSOLS
This profile area contributes to creating solutions and technologies for clean air in the transition towards a sustainable society.

CIRCULAR BUILDING SECTOR (AC)
A circular building sector is an important part of the transition to carbon neutrality and a sustainable society.

ENERGY TRANSITION - POWER AND TRANSPORT
Solutions for making our society independent of fossil fuels.

ENGINEERING HEALTH (AC)
Contributes to improving human health and solving challenges in healthcare by developing and providing new tools for diagnostics, treatments, and home care solutions.

NANOSCIENCE AND SEMICONDUCTOR TECHNOLOGY
This area has world leading expertise and infrastructures, and explores the unique opportunities offered by nanoscience and semiconductor technology.

PHOTON SCIENCE AND TECHNOLOGY
This area addresses specific societal challenges related to climate change, environmental impact and combatting cancer and other threats to human health.

PILLARS OF AI AND DIGITALIZATION (AC)
AI and digitalization are a rapidly growing part of the development of almost all engineering systems and will fundamentally change society and industry.

EXCELLENCE CENTERS AND NATIONAL PROJECTS

ERC – European Research Council, Advanced Grant
ELLIIT – The Linköping–Lund Initiative on IT and mobile communication
WASP – Wallenberg AI, Autonomous Systems and Software Program
HI2OT – Nordic University Hub on Industrial Internet of Things

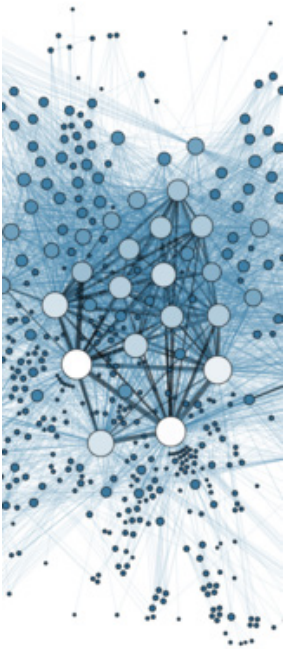
SCALABLE CONTROL OF INTERCONNECTED SYSTEMS

Funding: European Research Council - ERC Advanced Grant

Modern society is critically dependent on large-scale networks for services such as energy supply, transportation and communications. The design and control of such networks is becoming increasingly complex, due to their growing size, heterogeneity and autonomy. A systematic theory and methodology for control of large-scale interconnected systems is therefore needed. In an ambitious effort towards this goal, this project will address the following key aspects:

- Modeling by leveraging tools from learning and adaption
- Control design by utilizing structural properties of the system
- Verification of system performance using decomposable certificates

Energy networks (electricity and district heating*) will be used as a guiding example for the development of theory and methodology. Close collaboration with industrial partners will ensure that the research is relevant and useful in practice.



*Scalable Control for Increased Flexibility in District Heating Networks - This project investigates the development and application of scalable control strategies to explore the flexibility of large scale district heating networks. In particular, we aim to leverage theoretical tools from the field of control theory with a specific focus on those developed for positive systems. The objective is improving the operation of district heating networks while taking into account their limited communication architecture and the need for scalability to large network structures. These control strategies will be employed in demand response and load control architectures that can allow heating networks explore increased flexibility through e.g. demand response and direct load control.

ELLIIT – THE LINKÖPING–LUND INITIATIVE ON IT AND MOBILE COMMUNICATION

Funding: Government-funded Strategic Research Area

ELLIIT is a strategic research environment funded by the Swedish government in 2010, as part of its initiative to support strong research in information technology and mobile communications.

ELLIIT has four partners: Linköping University, Lund University, Halmstad University and Blekinge Institute of Technology.

ELLIIT constitutes a platform for both fundamental and applied research, and for cross-fertilization between disciplines and between academic researchers and industry experts. ELLIIT stands out by the quality and visibility of its publications, and its ability to attract and retain top talented researchers and aims at being recognized as a top international research organization.

ELLIIT achieves its goals by a judicious choice of funded focus projects, a structured process for international recruitment, a balanced way of stimulating cooperation between research areas and between the sites involved (LiU, LU, BTH, HH), and a proactive approach towards fostering and maintaining cooperation with Swedish industry. The overarching objective of ELLIIT is to support scientific excellence in combination with industrial relevance and impact.

In the 2020 national budget bill for University Research and Education, an additional 72 MSEK/year were allocated to the strategic research area in IT and mobile communication with a focus on digitalization, i.e., an increase of the original budget with close to 200%. This initiated a major restart of ELLIIT including a new organization and restructuring of the research programme.

During 2022 the following projects involving PIs from our department were started.

- Optimal estimation and control at scale (Richard Pates as PI with Anders Hansson, Linköping University)
- Visual analytics of large and complex multilayer technological networks (Andreas Kerren, Linköping University with Richard Pates)
- Integrated reactive motion planning and motion control (Daniel Axehill, Linköping University with Anders Robertsson)

April 19 to May 20, the ELLIIT Focus period named Data-driven modelling and learning for cancer immunotherapy was held in Lund. For five weeks, in the prestigious university town Lund, the focus period united young international scholars, ELLIIT researchers and other top international academics active in domains such as systems biology, cancer treatment, machine learning and dynamical systems.

ELLIIT Tech Talks - introduced in autumn 2022
ELLIIT has recorded an ambitious seminar series on digitalization and societal challenges from an ICT perspective. All four ELLIIT campuses have been involved, and the production stars the well-known Swedish research communicator and comedian Johan Wester. Topics are based on visions from the 2030 Technology Foresight. A new theme was published every other Tuesday, started in October 2022 and the last one will be released in March 2023.

Funding: Knut and Alice Wallenberg Foundation (KAW)

Wallenberg AI, Autonomous Systems and Software Program (WASP) is Sweden's largest individual research program ever, and provides a platform for academic research and education, fostering interaction with Sweden's leading technology companies. The program addresses research on autonomous systems acting in collaboration with humans, adapting to their environment through sensors, information, and knowledge, and forming intelligent systems-of-systems. Software is the main enabler in autonomous systems and is an integrated research theme of the program. WASP's key values are research excellence and industrial relevance.

WASP is funded by the Knut and Alice Wallenberg Foundation with co-funding from industry and the involved universities. The program, which started in 2015, will continue until 2031 with a total budget of SEK 6.2 billion.

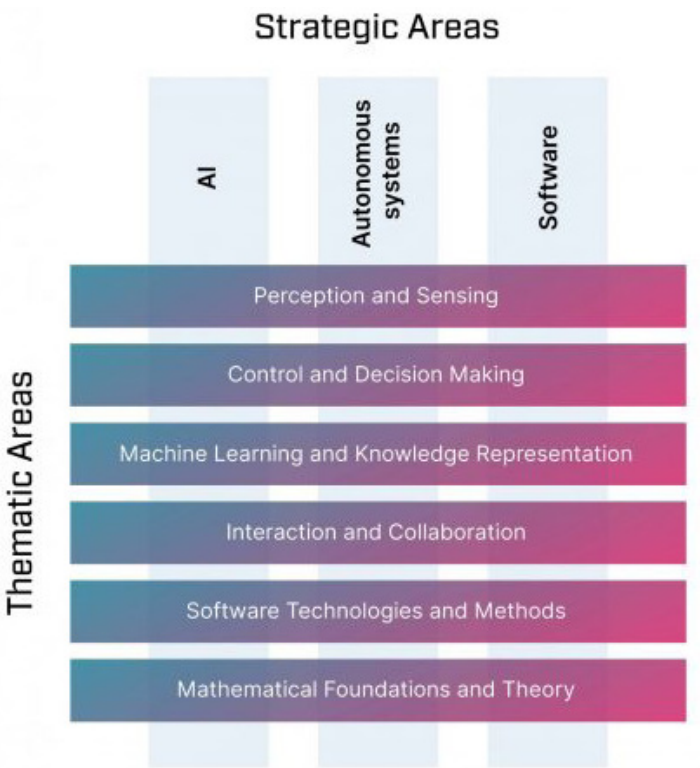
The graduate school within WASP is dedicated to providing the skills needed to analyze, develop, and contribute to the interdisciplinary area of AI, autonomous systems and software. The curriculum provides the foundations, perspectives, and state-of-the-art knowledge in the different disciplines taught by leading researchers in the field. Through an ambitious program with research visits, partner universities, and visiting lecturers, the graduate school actively supports forming a strong multi-disciplinary and international professional network between PhD-students, researchers, and industry. The graduate school provides added value on top of the existing PhD programs at the partner universities, providing unique opportunities for students who are dedicated to achieving international research excellence with industrial relevance.

WASP involves seven Swedish universities together with numerous Swedish industries. At Lund University the following four departments participate: Department of Automatic Control, Department of Computer Science, Department of Electrical and Information Technology, and the Mathematical Imaging Group at the Department of Mathematics.

During 2022 the collaboration between WASP and the Data-Driven Life Science (DDLS) program has continued and increased. Also, a new collaboration with the Wallenberg Initiative on Material Science for Sustainability (WISE) has been initiated. Also cyber-security was added as one of the key areas of WASP with an associated increase in funding with 180 million until 2031. Finally during 2022 industrial postdocs was introduced as a new funding instrument.

At the beginning of 2023 WASP funds the following positions at our department: 7 academic PhD students, 2 industrial PhD students (with Saab Kockums and Boliden), 8 affiliated PhD students (funded from other sources), 1 associate professor (Emma Tegling), and 2 postdocs. During 2022 five WASP PhD students have defended their theses: Alexandre Martins, Tommi Berner, Johan Ruuskanen, Claudio Mandrioli and Hamed Sadeghi.

Karl-Erik Årzén (WASP Co-director for Research Program Coordination since beginning 2021) and Anders Rantzer are involved in the management of WASP and Monika Rasmusson is the WASP Financial Officer for Lund University.



The research in WASP can be illustrated as a matrix with two dimensions, a strategic dimension and a thematic dimension. The strategic dimension emphasizes areas of impact on individuals, society, and industry, whereas the thematic areas represent the underlying scientific and technological challenges that are common to all types of autonomous systems. The research is conducted at seven Swedish universities: Chalmers University of Technology, KTH Royal Institute of Technology, Linköping University, Lund University, Umeå University, Örebro University, and Uppsala University.

HI2OT – NORDIC UNIVERSITY HUB ON INDUSTRIAL INTERNET OF THINGS

Reseachers: Årzén, Karl-Erik; Maggio, Martina; Robertsson, Anders; Cervin, Anton; Eker, Johan; Berner, Tommi; Martins, Alexandre; Mandrioli, Claudio; Vreman, Nils; Heimerson, Albin; Ruuskanen, Johan

Partners: DTU – Technical University of Denmark, Lund University, KTH – Royal Institute of Technology, NTNU – Norwegian University of Science and Technology, Aalto University

Funding: Nordforsk - Nordic University Hubs

The overall aim of HI2OT is to promote Nordic collaboration in Industrial Internet of Things (IIoT), which will increase the capacity of the participating organizations and create the critical mass needed to establish a world-leading Nordic research environment on IIoT.

There will soon be 50 billion "smart things" worldwide. When these become interconnected they form the Internet of Things, IoT. Industrial IoT (IIoT) is providing the infrastructure that underpins our Smart Society (Smart Energy Grid, Smart Cities, Smart and Green Mobility, Smart Manufacturing, etc.).

The proposal Nordic University (H)ub on (I)ndustrial (IoT) (HI2OT) is focused on Industrial IoT, a Nordic area of growth and a key technology enabler in solutions to several societal challenges. IIoT will only become a reality through the convergence of Operational and Information Technologies (OT & IT), which are currently separated. This will require multidisciplinary large-scale research effort. Hence, HI2OT brings together the strongest Nordic research groups in IIoT (8 groups at 5 universities) to form a long-term partnership for expanding IIoT cooperation in the Nordic region.

The overall aim of HI2OT is to promote Nordic collaboration in IIoT, which will increase the capacity of the participating organizations and create the critical mass needed to establish a world-leading Nordic research environment on IIoT. HI2OT provides a unique integration of expertise, generating the synergies required to support the convergence of IT and OT. HI2OT will build a platform and a community to strengthen and structure the IIoT research and innovation. This will enhance strengthen national research and innovation systems by increasing their capacity, increase the ability of Nordic nations to address European and global cooperation and competition in IIoT, as well as increasing their competitiveness and growth via research and innovation.

The current Nordic IIoT research efforts are fragmented and address local national industries, lacking the necessary mass to become an international area of excellence. Research infrastructures are not cost-efficient, and will require the pooling of resources through increased coordination. HI2OT will build a platform and a community to strengthen and structure the IIoT research and innovation. HI2OT fits perfectly with the objectives of the participating universities, who have explicit IIoT strategies and strategies for Nordic cooperation. HI2OT will enhance the competitiveness of participating institutions, strengthen national research and innovation systems by increasing their capacity, and increase the ability of Nordic nations to address European and global cooperation and competition in IIoT.

During 2022 HI2OT completed the *Nordic Industrial IoT Roadmap – Research and Innovation for the Green Transition* and held its annual workshop in Trondheim.

RESEARCH BRANCHES

The goal of the department is to provide students with a solid theoretical foundation combined with a good engineering ability. This is reflected in its research program, which covers both theory and applications. Automatic control, mathematics, and computer science form the core of all our research. To make our research more visible we have during 2022, produced short films to be found on the department webpage about our different reserach areas.

The research activities can roughly be divided into three thematic branches:

LARGE-SCALE SYSTEMS AND LEARNING

What do traffic networks, wind farms, Facebook and economic markets have in common? They are all large-scale networked systems, which can be analyzed and optimized using automatic control techniques.

AUTONOMOUS REAL-TIME SYSTEMS

Their vision? To create user-friendly, self-adaptive, resilient, high-performing systems, with low latency and jitter, while being cost-effective.

INNOVATIVE CONTROL APPLICATIONS

This is a branch of application-driven research motivated by the desire to create a more sustainable society. It addresses several of the UN's 17 Sustainable Development Goals.

LARGE SCALE SYSTEMS AND LEARNING

What do traffic networks, wind farms, Facebook and economic markets have in common? They are all large-scale networked systems, which can be analyzed and optimized using automatic control techniques. By developing scalable methods for control and optimization, researchers at the Department of Automatic Control are contributing to solving one of the greatest challenges in modern engineering - the sustainable and safe operation of these large-scale systems.

A significant part of this field of research is directed towards developing theories and methodologies supporting the design and verification of distributed control structures. Other important parts focus on combining classical physics-based models with machine-learning tools, and combining models for traditional networks, for example, for electricity and heating, with learning algorithms for consumer behavior and decision-making. The aim is to improve efficiency and reliability, while at the same time reducing costs.

Ongoing projects:

- Dynamics, Information and Control in Networks
- Learning and Adaptation
- Large-Scale Convex Optimization
- Scalable Control Using Learning and Adaptation
- Statistical and Adversarial Learning in Continuous System Control
- AI4GNC - Artificial Intelligence Techniques for Guidance, Navigation and Control
- Efficient Learning of Dynamical Systems
- Throughput Control in Autonomous Networks
- Learning in Networks; Structure, Dynamics and Control
- Scalable Optimization for Control Systems
- Dynamics of Complex Socio-Technological Network Systems
- Optimal estimation and control at scale
- Visual analytics of large and complex multilayer technological networks

DYNAMICS, INFORMATION AND CONTROL IN NETWORKS

Researchers: Heyden, Martin; Pates, Richard; Como, Giacomo; Rantzer, Anders; Tegling, Emma

Funding: ERC, VR and SSF

Large-scale networks play a constantly increasing role in our modern society, e.g., affecting the access to essential services like mobility and energy, influencing the outcome of electoral polls, and determining the quality of the economic systems.

The Department hosts a research group on Dynamics, Information, and Control in Networks. The focus of this group is on the mathematical foundations of large-scale network systems with particular emphasis on issues related to their resilience, centrality, and scalability.

Applications include cyber-physical systems, transportation networks, as well as social and economic networks.

One project is focused on transportation networks, with publications about decentralized traffic signal control and distributed dynamic tolls.

Another project studies the interplay between economics and traffic flows in transport networks. We will study exchange equilibria in traffic networks and network dynamics in presence of human decision makers. The goal is to gain deeper understanding of, and be able to exploit, the interaction between node demands and network flows.

LEARNING AND ADAPTATION

Researchers: Grönqvist, Johan; Rosdahl, Christian; Kjellqvist, Olle; Heskebeck, Frida; Bernhardsson, Bo; Rantzer, Anders

Funding: ERC and WASP

There are many important applications where classical physics based models need to be combined with machine learning tools. A good example is in autonomous driving, where automotive industry have extensive experience of control technology such as ABS braking, cruise control and ESP systems for vehicle stabilization. This technology now needs to be combined with machine learning methods to analyze traffic situations and human behavior. To do this in a safe and robust manner, it is essential to understand how learning algorithms for discrete sequential decision-making can interact with continuous physics based dynamics. Many other applications can be found. In the energy sector, well established control solutions for power networks and generators are increasingly being combined with learning algorithms for consumer behavior and decision-making, to minimize costs and optimize efficiency. In medicine, standard practice for disease therapies is combined with expert systems and sequential decision-making for medical diagnosis.

In our collaboration project with Alexandre Proutiere at KTH the aim is to bridge the gap between machine learning and control engineering. These research fields have traditionally evolved more or less separately, but in recent years the intersections in terms of applications as well theoretical challenges have been growing. This project is concerned with sequential decision making in systems whose dynamics are initially unknown, i.e., with adaptive control or reinforcement learning. Statistical models are of fundamental importance in both areas, but while learning theory has been focused on sample complexity and regret, the corresponding control literature is discussing stability robustness and asymptotic performance. An important focus of our project is the tradeoff between exploration and exploitation, sometimes known as ”dual control”. The optimal tradeoff strategy can be formulated as the solution to a dynamic programming problem. We study properties of the solution as well as computational schemes. Optimal strategies are compared with common heuristics, both in control and reinforcement learning.

LARGE SCALE OPTIMIZATION

Researchers: Giselsson, Pontus; Sadeghi, Hamed; Morin, Martin; Banert, Sebastian; Upadhyaya, Manu

Funding: VR and WASP

Optimization is a modeling tool that has been used in many engineering fields for a long time. It can be used, e.g., for optimal control, financial decision making, signal reconstruction, route planning, statistical estimation, and training of supervised learning machines. Different optimization problems have different properties and fall into different categories. They can be coarsely divided into convex or nonconvex problems, smooth or nonsmooth problems, and small-scale or large-scale problems. Contemporary optimization problems in, e.g., machine learning, signal reconstruction, control, and statistical estimation are often large-scale. The research in this group is focused on understanding and developing efficient algorithms for solving such problems. We focus on convex and nonsmooth problems with a primary focus is on so-called operator splitting methods and their stochastic variants. In particular, we develop frameworks for understanding a wide range of operator splitting methods that allow for a unified analysis and paves the way for design of new and improved algorithms. We also develop tools for automated algorithm analysis in which a so-called performance estimation optimization problem is formulated that exactly captures the worst possible performance of an optimization algorithm for some user-specified class of optimization problems. A solution to this, typically small-scale, performance estimation problem can give convergence guarantees for the analyzed algorithm.

SCALABLE CONTROL USING LEARNING AND ADAPTATION

Researchers: Kjellqvist, Olle; Rantzer, Anders; Bernhardsson, Bo

Funding: ERC

At the United Nations Summit 2015, our world leaders adopted 17 Sustainable Development Goals. A necessary condition for the completion of these goals is efficient, reliable, and safe infrastructure. For example, Goal 7: Affordable and Clean Energy requires infrastructure robust to loss of the inertia prevalent in conventional power plants, such as coal, gas, and nuclear power. As the nature of consumption and production changes, the networks' structures and underlying control mechanisms must keep up. Unfortunately, many of the anticipated changes increase the load and introduce additional complexity. Examples are micro-producers of electricity, autonomous vehicles in transportation networks, and increased nodes in communication networks. As complexity can increase by orders of magnitude, controlling these networks requires models at an entirely new scale. Manually sustaining accurate models of individual components becomes infeasible. A solution is to use adaptation and learning to automatically learn and sustain models, taking care to do so in a reliable and scalable way.

In the doctoral studies, he addresses the fundamentals of scalable modeling's technical challenges using adaptation and learning. He study minimax control and graph realizability of controllers, meaning controllers that respect information exchange constraints in networks. The aim is to synthesize algorithms for scalable, robust adaptive control that automatically sustains accurate models of highly complex networks. Such algorithms can facilitate the complex technologies and infrastructures needed to reach the Sustainable Development Goals.

STATISTICAL AND ADVERSARIAL LEARNING IN CONTINUOUS SYSTEM CONTROL

Researchers: Grönqvist, Johan; Kjellqvist, Olle; Rantzer, Anders

Funding: ERC and WASP

This project aims to bridge the gap between machine learning and control engineering. These research fields have traditionally evolved more or less separately, but in recent years the intersections in terms of applications as well theoretical challenges have been growing. This project is concerned with sequential decision making in systems whose dynamics are initially unknown, i.e., with adaptive control or Reinforcement Learning (RL) when using the control engineering and machine learning terminologies, respectively.

We will work on problems where disturbances are assumed to be of worst-case nature. In control theory, this assumption is the basis for H-infinity optimal control, which was introduced in the 1980s to counteract the fact that optimization in a statistical setting often gives poor robustness to unmodeled dynamics.

Inspired by the theory for robust control, based on worst-case assumptions, we would like to develop a theory to make RL or adaptive control algorithms robust to unmodeled dynamics.

AI4GNC - ARTIFICIAL INTELLIGENCE TECHNIQUES FOR GUIDANCE, NAVIGATION, AND CONTROL

Researchers: Cervin, Anton; Rantzer, Anders; Grönqvist, Johan; Kjellqvist, Olle; Renganathan, Venkatraman; Vladu, Emil; Upadhyaya, Manu

Funding: ESA

The goal of this ESA-funded project is to investigate the feasibility of recent advances in control and AI for space missions. The first step is to review the state of the art in AI for the development and implementation of embedded guidance, navigation, and control (GNC) systems. The objective is to improve the GNC design process and manage system complexity through the vertical and horizontal integration of disciplines. Upon the outcome of the review, we will establish the functional and performance requirements applicable to an AI-assisted GNC design process and to an AI-augmented GNC system.

In the second phase of the project, we will perform a trade-off of suitable mathematical AI approaches compatible with the current GNC architectures and design processes (model-based approach), including complexity, effort, and expected benefits assessment. This will allow us to establish the AI techniques suitable to the modeling, control, and verification needs in the view of robust and explainable AI-supported GNC architectures and functions.

In the last stage, we will develop a prototype set of benchmark problems for AI-assisted GNC design and AI-augmented GNC systems as well as for AI-supported autonomy (using an in-orbit assembly scenario or precision landing scenario including handling of failures and degradations). We will then perform a detailed design and coding of the established AI techniques applied to AI-assisted GNC design and to the AI-augmented GNC system. Finally, we will assess the performance and robustness of the AI-assisted GNC system and define the way forward for AI-GNC system deployment.

EFFICIENT LEARNING OF DYNAMICAL SYSTEMS

Researchers: Rosdahl, Christian; Bernhardsson, Bo; Cervin, Anton; Rantzer, Anders

Funding: WASP

The research project focuses on efficient learning of dynamical systems. Some methods for controlling partially unknown systems are examined. We strive to find control policies that balance exploration and exploitation, in the sense that relevant uncertainties are diminished such that the long-term control performance is improved. To this end, classical control methods, such as dual control, are combined with modern machine learning techniques. As a practical example of control of a complex dynamical system have examined control of a chiller process. The project resulted in the licentiate thesis of Christian Rosdahl, described in the previous chapter.

THROUGHPUT CONTROL IN AUTONOMOUS NETWORKS

Researchers: Vladu, Emil; Rantzer, Anders; Pates, Richard

Funding: ERC

In many areas of application, it is important to suppress the impact of disturbances and model uncertanties on the desired output behavior. Large-scale systems in particular benefit additionally from transparent and sparse controllers. In this research, we are interested in sparse controller structures which give rise to optimal or near-optimal worst-case disturbance attenuation. The research output thus far considers linear as well as nonlinear systems, and positive systems in particular.

LEARNING IN NETWORKS: STRUCTURE, DYNAMICS, AND CONTROL

Researchers: Proutiere, Alexandre; Tegling, Emma; Rantzer, Anders; Skerman, Fiona; Gurpegui Ramón, Alba; Hansson, Jonas; Bencherki, Fethi; Ohlin, David; Govaert, Alain

Funding: WASP-NEST

Many complex systems, whether biological, physical, social, or economical, are structured in networks consisting of a large collection of interacting entities. Some of these networks, such as social networks on the Internet emerge without our control or intervention. As a consequence, their structure, the way their entities interact and evolve are a priori unknown. Some are designed and deployed by engineers, but their scale may become so large (this is for instance the case of future mobile networks) that their individual entities cannot be finely tuned when deployed, and again the structure of the network and the interactions between its entities cannot be predicted. Our ability to optimize the operation of a network, however, strongly relies on an accurate knowledge of its characteristics.

In this project, we will develop novel mathematical and computational tools to devise efficient algorithms learning the network structure and dynamics, as well as efficient ways to control it. This vast and ambitious objective calls for a multidisciplinary effort, and we envision to reach it leveraging and combining techniques from probability theory, statistical machine learning, and control theory.

SCALABLE OPTIMIZATION FOR CONTROL SYSTEMS

Researcher: Rantzer, Anders

Funding: ELLIIT

Modern control systems put new demands on control theory. Many of the modelling, analysis and design methods available do not scale well with increasing complexity. Applications and/or industrial practice often relies on distributed control structures, and there is a strong need for more systematic approaches to design and analysis of such structures and the corresponding information interfaces, especially with the development of "internet of things" and the so-called "smart society".

An important challenge for control and optimization is industrial robots where the task is to plan and carry out an operation as fast as possible given a number of constraints in terms of accelerations, loads on the mechanical structure, energy consumption, etc. The constraints in combination with dynamical models of very high complexity imply a strong need for efficient optimization methods. There are several challenges. One is that the dynamics is nonlinear making the optimization problem highly non-convex.

Another is that re-planning of operations in real time due to obstacles makes the need for efficient optimization methods much more relevant than before. Current industrial standard does not allow for re-planning. Optimization for industrial robots has not been considered in previous ELLIIT projects. The vision is to within 5 years have online optimization routines performing planning and re-planning of optimal robot trajectories in real time. Another important challenge for control and optimization is robustness analysis of large-scale interconnected systems such as power grids. The introduction of renewables in the power grid requires high-fidelity models, which also imply a strong need for more efficient optimization methods. In this project we will investigate and develop new optimization methods and software for modelling, analysis and design of large-scale control systems that scale well with problem size. Within ELLIIT we have previously developed scalable robustness analysis methods assuming that suitable models where available. For systems like power grids, this is not the case. A major challenge is to in a distributed manner obtain linearized models for power grids, and to in a distributed manner build so-called LPV models which capture the uncertainties of the power grid. The vision for 5 years is to have efficient tools for modelling power-grids based on the Modelica modelling language which admits efficient analysis of robustness of the grid. This work will be carried out in collaboration with ABB Corporate Research in Switzerland.

DYNAMICS OF COMPLEX SOCIO-TECHNOLOGICAL NETWORK SYSTEMS

Researchers: Tegling, Emma; Como, Giacomo; Ohlin, David; Bencherki, Fethi; Govaert, Alain; Altafini, Claudio; Bakovic, Luka

Funding: ELLIIT

We investigate how opinions and beliefs propagate on social networks, i.e., on networks of individuals interacting over socio-technological media. We use data and dynamical models in order to understand the mechanisms by which sociologically relevant macroscopic collective behaviors can emerge from microscopic (i.e., individual-level) interactions.

OPTIMAL ESTIMATION AND CONTROL AT SCALE

Researcher: Pates, Richard; Adlercreutz, Julia; Hansson, Anders, Linköping University

Funding: ELLIIT

Many classical optimal methods for estimation and control have provable robustness and performance guarantees that can enhance the sustainability and resilience of engineering systems. However, their implementation typically requires all-to-all communication of sensor measurements, making them an infeasible choice for many practical applications. The aim of the project is to systematically investigate optimal estimation and control approaches through the lens of sparse linear algebra. In particular, the project aims to exploit techniques from sparse linear algebra to reduce the communication burden of classical optimal estimation and control methods. Reducing the need for communication will allow these methods to be applied in important sensor rich application areas, such as autonomous vehicles, transportation networks, and power grids. This has the potential to greatly improve energy efficiency and resilience in these applications, where suboptimal design approaches, that typically provide no formal guarantees, must currently be used for reasons of system scale.

VISUAL ANALYTICS OF LARGE AND COMPLEX MULTILAYER TECHNOLOGICAL NETWORKS

Researchers: Kerren, Andreas, Linköping University; Pates, Richard

Funding: ELLIIT

Multilayer networks are a relatively new way to model complex real-world systems that demand novel and efficient solutions for their analysis. Especially when regarding large and heterogeneous data typically used in power systems control, the use of multilayer networks for data representation, modeling, and analysis is promising. To explore such multilayer technological networks and to incorporate the human perspective into the analysis process for increasing the trust into the results, interactive visualization approaches are key. This project will be performed in an interdisciplinary team; we will study and develop novel visual analytics approaches for the exploration and analysis of multilayer technological networks, which is not only highly relevant for the field of visual analytics, but also for the energy efficiency of power systems

AUTONOMOUS REAL-TIME SYSTEMS

A significant part of the research in this field revolves around cyber-physical systems, clouds, and cloud control. Historically, control systems have been deployed as monolithic software implementations on carefully tuned hardware, adjacent to the plants they control. This has resulted in systems that are undesirably non-modular, not easily extensible and that have limited ability to self-adapt. In contrast, feedback-based cyber-physical systems and cloud-native applications offer the prospect of greater accessibility and flexibility, as well as higher reliability and lower latencies. Furthermore, when applications are implemented in a disaggregated manner, their execution can be distributed across the system's many nodes, migrated, and scaled to meet individual objectives as well as that of the system as a whole.

Ongoing projects:

- Autonomous Cloud
- Optimizing Radio Access Networks for Efficient Massive MIMO
- Event-Based Information Fusion for the Self-Adaptive Cloud
- Robust and Secure Control over the Cloud
- Event-Based Control of Stochastic Systems with Application to Server Systems
- Mission-Critical Control over the Cloud
- Testing of Self-Adaptive Software Systems
- Testing Autonomous Self-Adapted Software System
- Towards Adaptively Morphing Embedded Systems
- Control-based Resource Management in the Distributed Cloud
- Autonomous Camera Systems in Resource Constrained Environments

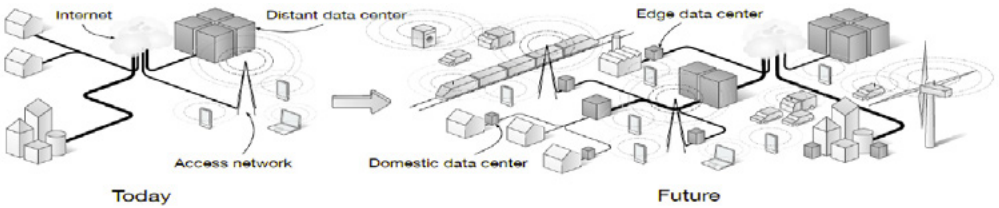
AUTONOMOUS CLOUD

Researchers: Årzén, Karl-Erik; Maggio, Martina; Eker, Johan; Berner, Tommi; Skarin, Per; Martins, Alexandre; in collaboration with the Department of Electrical and Information Technology at LTH, Umeå University, and KTH.

Funding: WASP

Background

An increasing amount of computing and information services are moving to the cloud, where they execute on virtualized hardware in private or public data centers. Hence, the cloud can be viewed as an underlying computing infrastructure for all systems of systems. The architectural complexity of the cloud is rapidly increasing. Modern data centers consist of tens of thousands of components, e.g., compute servers, storage servers, cache servers, routers, PDUs, UPSs, and air-conditioning units, with configuration and tuning parameters numbering in the hundreds of thousands. The same increasing trend holds for the operational complexity. The individual components are themselves increasingly difficult to maintain and operate. The strong connection between the components furthermore



The following figure illustrates how the computations in the distributed cloud are migrating from back-end data centers out in the network.

makes it necessary to tune the entire system, which is complicated by the fact that in many cases the behaviors, execution contexts, and interactions are not known a priori. The term autonomous computing or autonomic computing was coined by IBM in the beginning of the 2000s for self-managing computing systems with the focus on private enterprise IT systems. However, this approach is even more relevant for the cloud. The motivation is the current levels of scale, complexity, and dynamicity which make efficient human management infeasible. In the autonomous cloud control, AI, and machine learning/analytics techniques will be used to dynamically determine how applications should be best mapped onto the server network, how capacity should be automatically scaled when the load or the available resources vary, and how load should be balanced.

Currently there is also a growing interest in applying cloud techniques, such as virtualization and collocation, in the access telecommunication network itself. The unification of the telecom access network and the traditional cloud data centers, sometimes referred to as the distributed cloud, provide a single distributed computing platform. Here the boundary between the network and the data centers disappears, allowing application software to be dynamically deployed in all types of nodes, e.g., in base stations near end-users, in remote large-scale datacenters, or anywhere in between. In these systems the need for autonomous operation and resource management becomes even more urgent as heterogeneity increases, when some of the nodes may be mobile with varying availability, and when new 5G-based mission-critical applications with harder requirements on latency, uptime, and availability are migrated to the cloud.

Project outline

In the project distributed control and real-time analytics will be used to dynamically solve resource management problems in the distributed cloud. The management problem consists of deciding the types and quantities of resources that should be allocated to each application, and when and where to deploy them. This also includes dynamic decisions such as automatic scaling of the resource amount when the load or the available resources vary, and on-line migration of application components between nodes. Major scientific challenges include dynamic modeling of cloud infrastructure resources and workloads, how to best integrate real-time analytics techniques with model-based feedback mechanisms, scalable distributed control approaches for these types of applications and scalability aspects of distributed computing.

In order to develop efficient methods for resource management, it is crucial to understand the performance aspects of the infrastructure, what the workloads look like, and how they vary over time. Hence, Infrastructure modeling and Workload modeling for the distributed cloud are important topics. Due to user mobility and variations in usage and resource availability, applications using many instances are constantly

subject to changes in the number of instances; the individual instances relocated or resized; the network capacity adjusted; etc. Capacity autoscaling is needed to determine how much capacity should be allocated for a complete application or any specific part of it; Dynamic component mapping to determine when, where, and how instances should be relocated, e.g., from a data center to a specific base station; and Optimized load mix management to determine how to "pack" different instances on individual servers or clusters. Since not all applications are equally important, e.g., due to differently priced service levels or due to some being critical to society (emergency, health care, etc.), the solutions to the three problems above must take into account Quality of Service differentiation. Finally, we address Holistic management to perform full-system coordination.

The primary software infrastructure will be based on Calvin, an open source application environment developed by Ericsson and aimed at distributed clouds for IoT services. Calvin is based upon on the well-established actor model, it scales well, and it supports live migration of application components. We believe this infrastructure is suitable to investigate the application performance behavior of future commercial systems and validate our developed management solutions. It will enable accurate estimations of, for example, application latency and system loads.

The project results have the potential to be demonstrated in several WASP demonstrator arenas, including the Autonomous Research Arena (ARA), the Ericsson Research Data Center (ERDC); as well as in different university lab facilities.

OPTIMIZING RADIO ACCESS NETWORKS FOR EFFICIENT MASSIVE MIMO

Researchers: Pjanic, Dino; Tufvesson, Fredrik; Bernhardsson, Bo

Funding: SSF

Massive MIMO has today been incorporated as one of the main technologies in the standard to meet the requirements for 5G. While the core technology is in place, there are still many open topics with respect to the implementation and optimization of the cellular network using this technology. In this project, we aim for a machine learning approach for efficient operation of cellular networks based on massive MIMO. The many antennas in massive MIMO base stations give access to details in the radio channel and opens up for better prediction of both small scale behaviour such as user correlation as well as large scale behaviour such as mobility patterns. This in turn can lead to new opportunities with respect to scheduling approaches and handover strategies in order to provide low latency reliable user connection in mixed and dynamic environments.

The project is divided into four work packages

1. Long and short term channel prediction in massive MIMO
2. Mobility and traffic pattern estimation, handover prediction
3. Physical and virtual UE positioning based on network data, and
4. 5G user scheduling based on machine learning.

We will use a mix of experiments from the massive MIMO testbed at Lund University together with state of the art network simulators and real world traffic patterns to achieve our end goal: A machine learning enabled scheduling framework for mixed traffic in realistic 5G networks.

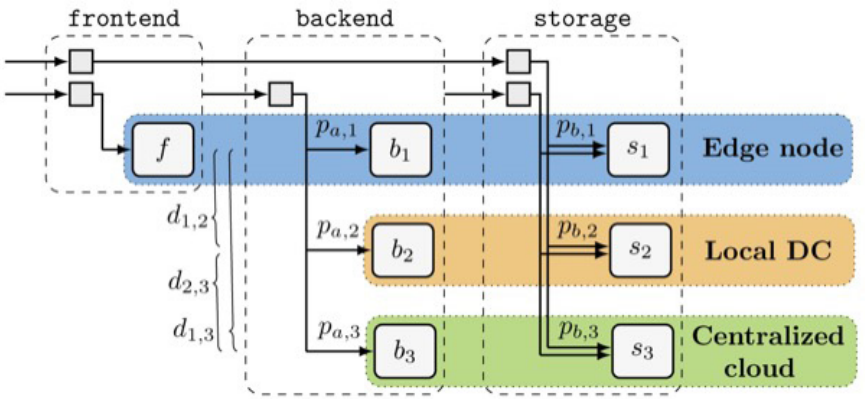
EVENT-BASED INFORMATION FUSION FOR THE SELF-ADAPTIVE CLOUD

Researchers: Ruuskanen, Johan; Cervin, Anton; Årzén, Karl-Erik

Funding: WASP

Successful self-adaptive resource provisioning in the cloud relies on accurate tracking of workload variations and timely detection of changes in the infrastructure. The general estimation problem is very challenging due to the massive number of observable events in various subsystems, each containing some useful information. In this project, we will develop novel, event-based estimation techniques for information fusion in cloud server systems. Our starting point will be the family of Monte Carlo-based inference methods known as Particle Filters, which will be adapted to handle event-based measurements from different sources and with different time scales. The results will enable more responsive and exact decision making in the autonomous cloud.

During the second half of the project lifespan, we shifted focus towards identification of networks of microservices using queueing network models and measurements from Cloud applications. The main scientific innovation was a new mean-field fluid model for mixed queuing networks, with a smoothing parameter that can be estimated from logged timing data. The model was applied to a real microservice application and was shown to better predict queue lengths and response-time distributions than previous methods. The results were summarized in Johan Ruuskanen's doctoral thesis, which was defended on November 18.



ROBUST AND SECURE CONTROL OVER THE CLOUD

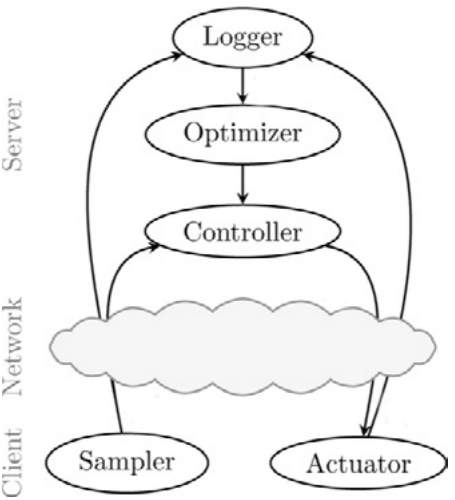
Researchers: Cervin, Anton; Nyberg Carlsson, Max; Årzén, Karl-Erik and Peng, Zebo; Eles, Petru; Pan, Yungang, Linköping University

Funding: ELLIIT

The ELLIIT-funded research project Robust and Secure Control over the Cloud runs between 2021 and 2025 and is a collaboration between the Department of Automatic Control and the Embedded Systems Laboratory at Linköping University, with one PhD student at each site. The project will develop theory and design methodology to explore the interplay between local and cloud-based control as well as the trade-offs between robustness, security, and adaptivity. The Lund team focuses on the control and autonomy aspects, while the Linköping team focuses on security and optimization. The results will be verified in real feedback control experiments over the Cloud.

The Cloud, with its virtually infinite storage and computing capacity, provides ample opportunities for applying advanced control and estimation algorithms in completely new settings. While local feedback is needed to ensure the stability of individual control applications regardless of the current status of the network, the cloud is ideal for running high-level control and optimization algorithms in large-scale networked systems. Compute-intensive algorithms such as model-predictive control (MPC), particle filtering, and reinforcement learning can exploit the massive amounts of data generated by local devices to continuously adapt to the circumstances and optimize the overall system behavior. Fast-growing market demands, the need to reduce production cost, flexible product lines, and scalability issues are all driving forces towards shifting the control applications from being implemented on dedicated hardware to pieces of software running in the Cloud.

During 2022, we investigated timing-robust control over the Cloud using online parametric optimization. The goal is to adapt a linear networked feedback to unpredictable timing complications, such as long delays, aborted computations, and dropped packets. The core concept of the approach is to log successful sampling and actuation events and then, at regular intervals, use non-convex parametric optimization to improve the expected performance of the controller under the assumption that the future timing behavior will be similar to the current one. The expected future cost is computed using our Julia toolbox JitterTime.jl. To reduce the time complexity of the optimization algorithm, automatic differentiation in Julia is applied for efficient gradient descent. The approach has been evaluated on a physical ball and beam plant, where both the controller and optimization algorithm can be located in the Cloud.



EVENT-BASED CONTROL OF STOCHASTIC SYSTEMS WITH APPLICATION TO SERVER SYSTEMS

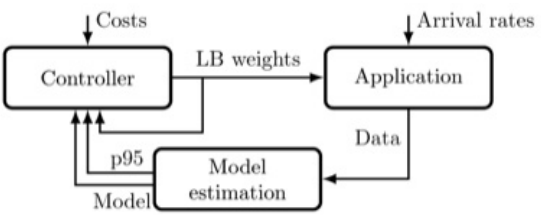
Researchers: Cervin, Anton; Thelander Andrén, Marcus; Bernhardsson, Bo; Soltesz, Kristian; Heimerson, Albin; Ruuskanen, Johan

Funding: VR

With the current strong trend towards networked and autonomous systems, it becomes less realistic to demand that all elements of a control loop should operate in a synchronous, time-triggered fashion. Above the lowest level of feedback control, it is often more natural and efficient to communicate, decide, and act based on events. Previous work shows that event-triggered control can achieve both lower average sampling rates and better performance than standard, periodic control. There is however not yet a coherent theory for the analysis and synthesis of event-based controllers.

The aim of this project is to develop theory, tools, and design methodology for event-based control of stochastic systems. The overall goals are more efficient resource usage and better performance compared to standard sampled-data control. At the same time, the methods are aimed at a wider class of control problems, including those that combine local feedback with higher-level decision-making. Such features are common in various applications such as autonomous vehicles, traffic routing, control of computing systems, supervisory plant control, and resource management in the cloud.

In the final phase of the project, in 2022 we investigated the combined identification and optimization of server systems using queueing network models. The goal was holistic load balancing, where optimal routing probabilities in a distributed microservice application were found using optimization. Applying automatic differentiation to a mean-field fluid model of the application enabled iterative grading stepping and model refitting online. The approach was evaluated on a real microservice Cloud application running Kubernetes/Istio.



MISSION-CRITICAL CONTROL OVER THE CLOUD

Researchers: Skarin, Per; Årzén, Karl-Erik; Kihl, Maria; Maggio, Martina; Eker, Johan

Funding: WASP

Cloud technology has swiftly transformed the ICT industry and it is continuing to spread. Many ICT applications are suitable for cloud deployment in that they have relaxed timing or performance requirements. In order to take the cloud concepts beyond the ICT domain and

apply it to mission critical use cases such as industrial automation, transport and health care we must provide guarantees and predictability. To this end we need new tools and new ways of working. This project attacks this problem from two angles. We will work at developing a cloud infrastructure with a deterministic behaviour, thereby suitable for critical applications. Zero-touch configuration of the cloud based on feedback is a fundamental building block in our approach. Secondly we will showcase the viability of the hardened cloud through mission critical cloud application running in a real data center and operating real-world process, e.g. robotics, unmanned vehicles.

TESTING OF SELF-ADAPTIVE SOFTWARE SYSTEMS

Researchers: Mandrioli, Claudio; Maggio, Martina

Funding: WASP

Many cyber-physical systems change their behaviour depending on environmental data and internal states. This is the case of control systems, that compute a control signal that depends on input values like a desired position, measured values like the current position, and internal states like the previous control action. This is also the case of systems embedding machine learning algorithms, that receive new samples and incorporate what they learnt using these new samples into a policy that determines how to behave in new conditions. All these systems are adaptive, in that their behaviour changes over time in a prescribed - but a priori unpredictable - way. This project is about testing and comparing systems that incorporate some adaptivity.

Testing systems whose behaviour varies over time is difficult. Think of a machine learning algorithm: how many and which samples should we give to the system before we can consider its behaviour testable? And what is the correct outcome? Of course we can apply unit testing to each function in the code, check for coverage, select a few cases in which the ideal behaviour of the code is known. But this does not give us any guarantee that the code is behaving correctly for the task it has to complete in the physical environment.

We advocate that a formal and rigorous methodology is needed to test systems with adaptivity like self-adaptive software. This methodology should be used in conjunction with other forms of testing (e.g., unit testing) to provide guarantees on the cyber-physical system behaviour.

When learning is involved, it is impossible to provide any deterministic guarantees, since the function to be learnt may not have been explored. In such cases, drawing any general conclusion is impossible (and undesirable), unless probabilistic guarantees are targeted. We are convinced that this is true also for adaptive software and a paradigm shift is necessary for its testing: guarantees deriving from the tests' execution should be provided in the probabilistic space rather than in the deterministic one.

In the probabilistic space, we investigate three alternative methods to analyse testing data and provide guarantees:

- Monte Carlo experiments
- Extreme Value Theory
- Scenario Theory

TESTING AUTONOMOUS CONTROL-BASED SOFTWARE SYSTEMS

Researchers: Mandrioli, Claudio; Maggio, Martina, Årzén, Karl-Erik

Funding: WASP

Self-Adaptive software usually comprises the software itself and an adaptation layer, in charge of observing the current execution conditions and reacting to these conditions with changes in the software behavior. The adaptation layer is often realized with control-theoretical techniques, to exploit the large set of guarantees that control-based adaptation provides. Properly testing these systems is a complex problem. First, the control strategy should be verified on its own to assess the formal guarantees that it entails. Second, it should be possible to verify that the introduction of control theory does not influence the behavior of the software in terms of functional properties. Third, the formal guarantees that the control-theoretical adaptation offers should be verified in practice when the controller is connected to the software system. The project proposes the study of testing for self-adaptive software where the adaptation layer is based on control-theoretical principles.

TOWARDS ADAPTIVELY MORPHING EMBEDDED SYSTEMS - ADMORPH

Researchers: Maggio, Martina; Vreman, Nils; Cervin, Anton

Funding: EU Horizon2020

Due to the increasing performance demands of mission- and safety-critical Cyber Physical Systems (of Systems) – CPS(oS) – these systems exhibit a rapidly growing complexity, manifested by an increasing number of (distributed) computational cores and application components connected via complex networks.

However, with the growing complexity and interconnectivity of these systems, the chances of hardware failures as well as disruptions due to cyber-attacks will also quickly increase. System adaptivity, foremost in terms of dynamically remapping of application components to processing cores, represents a promising technique to fuse fault- and intrusion tolerance with the increasing performance requirements of these mission- and safety-critical CPS(oS). In the ADMORPH project, we evaluate this hypothesis using a novel, holistic approach to the specification, design, analysis and runtime deployment of adaptive, i.e., dynamically morphing, mission- and safety-critical CPS(oS) that are robust against both component failures and cyber-attacks. To this end, we will address four aspects that are instrumental for the realisation of these adaptively morphing systems:

- the formal specification of adaptive systems
- adaptivity methods like strategies for maintaining safe and secure control of CPS(oS)
- analysis techniques for adaptive systems to, e.g., perform timing verification of adaptive systems to avoid timing violations after system reconfigurations
- run-time systems for adaptive systems that realise the actual run-time system reconfigurations to achieve fault and intrusion tolerance

The developed methodologies, methods and tools will be evaluated using three industrial use cases taken from the radar surveillance systems, autonomous operations for aircrafts, and transport management systems domains.

CONTROL-BASED RESOURCE MANAGEMENT IN THE DISTRIBUTED CLOUD

Researchers: Berner, Tommi; Årzén, Karl-Erik; Maggio, Martina

Funding: WASP

In the project control and real-time analytics are used to dynamically solve resource management problems in the distributed cloud. The management problem consists of deciding the types and quantities of resources that should be allocated to each application, and when and where to deploy them. This also includes dynamic decisions such as automatic scaling of the resource amount when the load or the available resources vary, and on-line migration of application components between nodes. Major scientific challenges include dynamic modeling of cloud infrastructure resources and workloads, how to best integrate real-time analytics techniques with model-based feedback mechanisms, scalable distributed control approaches for these types of applications and scalability aspects of distributed computing.

AUTONOMOUS CAMERA SYSTEMS IN RESOURCE CONSTRAINED ENVIRONMENTS

Researchers: Martins, Alexandre; Årzén, Karl-Erik; Maggio, Martina and Lindberg, Mikael at Axis

Funding: WASP

The future networked society will contain a huge number of devices, many of them processing a very large amount of sensor data. One example of this is distributed video cameras in surveillance and supervision applications. Due to efficiency and price constraints the communication and computing platforms are often limited, hence dynamic resource management is required. This project aims to turn camera systems into a swarm of autonomous scene-learning devices that share the same resources, turning today's central server as a viewing-only client. The systems will make sure that available resources are dynamically and optimally allocated at all time. The swarm will be completely flexible allowing devices to be added or removed from it and reallocating resources accordingly. Each of these devices will be communicating with its surroundings, and, will in the process learn situation specific parameters, such as resources availability and expenditure, scene properties etc, in order to predict future resource needs and allow for superior system wide resource management.

INNOVATIVE CONTROL APPLICATIONS

This is an area of application-driven research motivated by the desire to create a more sustainable society. It addresses several of the UN's 17 Sustainable Development Goals. It also has an impact on LTH's five core research areas, meaning that this field of research is important in digitalization, industry, the built environment, our climate, and life itself.

Numerous applications are being addressed, for example, within robotics, health care, the process industry, and smart manufacturing. A substantial part of the research takes place in the robotics lab. Apart from research on automatic control, this focus area also concentrates on teaching and learning methods, standards for smart industries, and innovation indexes.

Much of the research is performed in collaboration with, and is co-funded by, industrial partners.

Ongoing projects:

- Robotics Lab
- Contruction Robotics od today and tomorrow
- Collaborative Robotic Systems
- Semantic Mapping and visiual navigation for smart robots
- Autonomous Flight (UAS@Lund)
- The Future of Drones: Technologies, Applications, Risks and Ethics
- Increasing the Speed of Analysis from Images Obtained from Unmanned Aerial Vehicule
- Hemodynamic Stabilization
- Biomimetic Fabrication through Robotic 3D Printing
- Historical Female Influencers in Automatic Control
- Leverage Digital Technology to Unveil Biomedical Mechanisms in Avian Migration
- Autonomous Force-Aware Swift Motion Control
- DigIT Hub
- Forum for Standardisation of Digitalisation in Production
- Data-driven Modeling for Sustainable Mining
- Realtime Individualization of Brain Computer Interfaces
- Learning Pharmacometric Model Structures from Data

ROBOTICS LAB

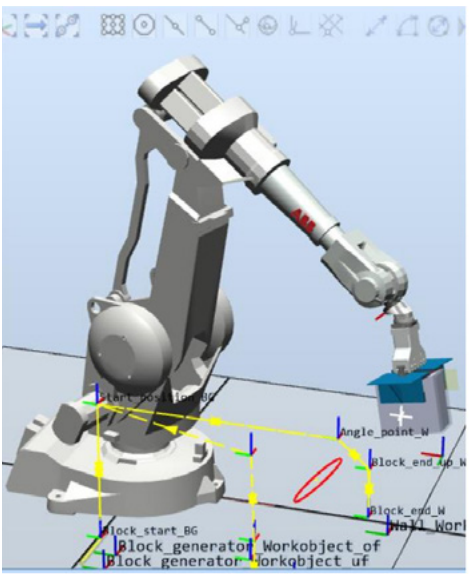
The Robotics Lab at LTH is an experimental arena shared by the Department of Automatic Control and the Department of Computer Science. Robotics is a multi-disciplinary topic, and we collaborate with both national and international robotics colleagues regarding different aspects of robotics and we also have a close cooperation with industrial partners. Our main research is in motion and compliance control, control system architectures and different sensor fusion problems with application mainly to industrial manipulators. We mainly use modified industrial robot control systems and UAVs as experimental platforms.

The purpose of past and present research projects is to show how to organize open robot control systems and to verify these ideas by means of experimental verification. As a part of this research, we have developed several experimental open robot control systems. The systems are built around industrially available robots that have been reconfigured for experimental purposes.

The developed specific robot interfaces and the integration of the robots into a complete system forms a unique environment for testing and development of algorithms for improvement of performance, sensor integration, programming automation and autonomous operation. New sensor interfaces with modification of hardware and realtime software architectures have been developed to accommodate the use of force control algorithms based on workspace sensing. The research in this area has been awarded with e.g., the EURON Technology Transfer award and an ICRA Best Automation paper.

Current robotics-related projects at the department include:

- Contruction Robotics of Today and Tomorrow
- Semantic Mapping and Visual Navigation for Smart Robots
- Autonomous Flight



CONSTRUCTION ROBOTICS OF TODAY AND TOMORROW

Researchers: Robertsson, Anders; Johansson, Rolf and colleagues from the Department of Computer Science, Division of Structural Engineering, and Department of Architecture and Built Environment

Funding: Vinnova

Since a couple of years new activities within construction robotics have started at LTH and a new cross-disciplinary laboratory facility is under establishment in the V-buiding, LTH, with serial and parallell kinematic robots for use in building construction, large structure 3D-printing etc.

Ongoing collaboration projects are

- Innovative Agile Construction for Globally Improved Sustainability (ACon 4.0) (VINNOVA UDI-2)

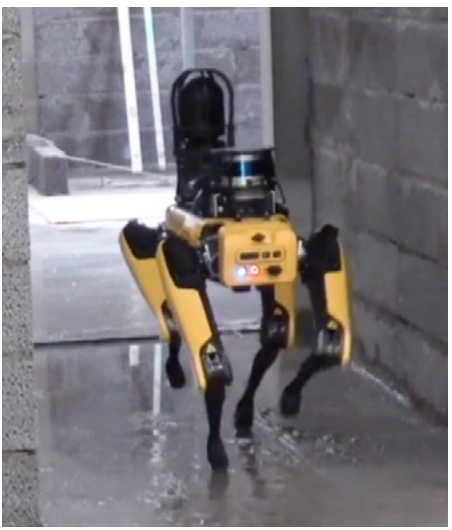
Purpose and goal

The construction industry has major problems linked to productivity, building quality, gender equality & safe work environment and environmental impact. Today's tools are developed to support existing value chains and building systems, and can be seen as part of the sector's problems. The ACon project will develop solutions in construction by (i) reducing the current fragmentation of the construction industry (ii) link digital design to production automation (iii) develop safer and more equal workplaces (iv) develop customized robotization for collaboration with workers at construction sites.

Planned presentation and action

Implementation of the ACon 4.0-project takes place in three work packages with underlying "tasks". There is a pronounced organization that ensures that deliveries and results are obtained.

- WP 1. Value chains & Business models - develop a traditional and new disruptive business model linked to small-scale robot production.
- WP 2. Technology development - digital information structure, building system, robot, rules and sensor technology
- WP 3. Communication & dissemination to Swedish construction industry and international collaboration - Initiate a construction robot lab at LTH with several stakeholders in academia and national construction industry, and there is also a dedicated international collaboration with the German INKOBAU-project



Above: Boston Dynamics SPOT at contruction site Vipan, Lund

COLLABORATIVE ROBOTIC SYSTEMS

Researcher: Robertsson, Anders

Funding: ELLIIT

As robotic systems begin to enter society and take on tasks in cooperation and collaboration with humans, there are a great many research challenges that need to be tackled before robots and humans can operate together in a robust, reliable, resilient and safe manner. The focus of the following sub-projects in this new 5-year plan for ELLIIT will cover a broader set of topics essential for the realization of this goal. The primary flavor of these projects combines artificial intelligence techniques with traditional robotics technologies. This is a trend that will only increase in the coming decades. Consequently, these topics are well-placed to have great impact in contributing to viable solutions for some of the challenges that lie ahead of us.

Symbiotic Human-Robotic Interaction - In the project context, we are interested in closely coordinated and long term interaction between robotic systems and humans. This is a special type of interaction in which symbiotic relationships between both human and robot can help each other overcome their specific limitations. In this sub-project, we want to formally specify such interaction and provide software functionalities in robotic systems that operationally implement such specifications. We propose extending a previously developed delegation-based framework for collaboration based on task specification trees (TSTs) and constraints, where the latter contextualize tasks.

Collaborative Automated Planning - Collaboration between humans and robots is not simply about delegating tasks to each other. It also requires automatic generation of joint plans that can be used to solve complex mission goals. These plans may involve execution time interaction with humans and also require use of resources constrained by time and space considerations. This sub-project will investigate formal characterizations and pragmatic implementations of these different forms of collaborative automated planning in the context of teams consisting of both humans and robots.

On-line learning for Safe and Resilient Robots - Safety and resiliency are key concerns as robots are expected to work alongside humans in cluttered real-world environments. By using models of a task, each task can be solved as an optimization problem, and safety can be guaranteed by constraints on the problem. However, models are often uncertain or inadequate in practice, especially when humans are involved. To enable resilient operation the robot needs to learn iteratively online. In this sub-project, we will extend our work with fast optimization using safety constraints to online learning, such that robots can adapt to new conditions or recover from failures while remaining safe for themselves and others.

SEMANTIC MAPPING AND VISUAL NAVIGATION FOR SMART ROBOTS

Researchers: Robertsson, Anders; Johansson, Rolf; Godoy, Boris with colleagues from departments of Mathematics, Lund and Chalmers University of Technology.

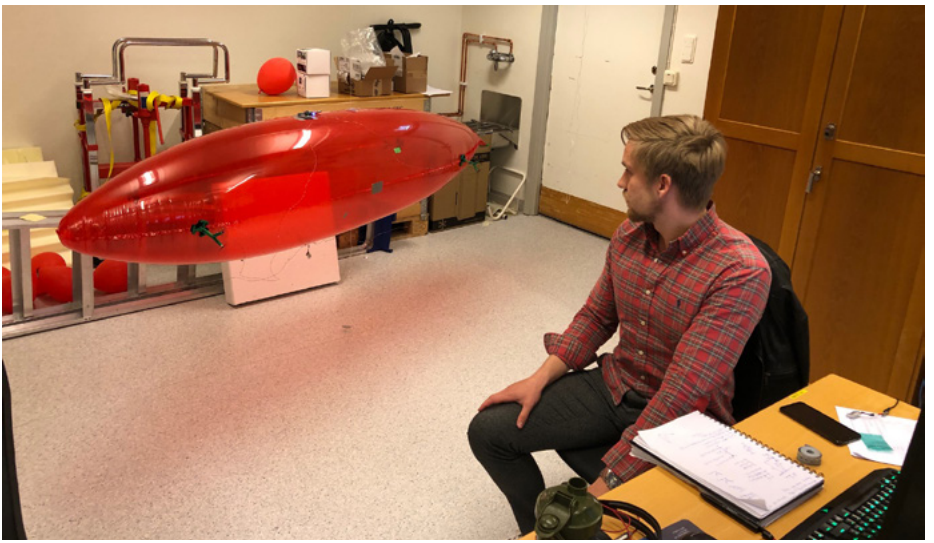
Funding: SSF

Why is it that today's autonomous systems for visual inference tasks are often restricted to a narrow set of scene types and controlled lab settings? Examining the best performing perceptual systems reveals that each inference task is solved with a specialized methodology. For instance, object recognition and 3D scene reconstruction, despite being strongly connected problems, are treated independently and an integrated theory is lacking. We believe that in order to reach further, it is necessary to develop smart systems that are capable of integrating the different aspects of vision in a collaborative manner. We gather expertise from computer vision, machine learning, automatic control and optimization with the ambitious goal of establishing such an integrated framework.

The research is structured into four work packages:

- Scene modelling
- Visual recognition
- Visual navigation
- System integration to achieve a perceptual robotic system for exploration and learning in unknown environments.

As a demonstrator, we will construct an autonomous system for visual inspection of a supermarket using small-scale, low-cost quadcopters. The system goes well beyond the current state-of-the-art and will provide a complete solution for semantic mapping and visual navigation. The basic research outcomes are relevant to a wide range of industrial applications including self-driving cars, unmanned surface vehicles, street-view modelling and flexible inspection in general.



AUTONOMOUS FLIGHT (UAS@LUND)

Participants: Bergström, Johan; Johansson, Rolf; Robertsson, Anders in cooperations with partners at other departments at Lund University.

Funding: ELLIIT, Lund University cooperation grant *The future of drones*

This research project addresses and develops the technologies of unmanned flying systems (UAS or drones) in order to make such systems more suitable for addressing various social challenges. A current collaboration project (UAV@LU, currently changing name to UAS@LU) addresses the potential of UAS for addressing societal challenges including, but not limited to, more efficient and sustainable forestry and farming, urban planning and landscape modelling, monitoring of critical infrastructure system, smarter transport, as well as more efficient and safe emergency service operations. A problem shared across all sectors mentioned above is making the UAS autonomous; the transition from actively piloting a drone with continuous (human) control inputs from a remote ground station while having the drone within visual line of sight to an autonomous UAS solving complex problems without continuous human control inputs but as an autonomous agent beyond the visual line of sight in an airspace populated by unmanned as well as manned aircraft. Consequently, the here proposed research project aims at developing and demonstrating autonomous flight missions in an airspace with mixed autonomous and manned aircraft under supervision and management of air traffic control. While the actors in the UAS@LU network represent a vast number of possible applications for autonomous UAS systems; this project will focus on two applications which are being developed with the purpose of enhancing societal safety: the cases of autonomous radiation detection and Sear-And-Rescue (SAR). The project serves the wider purposes of the collaboration UAS@LU and is conducted by Lund University School of Aviation and the Lund University Deptartment of Automatic Control in close collaboration with research conducted at the departments for Nuclear Physics and Medical Radiation Physics. External actors include those involved in Testbed Ljungbyhed as well as actors collaborating with LU researchers in UAS applications for societal safety.

In beginning of June 2021, Marcus Greiff, Emil Rofors, Rikard Tyllström and Rohith made field tests on UAV-based radiation measurements in the area around Gävle, which is the Swedish region which was most polluted after the Chernobyl accident in 1986. The research was made within the ELLIIT-project *Autonomous Radiation Mapping and Isotope Composition Identification by Mobile Gamma Spectroscope.*

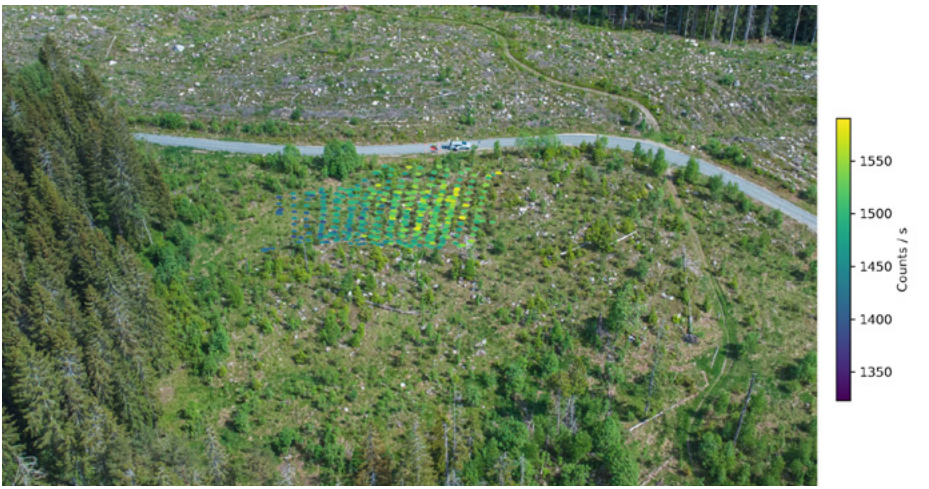
THE FUTURE OF DRONES: TECHNOLOGIES, APPLICATIONS, RISKS AND ETHICS

Participants: Bergström, Johan; Dell'Unto, Nicolo; Robertsson, Anders; Tyllström, Rikard; Landeschi, Giacomo; Revstedt, Johan; Olsson, Per-Ola; Smoker, Anthony; Johansson, Rolf

Unmanned Aerial Systems (UAS) are today considered a 'disruptive technology' which affects the way in which we address a variety of societal challenges, including agriculture and forest analysis, identifying property boundaries, surveying construction sites or corridors for roads and railroads, stockpile volume calculations, flooding and coastal erosion assessments, building information management, Search-And-Rescue, radiation detection, disaster planning and handling, surveys in remote or undeveloped areas, the delivery of goods, etc. The possibilities of digitalisation and technology development address societal challenges such as making societal sectors and domains more ecosystem friendly, efficient and competitive. This project will continue to work to connect academic actors with external stakeholders in their efforts to use UAS to identify and address such societal challenges. The project will also continue to study potential (unintended) consequences of such applications in terms of risks and ethical questions and also support internal as well as external stakeholders in their efforts to be compliant with the recently enacted European regulatory framework for UAS.

In the last three years the collaboration project UAV@LU has served as an important opportunity to develop and combine cross-disciplinary research activities in several, for Lund University, strategic fields (see self-evaluation for more details). In doing so, the problem and opportunity of 'system autonomy' has been identified as a boundary problem shared by most actors in the collaboration network. Hence, increased system autonomy will be given a specific focus in the collaboration over the coming two years. Another additional challenge which has emerged just recently is how to adapt organisations (including Lund University) in order to be compliant with the recently enacted European regulatory frameworks for UAS.

In order to mark the increased focus on drone systems (rather than simply the drones themselves) the collaboration project will change its name from UAV@LU to UAS@LU.



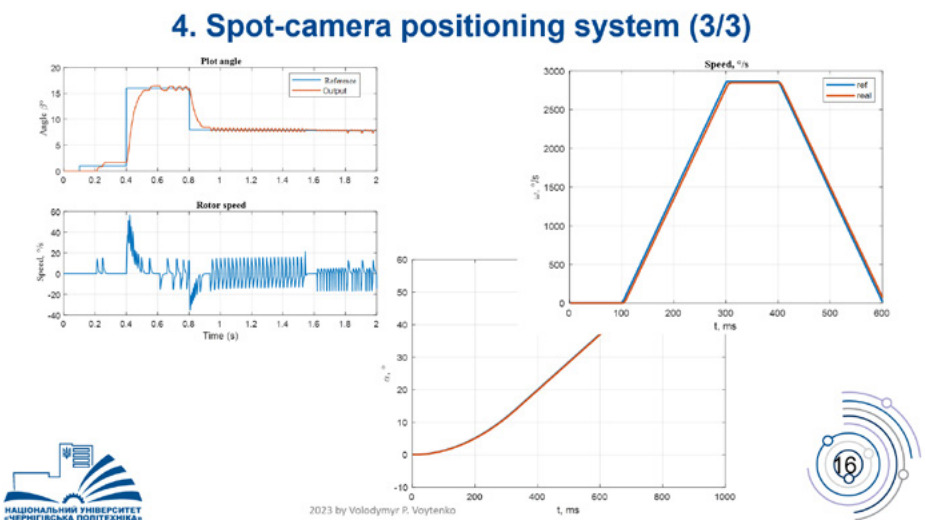
INCREASING THE SPEED OF ANALYSIS OF IMAGES OBTAINED FROM UNMANNED AERIAL VEHICLE

Researcher: Voitenko, Volodymyr

Funding: KAW

Carrying out long-term search and rescue missions, intelligence, surveillance and reconnaissance, which are carried out with the help of unmanned aerial vehicles (UAVs), overload the operator and reduce the effectiveness of solving the assigned tasks, up to the point of making their implementation impossible. It is proposed the concept of increasing the speed of the human-machine system based on information obtained from images transmitted in real time by video cameras installed on a platform moving relative to the UAV, by mean of the intelligent control system of this platform.

Thus, the image from the main video camera with a wide viewing angle is divided into rectangular sections (zones), the size of which is determined by the viewing angle (zoom) necessary for the operator to make the final decision. The software system of the lower level, evaluating the video frame, determines and marks the areas in which the object of interest may be present. For the zone where the probability of the presence of the candidate object is the greatest, the focal length is increased and focusing (ie, zooming the image), as well as the positioning of the main camera. In another variant, a separate spot camera with a reduced and fixed field of view is aimed at the yaw and pitch angles, which requires that this camera be directly suspended on a gyro-stabilized platform, where a block of other sensors is installed, including the main video camera.



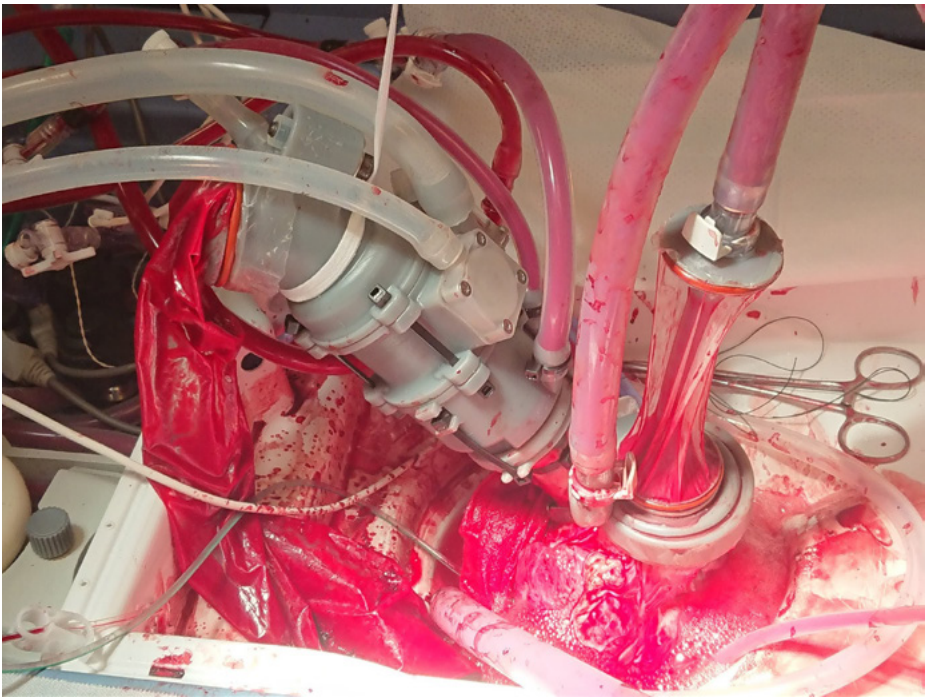
HEMODYNAMIC STABILIZATION

Researchers: Soltesz, Kristian; Pigot, Henry; Wahlquist, Ylva; Paskevicius, Audrius, (Heart and Lung transplantation), in collaboration with Igelösa Life Science

Funding: VR, Vinnova

Intensive care patients often rely on a combination of drug, fluid, and other therapies to achieve and maintain stable hemodynamics. This projects investigates how pharmacology, mathematical modeling, signal processing and closed-loop control can be combined to control hemodynamic entities such as blood pressure, heart rate, and vascular resistance, as well as related entities such as diuresis. The research relies on close inter-disciplinary collaboration between medical and control systems researchers. It is conducted in a systems engineering framework and comprises the development of both methods and dedicated equipment for clinical verification.

The aim of the project is to develop methods for hemodynamic stabilization of intensive care patients. It comprises closed-loop control of readily measurable signals, including heart rate, arterial and venous blood pressure. Furthermore,



Testing of a device for functional heart evaluation, with an adjustable flow resistance (left) connected to a porcine heart, and blood being supplied to the organ via a compliant column (right). The device is designed to mimic the normal physiology of a prospective transplantation patient. The clinical application of this technology would help increase the number of available donor hearts that can safely be used in transplantation.

the project aims at optimizing hemodynamic parameters, which are not directly measurable, such as cardiac output and responsiveness to volume expansion.

The aim of the project is to develop a generic platform for closed-loop intravenous drug delivery. Apart from being used in research, such a platform can be adapted to a multitude of medical treatment scenaraios, foremost in intensive care, where it has the potential to increase the availability of specialized physicians.

The aim of the project is to provide physicians with an 'auto pilot' for hemodynamic stabilization and optimization. The initially considered patient group are heart-beating braindead patients under intensive care (potential organ donors). Due to the complete loss of vasomotor center function, hormonal and fluid therapy is required to establish hemodynamic stability within this group.

We combine automatic control methods with medical insight, to develop closed-loop controlled therapies. Developed methods are implemented on our in-house developed control system comprising sensors for invasive blood pressure measurement, and urination rate, as well as syringe and volumetric infusion, pumps for closed-loop controlled intravenous drug and fluid administration.

The methods are pre-clinically evaluated in collaboration with the project partner Igelösa Life Science AB.

BIOMIMETIC FABRICATION THROUGH ROBOTIC 3D PRINTING

Researcher: Andréen, David; Robertsson, Anders; Goidea, Ana; Johansson, Anton Tetov

Funding: Formas

The purpose of this project is to develop a novel way of investigating and implementing biological design principles within architectural desing contexts. Taking its starting point in the current field of self-organized construction, we seek to demonstrate that a hybrid approach which combines simulated agents with a 3D printed material model can be used to overcome challenges associated with current simulation or collaborative robot approaches. To this end, we aim to build a digital agent simulation where the agents are correlated to a physical design space, and where their actions are materialized through a robot-mounted clay deposition device. In parallel, we aim to implement a real-time scanning and sensing mechanism which feeds back data from the material model into the simulation, allowing the model to be fully interactive and non-deterministic, responding in real-time to emergent behaviour of the built outcome. The project will be carried out in collaboration between two departments at Lund University (Architecture and Automatic Control), and will utilise the facilities and expertice of the newly founded construction robotics lab. The project stretches over four years, and is linked to an extensive international collaboration framework.

HISTORICAL FEMALE INFLUENCERS IN AUTOMATIC CONTROL

Researchers: Johnsson, Charlotta; Westin, Eva; Hägglund, Tore; Soltesz, Kristian; Bauer, Margret; together with X-Lab and Campus Helsingborg

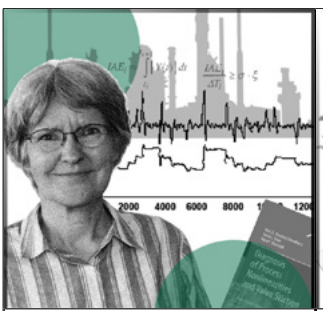
Funding: IFAC Activity Fund

It is interesting to look at the presence of role models in the automatic control community. The elder professionals in this field, influences the younger, and thereby shape the younger generation. There are many occasions where younger, potential future control professionals, could be influenced by elder professionals. One occasion is in the classroom e.g. when examples of pioneers in the field are highlighted. One other example is in the everyday working environment e.g. laboratories or offices, where histories and anecdotes from the passed are shared. Yet another example, are the award winners in the field, who just by getting the price raises their influence in the field.

Statistics from e.g. Department of Automatic Control, Lund University, Sweden, shows that only 11 out of the 128 PhD theses, throughout its 60 years of history, are written by women. Statistics also show that only 14% of the PhD-students, and 9% of the professors are of female gender. These numbers are very low. Most probably the statistics from automatic control departments in other corners of the world, are very similar. Could it be that female role models are missing?

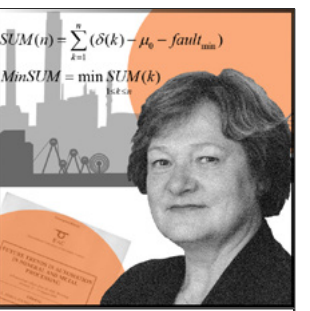
It is noted that early pioneers highlighted in basic control courses often (or always) are men e.g. Bode, Nyquist, Kalman, etc. Also, award winners are to a very large degree men, e.g. Richard E Bellman Award was given to a man 40 years in a row. This has an explanation in the fact that there are no women in the field, but how could they enter if there are hardly no role models to identify with?

The intention in this project is to find out if there are some early female historical influencers. We believe that the best way to find out would be to identify a set of elder (retired or emeritus) female professionals, and by interviewing them get to know if they had any female role models. We also believe that the identified (retired or emeritus) female control professionals, act as role models in themselves. The interviews with the identified (retired of emeritus) female control professionals will serve as material for a portrait-series of historical female influencers. The portrait-serie of these women could be used in various outreach material such as e.g. lecture notes, and other inspirational material for young and potential future control professionals. By this project we hope to inspire more females to enter the community of Automatic Control.



Nina Thornhill

Irmgard Flügge-Lotz



Sirkka-Liisa Jämsä-Jounela

LEVERAGE DIGITAL TECHNOLOGY TO UNVEIL BIOLOGICAL MECHANISMS IN AVIAN MIGRATION

Researchers: Åkesson, Susanne; Robertsson, Anders

The goal of the project is twofold. First, we will leverage new artificial intelligence algorithms to characterise the behavioural phenotype of migratory birds with unprecedented detail overtaking the limitations of manual and semi-manual methods and provide us with the opportunity to answer long-standing questions in migration ecology. By using cue-conflict experiments, we will be able to demonstrate (1) how the birds synchronise and use their internal clock, (2) which cue birds likely use to determine their location and how this is perceived, and (3) how magnetic and celestial compasses are calibrated during migration.

Second, we will develop a new and inexpensive open-source platform to study migratory behaviour directly at site of capture. In this project we will develop a portable computer-controlled device that will bring to the field all the analytical power currently possible only in the lab revolutionising the current 50-year-old state-of-the-art manual methods.

AUTONOMOUS FORCE-AWARE SWIFT MOTION CONTROL

Researcher: Robertsson, Anders; Olofsson, Björn; Jia, Zheng

Funding: ELLIIT

The research program for this project has a number of steps for moving autonomous force-aware swift motion control forward. Our recently derived novel methods for at-the-limit maneuvering will be extended to new scenarios, where previously non-dynamic kinematic models (with non-holonomic motion constraints) have been used under, sometimes highly restrictive, assumptions on limited slip and upper-bounded velocities. For example, maneuvering in highway driving at higher speeds (typically 70 km/h and higher) implies that consideration of the forces involved, i.e., the dynamic behavior, is of importance, e.g., if heavy-duty vehicles with their inherent roll sensitivity or mobile platforms with heavy manipulators onboard are considered. The new perspective has high potential to lead to new significant results with regard to planning and control strategies for a wide range of vehicle-maneuvering and robotic manipulation scenarios, and will also treat scenarios with multiple vehicles and moving robots, in traffic or on work sites. The core of the project is scientific questions in swift motion control that is safe, resilient, and efficient.

DIGIT HUB

Researchers: Charlotta Johnsson and Erik Larsson at Integrated Electronic Systems LTH School of Engineering in Helsingborg, in collaboration with Mobile Heights, Media Evolution, IUC Syd, Malmö University

Funding: European Regional Development Fund, Region Skåne

DigIT Hub is an initiative that helps companies and the public sector in southern Sweden to digitalise. DigIT Hub has financial support from the European Regional Development Fund and Region Skåne.

Digitalisation is a broad term, and digitalisation needs vary within each organization. Through DigIT Hub, we are using digitalisation as an engine to create sustainable and efficient processes and working methods, strengthened competitiveness, and better tailored services in the region. We help organisations in Skåne and Blekinge stay relevant through digital transition; allowing them to meet expectations of customers, employees and citizens who are becoming increasingly digital.

DigIT Hub is specifically aimed at small and medium-sized companies in the manufacturing industry, as well as entities in the public sector. The initiatives we work with fall broadly within the areas "Smart Cities" and "Smart Industry". No digitalisation issue is too big or too small to share with us, and we offer both introductory and advanced digitalisation support.

FORUM FOR STANDARISATION OF DIGITALISATION IN PRODUCTION

Researcher: Johnsson, Charlotta; in collabotation with KTH, RISE, Automation Region, Mälardalens högskola, SIS

Funding: Vinnova

The current increase of digitalisation in production provides many opportunities for Swedish manufacturing industry. An important challenge in this transition is how to relate to the large number of available standards and the standardization work within different groupings. Increased knowledge of this is important to be able to take advantage of the opportunities in an increasingly digitalized business landscape. The goal is a network forum for Swedish industry that convey knowledge and support in understanding and navigating among standards for smart production.

DATA-DRIVEN MODELING FOR SUSTAINABLE MINING

Researcher: Norlund, Frida; Soltesz, Kristian; Eker, Johan; Bauer, Margret

Funding: WASP

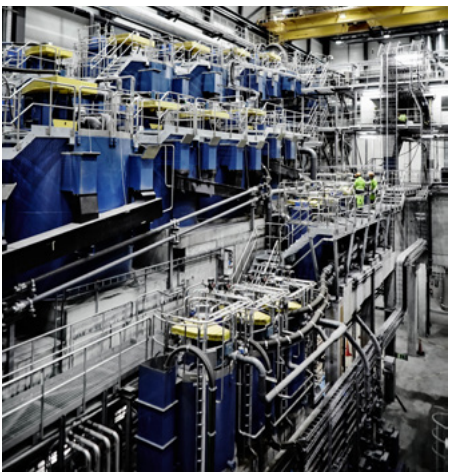
Flotation is the dominating process in the global copper, lead, and zinc mining industries to separate valuable minerals from waste material. In the upstream process steps, the ore is ground to liberate all mineral grains, and mixed with water to form a slurry. In flotation, chemical reagents are added to improve the hydrophobic properties of selected minerals. When air is added, these minerals follow the air bubbles to the surface and can be extracted in the resulting froth, forming a concentrate. This process is implemented in flotation tanks interconnected in a complex circuit that often includes re-grinding and recirculation. Floatation is a pivotal process step, as it defines the recovery (yield), which has a proportional impact on both environmental aspects and the financial result of the company.

Today, the flotation process is typically controlled semi-manually, where simple control loops stabilize tank levels and flow rates, while operators adjust parameters like airflow, reagent- and lime- addition based on the available measurements and experience. Model predictive control solutions have been attempted, with some success. However, performance is severely limited by poor model accuracy and the inability to adapt to changes in ore properties as new areas of the mine are excavated. To increase efficiency and autonomy of mineral processing, these challenges must be addressed.

Therefore, this PhD project addresses modeling of the flotation process for control purposes. Data-driven modeling through machine learning (ML) techniques holds great potential, but several aspects must be addressed before it can be applied in an industrial setting. In our setting, observation of a process is limited by physical restrictions and the available measurement technology. Furthermore, the effect of the measured properties on the system state are often both complicated and only known conceptually, making the interpretation of the measurements challenging. To use the limited data that is available efficiently, we will combine machine learning with physics-based modeling, avoiding wasting scarce data on learning known laws of physics.

In this project, we will therefore push the state-of-the-art within mining process control by complementing machine learning with physics-based models based on e.g., conservation laws.

We firmly believe that the future of floatation control, and indeed many associated process steps, lies in incorporating informal operator know-how into dynamical models, to enable model-based control solutions, where traditional data-driven paradigms suffer from lack of informative data. This physics-informed machine learning approach to increased autonomy is becoming increasingly feasible thanks to advances within scientific machine learning methodology. Within mining and the process industries, embracing it will provide the opportunity to increase efficiency of resource utilization, thereby enabling the transition to a sustainable technological future.



REALTIME INDIVIDUALIZATION OF BRAIN COMPUTER INTERFACES

Researchers: Bernhardsson, Bo; Heskebeck, Frida; Tufvesson, Pex; Gemborn Nilsson, Martin; in collaboration with Maria Sandsten, Rachele Anderson at Mathematical Statistics, LTH and Mikael Johansson at department of Psychology.

Funding: WASP, ELLIIT, Ericsson

Controlling the physical world with our mind only opens up for a vast number of exciting opportunities. This can be made possible through so called Brain Computer Interfaces (BCIs). In this project, we primarily focus on BCIs based on ElectroEncephaloGram (EEG) measurements, collected through the use of an EEG-cap. Although the technology behind BCIs have improved steadily over recent years, there is still much to be done. We investigate what the possibilities and limitations of BCIs are in terms of efficiency, reliability and individualizability.

The project is a collaboration between the Department of Automatic Control, the Department of Mathematical Statistics and the Department of Psychology at Lund University. Bringing together cross-disciplinary expertise, we have identified several critical obstacles that prevent BCIs from becoming a truly life-changing technology, and methods to overcome them. We see several important areas of use such as communication and control for severely motor-impaired users, smart hearing aids, gaming-devices and forensics tools, as well as different health-related applications, such as rehabilitation, including restoration of motor control after stroke.

Demo by Pex Tufvesson and Martin Gemborn Nilsson

LEARNING PHARMACOMETRIC MODEL STRUCTURES FROM DATA

Researchers: Bernhardsson, Bo; Sundell, Jesper; Wahlquist, Ylva; Soltesz, Kristian

Funding: WASP

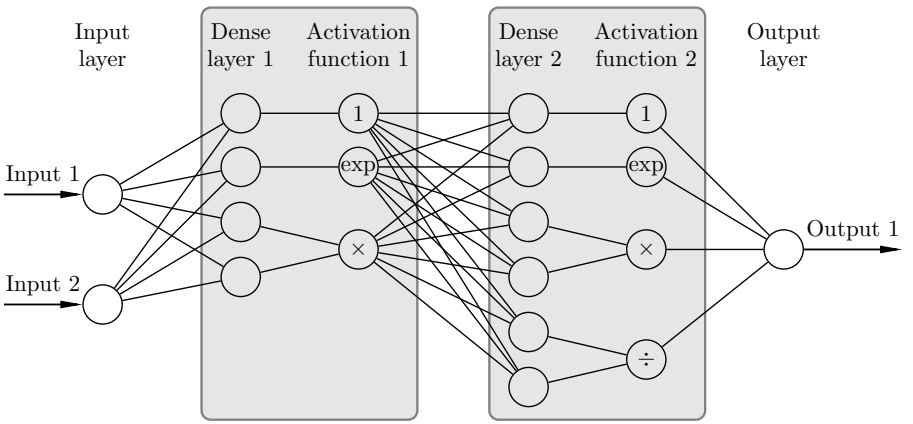
Pharmacometric modelling plays a central role in the development of novel individualized drug therapies, in the evaluation of medical treatments, and in gaining understanding of how life style changes may affect the evolution of a disease. The existence of well-established national quality registries puts us (as Swedish researchers) in an internationally unique position to lead the development of data-driven pharmacometrics modelling, that will constitute a cornerstone of tomorrow's precision medicine.

Broadly, the purpose of pharmacometrics modelling is to make predictions on an individual basis, based on known possible covariates. Traditionally covariates have been restricted to demographic parameters (age, weight, etc.), but lifestyle (smoking, exercise, etc.) and omics data (SNPs, etc.) are vastly expanding the possible parameter space, presenting both challenge and opportunity.

Ultimately predictive performance is limited by the amount of available training data, how informative that training data is, and how much of inter-patient variability that cannot be explained by the covariates present in the dataset. One key challenge lies in understanding or learning causality dependences and using them to establish a sound covariate model. In contemporary modelling, focus has foremost been on which covariates to include/exclude, with less attention on how to learn a structure of the covariate model that balances accuracy with the ability to generalize to data unseen in training.

This project has its emphasis on developing methods for simultaneously learning the structure and parameters of covariate models, to produce capable pharmacometric predictors suited for individualized precision medical therapies. Doing so prompts development of machine learning methods, with two central examples provided below:

Regularization: Rather than searching for a covariate mapping within a narrow class of ordinary functions, we will pursue two approaches, representing it either as an ANN or a kernel, and then learning the weights of either representation



Data-driven methods, such as artificial neural networks, can be used to describe the variability between patients in their drug response, enabling for a more individualized therapy.

from data. Without regularization, the resulting model will interpolate and generalize poorly due to overfitting, and too hard regularization will result in a model that does not exploit covariate dependence. The regularization should ideally enforce structure reflecting biological expected/relevant mechanism, requiring domain expertise to formulate. Our aim is to develop methods for adaptive data-driven hyper-parameter tuning to achieve such regularization, based on feedback from validation on random folds. Within the ANN approach this can be done for example by constraining the Lipschitz constant of the network, and within the kernel model, it can be achieved by tuning the parameters of the kernel (e.g., the covariance matrix of a Gaussian kernel).

Sparsity: The covariate candidates result in a high input dimensionality in relation to available training data. This is particularly true when omics data is considered and poses a risk of confusing correlation for causality. The reasonable assumption that the true relation lives on low-dimensional manifold fits well within the kernel formulation. However, selecting an appropriate kernel class requires some insight where knowledge from the ML and medical/biological/pharma domains need to be combined. Within the ANN model, we will pursue more autonomous dimensionality reduction through employing feedforward networks with the structure of an autoencoder.

The pharmacological expertise of our team will allow us to work with large data sets, make informed decisions on how to combine ANN or kernel components with classical dynamical components (e.g. compartment or Markov chains models) into capable pharmacometric predictors. A simple example is knowing that drug intake relates to blood concentration through a compartment model of a known structure but with unknown parameters for a particular individual. In this case a mapping from the covariates to the unknown parameters, rather than to the desired endpoint predictions is preferrable.

TOOLS AND SOFTWARE

- Julia packages
- JGrafchart
- Jitterbug: A Matlab toolbox for real-time control performance analysis
- JITTERTIME: Real-time control performance simulation
- TrueTime: Simulation of Networked and Embedded Control Systems

JULIA PACKAGES

Researchers at the department, in particular Fredrik Bagge Carlson and Mattias Fält, have contributed to several registered packages for the Julia programming language:

- ControlSystems.jl –A control systems toolbox for Julia. (Several add-on packages are available.)
- BasisFunctionExpansions.jl – Basis function expansions for Julia.
- DeterministicPolicyGradient.jl – Reinforcement learning with deterministic policy gradient methods.
- DifferentialDynamicProgramming.jl – A package for solving differential dynamic programming and trajectory optimization problems.
- DynamicMovementPrimitives.jl – Learning dynamic movement primitives in Julia.
- LPVSpectral.jl - A toolbox for least-squares spectral estimation and (sparse) LPV spectral decomposition.
- SingularSpectrumAnalysis.jl – A package for performing singular spectrum analysis. CholmodSolve2.jl – Package for solving linear systems given an LDLt factorization.
- FirstOrderSolvers.jl – Large scale convex optimization solvers in Julia.

JGRAFCHART

Grafchart is a language for supervisory level sequence control and procedure handling that has been developed at the department since 1991. Grafchart is based on ideas from Grafcet/Sequential Function Charts, Petri nets, Statecharts, and object-oriented programming.

The original implementation of Grafchart had the same name and was developed in G2 from Gensym Corporation. Using this platform Grafchart was used for batch recipe control, diagnosis of mode-changning processes, alarm filtering, implementation of operator decision support systems, and implementation of robot cells. In 2001 an open implementation of Grafchart was made in Java. It is called JGrafchart and is used in our laboratory exercises on logical sequence control and batch control as well as in several research projects.

JITTERBUG: A MATLAB TOOLBOX FOR REAL-TIME CONTROL PERFORMANCE ANALYSIS

Jitterbug is a MATLAB-based toolbox that allows the computation of a quadratic performance criterion for a linear control system under various timing conditions. Using the toolbox, one can easily and quickly assert how sensitive a control system is to delay, jitter, lost samples, etc., without resorting to simulation. The tool is quite general and can also be used to investigate jitter-compensating controllers, a periodic controllers, and multi-rate controllers. As an additional feature, it is also possible to compute the spectral density of the signals in the control system. The main contribution of the toolbox, which is built on well-known theory (LQG theory and jump linear systems), is to make it easy to apply this type of stochastic analysis to a wide range of problems.

JITTERTIME: REAL-TIME CONTROL PERFORMANCE SIMULATION

JitterTime is a spin-off from the Matlab toolbox Jitterbug and can be used for calculating the performance of a controller under non-ideal timing conditions. Examples of such conditions include delay and jitter due to CPU and network scheduling, lost samples or lost controls due to packet loss or execution overruns, and aperiodic behavior due to clock drift, asynchronous nodes, and random sampling. Both Jitterbug and JitterTime evaluate a quadratic cost function for a mixed continuous-time/discrete-time linear system driven by white noise. The main difference is the timing model. In Jitterbug, the timing of the discrete systems are governed by random delays with specified probability density functions. This allows the total system to be treated as a jump-linear system, and covariance can be calculated by solving a set of linear equations. In JitterTime, however, the timing is arbitrary and completely driven by the user. This allows for more complex timing scenarios to be analyzed, including scheduling algorithms with long-term timing dependencies and asynchronous execution in distributed control systems.

TRUETIME: SIMULATION OF NETWORKED AND EMBEDDED CONTROL SYSTEMS

TrueTime is a Matlab/Simulink-based simulator for real-time control systems. Offering Simulink blocks that model real-time kernels and wired/wireless networks, TrueTime facilitates co-simulation of scheduling algorithms, control tasks, network protocols, and continuous plant dynamics.

TrueTime has been developed at the Department of Automatic Control since 1999. It is open source, written in C++, and can easily be extended with new functionality. TrueTime has been used in wide range of research projects and has also found use in university courses and in industry.

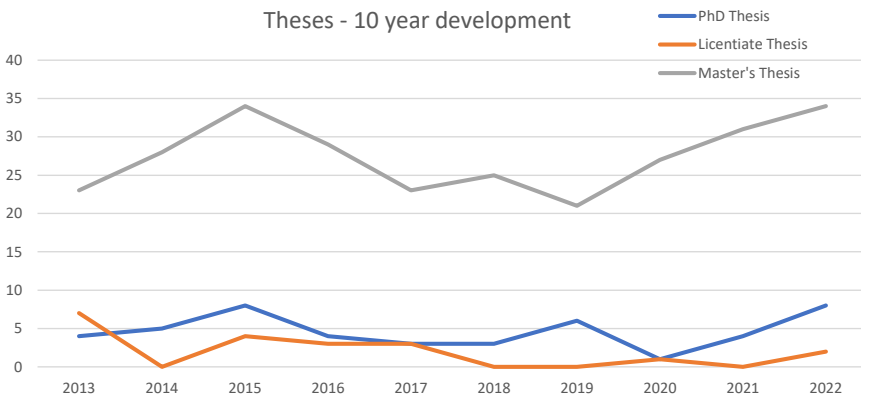
Publications and seminars

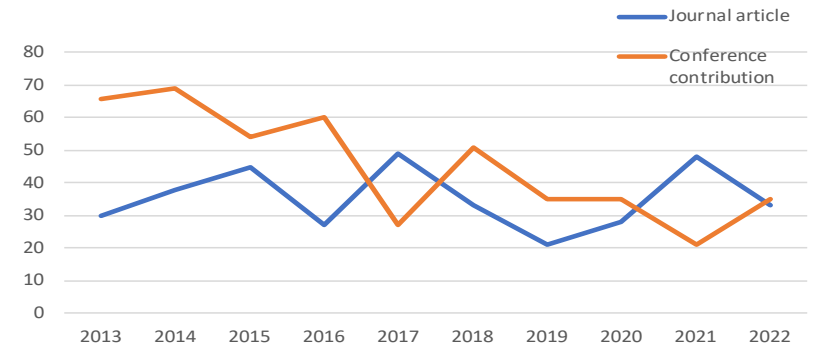
This chapter contains a list of publications and seminars during 2022

PUBLICATIONS 2022

You can find references to all the publications on www.control.lth.se/publications and almost all of them can be downloaded from this site. Any of the reports may, however, be borrowed through your library service or from the following libraries in Sweden:

- Göteborgs universitetsbibliotek
- Kungliga Biblioteket
- Linköpings universitetsbibliotek
- Lunds universitetsbibliotek
- Stockholms universitetsbibliotek
- Umeå universitetsbibliotek
- Uppsala universitetsbibliotek





JOURNAL ARTICLES

Agner, Felix; Kergus, Pauline; Pates, Richard; Rantzer, Anders; *Combating district heating bottlenecks using load control*. In Smart Energy 6.

Andréen, David; Goidea, Ana; *Principles of biological design as a model for biodesign and biofabrication in architecture*. International Conference on Structures and Architecture. In Architecture, Structures and Construction 2(4). p.481-491.

Anistratov, Pavel; Olofsson, Björn; Nielsen, Lars; A*nalysis and design of recovery behaviour of autonomous-vehicle avoidance manoeuvres*. In Vehicle System Dynamics 60(7). p.2231-2254.

Anistratov, Pavel; Olofsson, Björn; Nielsen, Lars; *Dynamics-Based Optimal Motion Planning of Multiple Lane Changes using Segmentation*. 10th IFAC Symposium on Advances in Automotive Control, AAC 2022. In IFAC-PapersOnLine 55(24).

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LICENCIATE THESES

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Andersson, Viktor and Ostréus, Nelly; *Speech activity detection in videos*. Master's Thesis TFRT-6171, Supervisors: Alickovic, Emina; Skoglund, Martin; Zaar, Johannes, Oticon A/S (external) and Bernhardsson, Bo; Soltesz, Kristian, Department of Automatic Control, Lund University.

Alptürk, Cem; *Risk Averse Path Planning Using Lipschitz Approximated Wasserstein Distributionally Robust Deep Q-Learning*. Master's Thesis TFRT-6166, Supervisors: Renganathan, Venkatraman; Rantzer, Anders, Department of Automatic Control, Lund University.

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Ekenberg, Kajsa; *Distributionally Robust Risk-Bounded Path Planning Through Exact Spatio-temporal Risk Allocation*. Master's Thesis TFRT-6174, Supervisors: Renganathan, Venkatraman; Robertsson, Anders, Department of Automatic Control, Lund University.

Enander, Sara and Karsten, Louise; *Computation models for audiovisual attention decoding*. Master's Thesis TFRT-6165, Supervisors: Alickovic, Emina; Skoglund, Martin; Zaar, Johannes; Eriksholm Research Centre (external) and Bernhardsson, Bo; Soltesz, Kristian, Department of Automatic Control, Lund University.

Fallenius, Emma and Karlsson, Linda; *Tensor Decompositions of EEG Signals for Transfer Learning Applications*. Master's Thesis TFRT-6172, Supervisors: Carolina, Bergeling (external) and Bernhardsson, Bo; Giselsson, Pontus, Department of Automatic Control, Lund University.

Fernández Fernández, Pablo; *Construction Supervision with Augmented Reality*. Master's Thesis TFRT-6154, Supervisors: Hägglund, Tore; Robertsson, Anders, Department of Automatic Control, Lund University.

Hansson, Ludvig and Lindeberg, Måns; *PTZ Camera Tampering Correction Using IMUs*. Master's Thesis TFRT-6161, Supervisors: Romner, Marcus; Axis Communications (external) and Cervin, Anton; Soltesz, Kristian, Department of Automatic Control, Lund University.

Hellmark, Johan; *A practical framework for the electric vehicle routing problem*. Master's Thesis TFRT-6155, Supervisors: Lincoln, Bo; Iternio Planning AB (external) and Como, Giacomo; Bernhardsson, Bo, Department of Automatic Control, Lund University.

Hofvander, Måns; *Design and Implementation of Bluetooth Mesh Outdoor Lighting*. Master's Thesis TFRT-6185, Supervisors: Wallinius, Mattias; Arvehammar, Maja, Adevo Consulting (external) and Årzén, Karl-Erik; Maggio, Martina, Department of Automatic Control, Lund University.

Kockum, Sofia; *Autonomous Docking of an Unmanned Surface Vehicle using Model Predictive Control*. Master's Thesis TFRT-6164, Supervisors: Wingqvist, Birgitta, Olofsson, Björn; Robertsson, Anders; Årzén, Karl-Erik, Department of Automatic Control, Lund University.

Koegst, Vilius and Orlova, Tatiana; *CHILLER DIAGNOSTICS Machine learning approach Carrier*. Master's Thesis TFRT-6167, Supervisors: Jacobson, Clas, Carrier (external) and Grönqvist, Johan; Bernhardsson, Bo, Department of Automatic Control, Lund University.

Lindström, Henrik and Sundström, Emil; *Physics-Enhanced Machine Learning for Energy Systems*. Master's Thesis TFRT-6163, Supervisors: Agner, Felix; Rantzer, Anders; Bernhardsson, Bo, Department of Automatic Control, Lund University.

Lundström, Mattias and Pettersson, Jakob; *3D Privacy Masking using Monocular Depth Estimation*. Master's Thesis TFRT-6168, Supervisors: Olofsson, Björn; Robertsson, Anders; Årzén, Karl-Erik, Department of Automatic Control, Lund University.

Mårtensson, Daniel; *Kalman-Filter Design and Evaluation for PMSM Rotor-Temperature Estimation*. Master's Thesis TFRT-6155, Supervisors: Turesson, Gabriel; Jonsson, Peter; BorgWarner (external) and Olofsson, Björn; Robertsson, Anders, Department of Automatic Control, Lund University.

Nilsson, David and Olsson, Albin; *Log Anomaly Detection of Structured Logs in a Distributed Cloud System.* Master's Thesis TFRT-6176, Supervisors: Gustav Hochbergs, Ingka Group Digital (external) and Eker, Johan; Årzén, Karl-Erik, Department of Automatic Control, Lund University.

Nilsson, Henry and Ternerot, Johan; *Path planning algorithm for levitating planar motion system*. Master's Thesis TFRT-6170, Supervisors: Jovanovski, Daniel, Beckhoff Automation AB (external) and Robertsson, Anders; Rantzer, Anders, Department of Automatic Control, Lund University.

Nilsson, Joachim; *Multi-Armed Bandit to optimize the pricing strategy for consumer loans*. Master's Thesis TFRT-6183, Supervisors: Paz Luna, Alfonso SEB (external) and Giselsson, Pontus; Como, Giacomo, Department of Automatic Control, Lund University.

Nilsson, Max; *Asymmetric Bregman Forward-Backward Splitting with Projection Correction*. Master's Thesis TFRT-6187, Supervisors: Giselsson, Pontus; Tegling, Emma, Department of Automatic Control, Lund University.

Nilsson, Ola; *Building dense reconstructions with SLAM and Spot*. Master's Thesis TFRT-6158, Supervisors: Klöckner, Meike and Robertsson, Anders; Cervin, Anton, Department of Automatic Control, Lund University.

Norlund, Frida; *Comparison of Level Control Strategies for a Flotation Series in the Mining Industry*. Master's Thesis TFRT-6178, Supervisors: Tammia, Rasmus, Boliden (external) and Hägglund, Tore; Soltesz, Kristian, Department of Automatic Control, Lund University.

Omodolor, Stevedan Ogochukwu; *Distance and orientation-based formation control of UAVs and coordination with UGVs*. Master's Thesis TFRT-6181, Supervisors: Olofsson, Björn; Robertsson, Anders; Hägglund, Tore, Department of Automatic Control, Lund University.

Patil, Vinay Venkanagoud; *High Precision Robotic Manipulator for Bluelining at MAX IV*. Master's Thesis TFRT-6173, Supervisors: Andersson, Alina; Lindstedt, Gunnar, MAX IV (external) and Robertsson, Anders; Hägglund, Tore, Department of Automatic Control, Lund University.

Ragnarsson, Eric; *Advanced Teleoperation with Haptic Feedback*. Master's Thesis TFRT-6153, Supervisors: Ghazaei, Mahdi; Cognibotics (external) and Robertsson, Anders; Årzén, Karl-Erik, Department of Automatic Control, Lund University.

Sandsjö, Måns and Sundbom, Oscar; *Edge Case searching for Autonomous Vehicles*. Master's Thesis TFRT-6180, Supervisors: Zhou, Guo, Scania CV AB (external) and Cervin, Anton; Giselsson Pontus, Department of Automatic Control, Lund University.

Scheidt, Teresa; *Probing Gray Matter Microstructure in Alzheimer's Disease using Diffusion MRI*. Master's Thesis TFRT-6160, Supervisors: Nilsson, Markus; Spotorno, Nicola and Soltesz, Kristian, Department of Automatic Control, Lund University.

Segui, Felicia and Timürtas, Andreas; *Real-time unsupervised log event anomaly detection in public transportation*. Master's Thesis TFRT-6184, Supervisors: Ekström, Hans; Olsson, Sara, Gaia (external) and Cervin, Anton; Eker, Johan, Department of Automatic Control, Lund University.

Selleck, Samuel; *Reducing Polarization in Opinion Networks in the Presence of Stubborn Leaders*. Master's Thesis TFRT-6157, Supervisors: Como, Giacomo; Tegling, Emma, Department of Automatic Control, Lund University.

Sidh, Fredrik and Sundell, Gustaf; *Data-driven forecasting of electric vehicle charging for frequency regulation*. Master's Thesis TFRT-6169, Supervisors: Madjidian, Daria; Emulate Energy AB (external) and Pates, Richard; Rantzer, Anders, Department of Automatic Control, Lund University.

Siwerson, Johan and Gunnarsson, Samuel; *Adaptive Server Control for Low-Latency Applications over the Cellular Network*. Master's Thesis TFRT-6175, Supervisors: Millnert, Victor, Ericsson (external) Eker, Johan; Årzén, Karl-Erik, Department of Automatic Control, Lund University.

Skoog, Emelie and Fredberg, Elin; *Automatic Virtual Tracking in a Multi-Participant Scenario for a Mobile Device*. Master's Thesis TFRT-6179, Supervisors: Raase, Sebastian, Sony (external) and Pates, Richard; Cervin, Anton, Department of Automatic Control, Lund University.

Wilson Andersson, Elin and Håkansson, Johan; *Improving a Reinforcement Learning Algorithm for Resource Scheduling*. Master's Thesis TFRT-6162, Supervisors: Korsell, Jonas; Tidelund, William; Bayomi, El-Tayed, Ericsson (external) and Årzén, Karl-Erik; Bernhardsson, Bo, Department of Automatic Control, Lund University.

Zumárraga, Blanca; *Implementation and integration of slip and traction controllers for a three-wheel electric vehicle*. Master's Thesis TFRT-6182, Supervisors: Svensson, Ola (external and Olofsson, Björn; Robertsson, Anders; Hägglund, Tore, Department of Automatic Control, Lund University.

SEMINARS AT THE DEPARTMENT

January

21 Defence of Doctoral Dissertation: On the Control of Transportation Networks with Delays, Martin Heyden, Department of Automatic Control, LTH. Opponent: Associate professor Laurent Lessard, Mechanical and Industrial Engineering, Northeastern University, USA.

21 *The Speed-Robustness Trade-Off for Iterative Optimization Algorithms,* Associate Professor Laurent Lessard, Mechanical and Industrial Engineering at Northeastern University.

27 Master's Thesis Presentation: *Reducing Polarization in Opinion Networks in the Presence of Stubborn Leaders*, Samuel Selleck.

27 *Non-expansive semiflows, saddle-point dynamics, and necessary and sufficient conditions for convergence*, Associate Professor Ioannis Lestas, Associate Professor at the University of Cambridge, Department of Engineering and Fellow of Clare College.

27 *Stochastic stability of phase-coupled oscillators in uncertain networks*, Matin Jafarian, Delft University of Technology.

27 *Cybersecurity in Power-electronics-dominated Power Grids*, Mahdieh Sadabadi, Department of Automatic Control and Systems Engineering, University of Sheffield.

28 Defence of Doctoral Dissertation: *Network Synchronization and Control Based on Inverse Optimality: A Study of Inverter-Based Power Generation*, Taouba Jouini, Department of Automatic Control, LTH. Opponent: University Associate Professor Ioannis Lestas, Department of Engineering, University of Cambridge, United Kingdom.

March

24 Master's Thesis Presentation: *Building dense reconstructions with SLAM and Spot*, Ola Nilsson.

April

01 *Analysis and Design of Neural Network Driven Systems with Performance Guarantees*, Assistant Professor Mahyar Fazlyab, Department of Electrical and Computer Engineering at Johns Hopkins University.

12 Presentation of final report within Engineering Training Course, Henrik Paldán.

19 *Modeling and simulation of district energy networks*, Johan Simonsson, Luleå University of Technology and Optimation AB.

May

4-6 ELLIIT workshop on *Data-driven modelling and learning for cancer immunotherapy,* held in Lund.

20 Master's Thesis Presentation: *Real-time unsupervised log event anomaly detection in public transportation*, Felicia Segui and Andreas Timürtas.

24 *Professor John S. Baras: 3 guest seminars*, Professor John S. Baras, University of Maryland.

30 Master's Thesis Presentation: *Edge Case Generation for Autonomous Vehicles*, Måns Sandsjö and Oscar Sundbom.

30 Master's Thesis Presentation: Physics-enhanced machine learning for energy systems, Emil Sundström and Henrik Lindström.

31 *Neuro-inspired control and systems level synthesis*, Professor John Doyle, California Institute of Technology.

31 Master's Thesis Presentation: *PTZ Camera Tampering Correction Using IMUs*, Ludvig Hansson and Måns Lindeberg.

31 Master's Thesis Presentation: Computation models for audiovisual attention decoding, Louise Karsten and Sara Enander.

June

01 Master's Thesis Presentation: Improving a Reinforcement Learning Algorithm for Resource Scheduling, Elin Wilson Andersson and Johan Håkansson, LTH.
02 Master's Thesis Presentation: *Comparison of Level Control Strategies for a Flotation Series in the mining industry*, Frida Norlund, LTH.
02 Master's Thesis Presentation: *Speech activity in realistic video*, Nelly Ostréus and Viktor Andersson.
02 Master's Thesis Presentation: Chiller diagnostics. Machine learning approach, Tatiana Orlova and Vilius Koegst, LTH.
03 Defence of Doctoral Dissertation: *Resource Management in Distributed Camera Systems*, MSc Alexandre Martins, Department of Automatic Control, LTH. Opponent: Associate professor Lukas Esterle, Aarhus University.
10 Master's Thesis Presentation: *Data driven modelling of electrical load patterns for control of virtual batteries*, Fredrik Sidh and Gustav Sundell, LTH.
10 Master's Thesis Presentation: *Distributionally Robust Risk Bounded Path Planning Through Exact Spatio-temporal Risk Allocation*, Kajsa Ekenberg, LTH.
10 Master's Thesis Presentation: Path planning algorithm for levitating planar motion system, Henry Nilsson and Johan Ternerot, LTH.
10 Master's Thesis Presentation: *Risk Averse Path Planning Using Approximated Wassertein Distributionally Robust Deep Q-learning*, Cem Alptürk, LTH.
14 Master's Thesis Presentation: *3D Privacy Masking using Monocular Depth Estimation*, Mattias Lundström and Jakob Pettersson, LTH.
14 Master's Thesis Presentation: *The versatility of virtual models - A practical case of virtual commissioning*, Lucas Gardebrand, LTH.
14 Master's Thesis Presentation: Automatic Virtual Tracking in a Multi-Participant Scenario for a Mobile Device, Emalie Skoog and Elin Freberg, LTH.
15 Master's Thesis Presentation: *Kalman-filter design and evaluation for PMSM rotor-temperature estimation*, Daniel Mårtensson, LTH.
15 Master's Thesis Presentation: *High precision Robotic Manipulator for Bluelining at MAX IV*, Vinay Venkanagoud Patil, LTH.
17 Master's Thesis Presentation: *Autonomous Docking and Trajectory Following of an Unmanned Surface Vehicle*, Sofia Kockum, LTH.
17 Master's Thesis Presentation: *Brainstem response estimation using continuous sound - a feasability study*, Julia Adlercreutz, LTH.
17 Defence of Doctoral Dissertation: *Modeling and Control for Improved Predictability of Cloud Applications*, MSc Tommi Berner, Department of Automatic Control, LTH. Opponent: Professor Bhuvan Urgaonkar, The Pennsylvania State University.
20 Master's Thesis Presentation: *Distance and orientation based formation control of UAVs and coordination with UGVs*, Stevedan Ogochukwu Omodolor, LTH.
20 Master's Thesis Presentation:*Log Anomaly Detection of Structured Logs in a Distributed Cloud System*, David Nilsson and Albin Olsson, LTH.

August

16 Master's Thesis Presentation: *Implementation and integration of slip and traction controllers for a three-wheel electric vehicle*, Blanca Zumarraga Arjonilla, LTH.

19 *Data-Driven Approximation and Reduction from Noisy Data in Matrix Pencils Frameworks*, Doctor Pauline Kergus, CNRS Toulouse, France.

25 *Data-driven Model Predictive Control: Concepts, Algorithms and Properties*, Professor Frank Allgöwer, University of Stuttgart, Germany.

26 Master's Thesis Presentation: *Multi-Armed Bandits to optimize the pricing strategy for consumer loans in digital platforms*, Joachim Nilsson, LTH.

September

23 *Operational Test and Evaluation for Safety-Critical Autonomous Systems: Progress, Challenges, and Opportunities*, Professor Richard Murray, Caltech, USA.

29 *Scalable robustness and distributed control of multi agent systems*, Professor Steffi Knorn, Technische Universität Berlin, Germany.

October

06 Force-Centric Perspectives on Autonomous Vehicle Safety-Maneuvers, Professor Lars Nielsen, Division of Vehicular Systems, LiU.

13 *Joint Renewable Generation Maximization and Network Reconfiguration for Power Distribution Systems*, Associate professor Kin Cheong Sou, National Sun Yat-sen University, Taiwan.

17 Master's Thesis Presentation: *Modelling of a Heat Conduction Calorimeter Used in Cement Plant Automation*, Hassan Alzeidi.

28 Licentiate seminar: Learning-Based Controller Design with Application to a Chiller Process, Christian Rosdahl, Dept. of Automatic Control, LTH. Reviewer: Professor John Bagterp Jørgensen, DTU, Denmark.

November

17 *Computational challenges in ancient genomics*, Doctor Nikolay Oskolkov, NBIS SciLifeLab and Lund University.

18 Defence of Doctoral Dissertation: *Dynamical Modeling of Cloud Applications for Runtime Performance Management*, Johan Ruuskanen, Dept. of Automatic Control, LTH. Opponent: Reader Giuliano Casale, Imperial College London, UK.

24 *Closed-loop control of anesthesia: a help for the anesthesiologists*, Professor Antonio Visioli, University of Brescia, Italy.

25 Defence of Doctoral Dissertation: *Fixed Point Iterations for Finite Sum Monotone Inclusions*, Martin Morin, Dept. of Automatic Control, LTH. Opponent: Associate Professor Mathias Staudigl, Maastricht University.

December

14 Licentiate seminar: *On Control and Estimation of Large and Uncertain Systems*, Olle Kjellqvist, Dept. of Automatic Control, LTH. Reviewer: Anders Helmersson, Beyond Gravity AB, LiU.

14 *Congruence methods for controller synthesis*,Professor Anders Helmersson, LiU.

15 Defence of Doctoral Dissertation: *Efficient and Flexible First-Order Optimization Algorithms*, Hamed Sadeghi, Dept. of Automatic Control LTH. Opponent: Professor Dirk Lorenz, TU Braunschweig.

16 Defence of Doctoral Dissertation: *Control-Theoretical Perspective on Feedback-Based Systems Testing*, Claudio Mandrioli, Dept. of Automatic Control, LTH. Opponent: Professor Pierre-Loïc Garoche, Ecole Nationale de l'Aviation Civile.
16 Master's Thesis Presentation: *Automatic testing of optical sight adjustment screws by a robotic arm*, Jonas Gabrielsson, LTH.
16 Master's Thesis Presentation: *Asymmetric Bregman Forward-Backward Splitting with Projection Correction*, Max Nilsson, LTH.
16 Master's Thesis Presentation: *Anomaly detection on a hybrid kinematic machine*, Henrik Paldán, LTH.
21 *Experiences from CommaAI, a self-driving tech startup in San Diego*, Lukas Petersson.
22 Engineering training presentation; Albin Olsson.

External Contacts

External contacts of importance to our projects, both academic and industrial

Together with external contacts and partners the goal is to solve real control problems. A mix of fundamental and applied work constitutes a cornerstone of our activities. In these kinds of projects the problems are approached with an open mind. One motivator is to solve real-world problems, another is to learn about new problems that can inspire theoretical research. An important role for universities is to organise knowledge in such a way that it can easily be digested by engineers in industry. One way is through the newly started the Automatic Control Industry Club another is through a new webpage created this year called External engagement.

INDUSTRY CLUB

The Automatic Control Industry Club, stands for Exploring, Expanding and Applying Control Technology.

The Industry Club is an initiative to build an ecosystem around the Department of Automatic Control at Lund University. We have created this as a way to share ideas and get feedback on the research we do. We want to reach out to the industry and other organizations to collaborate on new projects and initiate new research questions. The interface of the Industry Club will be a recurring newsletter, a webpage, and online and live events.

In the newsletters we will present interesting new developments at our department, report about advances in the field of automatic control, as well as opportunities for collaborations.

We have many collaboration activities with external partners. A common form is through master's thesis projects where we interact with both small start-ups and large companies and organizations. We also have a set of larger projects, often including industrial PhD students, with companies like SAAB, Axis Communications, Ericsson and Boliden, where we work together on more long-term challenges. Other types or organisations that we interact with are the European Space Agency and Region Skåne. We work closely with our spin-off companies, e.g., Modelon and Cognibotics, to bring research results to the market. Through our participation in large Swedish industry-academic research programs, such as the strategic research environment ELLIIT and the Wallenberg-funded WASP organization, we work closely with other leading Swedish universities.

These collaborations give us and our partners great opportunities for technology transfer, both from theory to applications, as well as between different application domains.

In late 2021, the Industry Club released its first newsletter and in March 2022 had its first event, where we opened up for round table discussions and networking with the aim to find future collaborations.

WEBPAGE FOR EXTERNAL ENGAGEMENT

The webpage is highlighting various forms of collaboration activities that the department is involved in. The activities all have societal impact and they are very diverse in their nature, including for example books aimed to the general public, continuous and commissioned education, engagement in external organizations, visits and outreach activities, innovation activities, and societal impact stories linked to the sustainable development goals.

The list below contains a number of collaborations in 2022 with academia and industry. It might be incomplete, and we ask for forgiveness if your organization is missing.

Lund / Academia
Lund University, AI Lund
Lund University, Dept of Architecture
Lund University, Dept of Computer Science
Lund University, Dept of Mathematics
Lund University, Dept of Electrical and Information Technology
Lund University, Division of Thoracic Surgery
Skåne University Hospital, Medical Services

Lund / Industry & Society
Axis Communications AB
Carrier
Cognibotics
Ericsson, Lund
Igelösa Life Science AB
Innovation Skåne
JuliaHub
Max IV
SUS Vävnadsbanken

Sweden / Academia
Blekinge Institute of Technology
Chalmers University of Technology
Halmstad University
KTH - Royal Institute of Technology
Linköping University
Luleå University of Technology
Umeå University
Uppsala University, Dept of Pharmacy
Örebro University

Sweden / Industry & Society
ABB
ABB Corporate Research, Västerås
ABB Automation, Malmö
Assa Abloy, Landskrona
Blue Institute
Boliden
BorgWarner, Landskrona
Gustaf Fagerberg AB
IUC Syd/IUC Lab - Industriellt utvecklingscentrum Syd
Prod2030
RISE

SAAB
Saab Kockums
Scania, Södertälje
Schneider Electric
SEK/IEC
SESAM-Sverige
SIS
SWEP International AB

Nordic countries / Academia
Aalborg University, Denmark
Aalto University, Finland
DTU - Technical University of Denmark
Jyväskylä University, Finland.
NordForsk - Nordic University of Hubs
NTNU - Norwegian University of Science and Technology, Dept of Engineering Cybernetics

Europe / Academia
Chernihiv Polytechnic National University, The Department of
Electronics, Automation, Robotics and Mechatronics, Ukraine
HAW Hamburg, Germany
Politecnico di Milano, Italy
Politecnico di Torino, Italy
Saarland University, Germany
TU Delft, Netherlands
UNED, Spain
Universidad de Almeria, Spain
University of Brescia, Dept Mechanical and Industrial Engineering, Italy
University of Ghent, Dept of Electromechanical, Systems and Metal Engineering, Belgium
University of Luxemburg
University of Rome Tor Vergata, Rome, Italy
University Science and Technology, Spain

Europe / Industry & Society
CNRS - Laboratories LAPLACE and LAAS, Toulouse, France
ESA, Portugal
euRobotics
Institut Roche, France
SmartFactory, DFKI, Kaiserslautern, Germany
State Scientific Research Institute of Armament and Military Equipment
Testing and Certification, Cherkasy (Chernihiv), Ukraine

World / Academia

California Institute of Technology - Caltech, USA.
IEC
IE University
ISO
Massachusetts Institute of Technology, USA
University of British Columbia (UBC), Dept Electrical and Computer Engineering, Vancouver, Canada
University of California, Berkeley, USA
World Bank
Zheijang University, Control Science and Engineering, Hangzhou, China

World / Industry & Society

Mitsubishi Electric Research Laboratories - MERL, Boston, USA

Economy

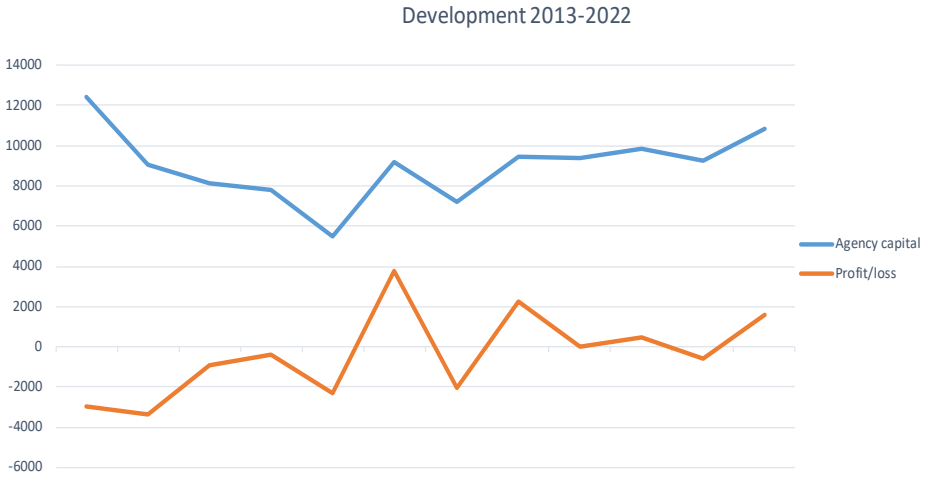
This chapter contains an overall view of the economy and funding

ECONOMY

The turnover for 2022 was 67,1 MSEK, an increase of 4,3 MSEK compared to 2021. About half of the income comes from Lund University and the remaining half from external grants. We made a profit of 1,6MSEK and have an Agency capital of 10,8 MSEK.

The activities and the number of employees are now in a growing phase since last year. The number of employees is currently 56 persons including part-time positions (51 full-time equivalents). Substantial support of our activities have been provided by the European Union Horizon 2020 programme, the Swedish Foundation for Strategic Research (SSF), Swedish Research Council (VR), Knut and Alice Wallenberg Foundation (KAW) and Swedish Government Agency for Innovation Systems (Vinnova). ELLIIT has grown and we have been successful in receiving funding for both new PhD and Postdoc positions.

The block grants from VR, KAW and ELLIIT are long range. Several projects do, however, have shorter duration such as three years or less. To match these with the length of a PhD position, normally for 5 years, we have a long-term internal research planning, and we are careful to bid on projects that fit into our research plan. This has proven efficient to match short-term funding, research planning and personnel.



Above: Profit/loss and agency capital development over the last 10 years

FUNDING

During 2022 we had the following external grants:

VR – Event-Based Control and Estimation with Application to Server Systems
VR – Fundamental mechanisms for scalable control of large networks
VR – A Framework for MPC Stability Analysis
Vinnova – Innovative Agile Construction for Globally Improved Sustainability (ACon4.0)
Vinnova – Forum for Standardisation in Digitalisation of Production
Vinnova – SelectiCa (cofunding EU Horizon 2020)
SSF – Societal-Scale Cyber-Physical Transport Systems
SSF – Semantic Mapping and Visual Navigation for Smart Robots
EU Horizon 2020 – Scalable Control of Interconnected Systems - an ERC project
EU Horizon 2020 – Admorph Towards Adaptively Morphing Embedded Systems
KAW – Wallenberg AI, Autonomous Systems and Software Program (WASP)
KAW – Support of ukrainian scientists
ELLIIT – Scalable Data Processing in Networked Systems
ELLIIT – Autonomous Radiation Mapping and Isotope Composition Identification by Mobile Gamma Spectroscop
ELLIIT – Efficient and Reliable Training of Generative Adversarial Networks
ELLIIT – Robust and Secure Control over the Cloud
ELLIIT – Autonomous Force-Aware Swift Motion Control
ELLIIT – Scalable Optimization for Learning in Control
ELLIIT – Visual Feature Based Data Reduction
ELLIIT – Dynamics of complex socio-technological network systems
ELLIIT – Recruitment of an Associate Professor in Robtics
ELLIIT – Infrastructure Robotics
ELLIIT – Optimal estimation and control at scale
ELLIIT – Visual analytics of large and complex multilayer technological networks
ELLIIT – Integrated reactive motion planning and motion control
NordForsk – Nordic University Hub on Industrial Internet of Things (HI2OT)
ESA – Artificial intelligence techniques for GNC design, implementation and verification - AI4GNC
IFAC Activity Fund

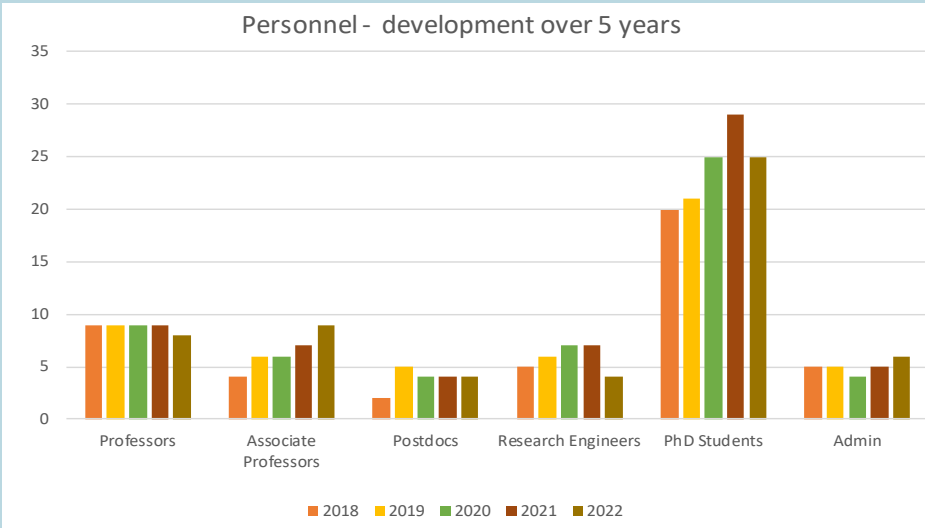
Our major sources of funding for the research are currently;

- Lund University faculty funding
- EU - Horizon 2020
- VR – Swedish Research Council
- SSF – Swedish Foundation for Strategic Research
- Vinnova – Swedish Government Agency for Innovation Systems
- KAW – Knut and Alice Wallenberg Foundation
- ELLIIT – Swedish gouvernment funding

Personnel

In this chapter the personnel and their activities are described

Kick off at Arild vineyard, August 2022



Professors
Årzén, Karl-Erik; deputy head of department
Åström, Karl Johan; senior professor (20%)
Bauer, Margret; Lise Meitner professor (20%)
Bernhardsson, Bo
Eker, Johan; adjunct professor (20%)
Johnsson, Charlotta
Rantzer, Anders; head of department
Robertsson, Anders

Professor Emeritus
Hagander, Per
Hägglund, Tore (from Aug)
Johansson, Rolf
Wittenmark, Björn

Associate Professors
Cervin, Anton
Como, Giacomo (25%)
Giselsson, Pontus; director of graduate studies
Karayannidis, Yiannis
Maggio, Martina (20%)
Olofsson, Björn (70%), director of undergraduate studies
Pates, Richard
Soltesz, Kristian
Tegling, Emma

Research engineers
Andersson, Leif (until June)
Blomdell, Anders
Nilsson, Anders
Pisarevskiy, Alexander

Administrators
Edelborg, Cecilia
Nishimura, Mika
Rasmusson, Monika (70%)
Westin, Eva

Project assistants
Tetov Johansson, Anton
Zilic, Tihomir

Postdocs
Govaert, Alain
Renganathan, Venkatraman
Sundell, Jesper (from April)
Wu, Dongjun (from May)

Researchers
Banert, Sebastian
Godoy, Boris
Voitenko, Volodymyr

PhD students
Adlercreutz, Julia (from August)
Agner, Felix
Bakovic, Luka (from May)
Berner, Tommi (until January)
Bencherki, Fethi
Gemborn Nilsson, Martin
Grönqvist, Johan
Guberina, Marko (from September)
Gurpegui Ramón, Alba (from August)
Hansson, Jonas
Heimerson, Albin
Heskebeck, Frida
Heyden, Martin (until January)
Jia, Zheng
Jouini, Taouba (until January)
Kjellqvist. Olle
Laban, Lara (LU School of Aviation)
Lindberg, Johan
Mandrioli, Claudio (until December)
Morin, Martin (until December)
Nyberg Carlsson, Max
Ohlin, David
Pigot, Henry
Rosdahl, Christian (until October)
Ruuskanen, Johan (until December)
Sadeghi, Hamed (until December)
Salt Ducaju, Julian
Upadhyaya, Manu
Vladu, Emil
Vreman, Nils
Wahlquist, Ylva

Industrial PhD students
Martins, Alexandre; Axis (until June)
Norlund, Frida; Boliden (from September)
Tufvesson, Pex; Ericsson
Wingqvist, Birgitta; Saab Kockums

LONG-TERM VISITORS

Chaffey, Tom, University of Cambridge, UK, August-September.
Cuiral-Zueco, Ignacio; University of Zaragoza, Spain, September-November.
Derksen, Harmen, MSc student, TU Eindhoven, The Netherlands, February-April.
Gosda, Joshua, MSc student, Technical University of Munich, Germany, February-July
García Mañas, Francisco, University of Almería, Spain, September-November.
Hoyo, Ángeles, University of Almería, Spain, September-Novembe.
Mañas Alvarez, Francisco José, UNED, Spain, September-November.
Monguzzi, Andrea, Politecnico di Milano, Italy, from October.
Resce, Akos, Ericsson Research and Eötvös Loránd University, Hungary, April-June.
Schwenkel, Lukas, University of Stuttgart, Germany, April-July.
Sileo, Monica, Universitá degli Studi della Basicila, Italy, September-December.
Wengel Mogensen, Søren, Copenhagen University, postdoc.

BOARD OF THE DEPARTMENT

Anders Rantzer
Karl-Erik Årzén
Charlotta Johnsson
Kristian Soltesz
Pontus Giselsson
Monika Rasmusson
Johan Lindberg

Deputy members
Björn Olofsson
Richard Pates
Sebastian Banert
Mika Nishimura
David Ohlin

ACTIVITIES OF PERSONNEL

Agner, Felix
MSc Engineering Physics, LTH, 2019. PhD student since January 2020.

His research interests are Scalable control for energy systems under Anders Rantzer's ERC funded project in scalable control, focusing on district heating systems. The focus is to create control coordination strategies between agents such as buildings that increase system-level benefits while being minimally intrusive in terms of communication and additional measurements.

In spring he has been in charge of a lab under the new *Learning Based Control* course, as well as supervised an MSc project together with Carrier. In fall he supervised projects in our project course as well as supervising some of the basic course labs. The research output of the year is a publication in Smart Energy, a poster presentation at the Swedish Automatic Control meeting, as well as a preprint which has been submitted to IFAC 2023. In addition, Felix spent two months of 2022 in Toulouse for a research collaboration with CNRS.

Adlercreutz, Julia
MSc in Engineering Physics 2022 at LTH. PhD student since August 2022.

Her main research area is structured optimal control, with the power grid as the main area of application. She is supervised by Richard Pates and is funded by ELLIIT.

During the fall she has been a teaching assistant in the *Automatic Control, Basic Course*.

Andersson, Leif
MSc, Research Engineer since 1970.

He retired formally in 2012, but was immediately rehired on 30%.

A large part of his time the past year has been spent as an internal LaTeX consultant.

In June 2022, he retired for the second and last time.

Årzén, Karl-Erik
Professor (2000), PhD (1987), joined the department in 1981.

His research interests are real-time and embedded control, real-time systems, cloud control, feedback computing, autonomous systems, and programming languages for control.

Coordinator for the Lund part of WASP (Wallenberg AI, Autonomous Systems and Software Program). WASP co-director for research program coordination. Chair of the Research Management Group of WASP. Member of the WASP Executive Committee.

During the year he has primarily been involved with WASP and the Nordforsk University Network HI2OT.

He is partly or fully involved in the supervision of three PhD students.

Åström, Karl Johan
Professor in Automatic Control since 1965 and founder of the department, retired as Senior Professor and become emeritus in January 2023.

Bakovic, Luka
MSc in Automatic Control, received in 2021 from the University of Zagreb. Doctoral student at the department since 2022.

Involved in research on socio-technical systems, which mostly has to do with dynamics of information exchange over networks. Generally interested in graph theory, dynamical systems on graphs and their connection with social phenomena.

Banert, Sebastian
Sebastian obtained his diploma and PhD degrees in mathematics from Chemnitz University of Technology in 2012 and University of Vienna in 2017, respectively. After a postdoc position at KTH, he joined the department in September 2019.

His research interests are algorithms for convex and large-scale optimisation and monotone inclusions in connection with deep learning and inverse problems. He is working in a VR project of Pontus Giselsson and co-supervises his PhD students.

Bauer, Margret
Margret received her undergraduate degree in electrical engineering from the University of Erlangen-Nuremberg in 2001. She is professor at Hamburg University of Applied Sciences in Germany, and is one of few women in automatic control.

In 2021 she was nominated for the Lise Meitner Professorship at the Department of Automatic Control at LTH, and is now working part-time in Lund.

Her research interest is on data analytics and big data for process control.

Bencherki, Fethi
BSc in Electrical and Electronic Engineering from the Institute of Electrical & Electronic Engineering (IGEE), Boumerdes, Algeria in 2015. MSc in control systems in 2020 from Eskisehir Technical University, Turkey. PhD student at the department since Aug 2020, Supervised by Anders Rantzer and Emma Tegling.

Fethi is within the NEST-WASP project and his research interest revolves around developing scalable control approaches for large scale networks. He is also interested in learning-based control and the identification of switched systems. Teaching Assignments for 2022 included the *Basic course* and *nonlinear control and servo systems*.

Bernhardsson, Bo
PhD 1992, Professor since 1999, has also worked at Ericsson 2001-2010 as an Expert in Mobile System Design and Optimization. Since 2020 he is one of the Master Programme Directors for the new international masters program in *Machine Learning, Systems and Control*.

During 2022 he taught the course *Modeling and Learning from Data* for about 70 students and together with Patric Jensfelt at KTH and

Gustaf Hendeby at LiU he also held the WASP PhD course in *Autonomous Systems* for about 40 students from 6 universities.

During May 2022 he was part of the organizing team for the first ELLIIT focus period on *Data-driven modelling and learning for cancer immunotherapy*, where he also, together with Professors Magnus Fontes and Gérard Besson, helped to give a short-course in *Statistical Learning and Visualisation*.

Bo's main current research interest is in statistical learning and control with applications on EEG signals and BCI systems.

He is the main supervisor of 3 PhD students within this area and co-supervisor of 5 PhD students.

Blomdell, Anders

Research Engineer at the department since 1988.

Responsible for the department network and lab computers for teaching and research. Started to catch up on all stuff that was neglected due to all extra work induced by the M-house rebuilding.

Cervin, Anton

Docent (2008), PhD (2003), MSc (1998). Anton joined the department in 1998 and has been employed as an Associate Professor since 2007.

His research interests include event-based and networked control, real-time systems, cloud control, and computer tools for analysis and simulation of controller timing.

During 2022 he was the main supervisor of two PhD students and co-supervisor of a further three doctoral students. He was responsible for the second-cycle courses *Project in Systems, Control and Learning* and *Automatic Control, Advanced Course*, and he was also supervisor or examiner of six master's theses. Furthermore, Anton co-led a doctoral-level study circle on real-time operating system. His administrative tasks included being deputy head and director of studies for the first- and second-cycle education at the department.

Como, Giacomo

PhD (2008), Docent (2012). He has been with the faculty at the Department of Automatic Control since 2011 and was promoted Associate Professor (universitetslektor) in 2013.

His research interests are in Dynamics, Information, and Control in Networks, with applications to transport, infrastructure, as well as social and economic systems.

During 2022, he has served as supervisor of Laura Arditti, Leonardo Cianfanelli, Martina Vanelli, Stephane Durand, and Mark Jeeninga, and co-supervisor of Luca Damonte, Leonardo Massai, Martina Alutto, and Roberta Raineri at Politecnico di Torino.

In Spring 2022, he taught the master level course *Network Dynamics* at Lund University.

During 2022, he has partly been on leave at Politecnico di Torino.

Edelborg, Cecilia

Cecilia is a Financial Administrator at the department since 2017.

She is responsible for accounting for travel expenses, intermittent employments, reimbursements, invoices and projects.

She is also CPR and Fire protection trained, and a member of the Equality group at the department and LTH JäLM group to work with these questions. In addition, she provides some responsibility with regards to human resources issues.

Her background is from the Faculty of Law at Lund University.

Eker, Johan

Johan is adjunct Professor and Principal Researcher at Ericsson Research, Sweden. He received his PhD in Automatic Control from Lund University in 1999 and subsequently joined the Ptolemy group at UC Berkeley. He was appointed adjunct Professor in Automatic Control at Lund University in 2013. He will start a position as full professor with focus on real-time control systems in the spring of 2023.

His research interests includes programming language design for parallel systems, real-time control systems, data-driven operation and cloud computing technologies. He is the co-designer of the CAL Actor Language, which is part of the MPEG standard ISO/IEC 23001-4:2011. He holds over 70 granted patents in the areas of telecom, IoT and cloud computing. He is involved in the operation of the Ericsson Research Data Center and works with industrial cloud applications and data-driven systems.

He is participating in a range of program committees and research projects on topics such as real-systems, signal processing, software development, cloud technology, brain-computer interfaces, and AI.

Johan is the main supervisor for Albin Heimerson and co-supervisor for Pex Tufvesson, Frida Norlund, and Max Nyberg Carlsson.

During 2022 he has been the master's thesis supervisor to Andreas Timürtas, Felicia Segui *Public Transport Passenger Experience Estimation using Deep Learning*, to Johan Siwerson, Samuel Gunnarsson *Adaptive server control for low-latency applications over the cellular network* and to Albin Olsson, David Nilsson *Anomaly detection using machine learning*.

Gemborn Nilsson, Martin
MSc in Electrical Engineering 2020. PhD student at the department since January 2021.

Supervised by Bo Bernhardsson and funded by ELLIIT, Martin's research project is about representation and visualization of EEG signals for improved efficiency of Brain-Computer Interfaces.

During the year, Martin has been a TA in the following courses: *Modeling and Learning from data*, and *Project in Systems, Control and Learning*.

Giselsson, Pontus
Pontus is currently an Associate Professor at the Department of Automatic Control. He received his MSc from Lund University in 2006, his PhD from the Department of Automatic Control at Lund University in 2012, and became Reader (Docent) in 2018.

His research interests are in optimization and its wide range of applications.

During 2022, Pontus was responsible for the undergraduate level courses in *Optimization for Learning*, *Systems Engineering*, and *Process Control*. He supervised four PhD students and one postdocs and is director of doctoral studies at the Department of Automatic Control.

Godoy, Boris
PhD, 2008, School of Electrical Engineering, The University of Newcastle, Australia. Since then, he has held several academic and industry positions in Australia, USA, and Sweden. He joined the Department of Automatic Control at Lund University in November 2021.

His main research interests are in system identification, signal processing, and process control.

In October, he visited KTH, Stockholm, where he discussed research ideas with Prof. Cristian Rojas.

Govaert, Alain
Alain received his PhD degree in 2020 from the University of Groningen. Since 2021 he is a postdoc at the department of automatic control at Lund University.

He is involved in research projects on Dynamics of Complex Socio-Technological Network Systems and Population Games on Dynamic Networks. His research interests include modelling and control of large-scale decision-making processes and dynamical systems on networks and dynamic random graphs.

Grönqvist, Johan
PhD (Physics), 2010, LTH and doctoral student, at the department since 2019.

His general control interest are Learning, and Robustness. He is trying to obtain Guaranteed Stability with Neural Networks.

He is participation in the project AI for Guidance, Navigation and Control (AI4GNC), funded by ESA, collaborators in Portugal.

He has been supervising Tatiana Orlova and Vilius Koegst, working with Carrier, identifing faults in Chillers from data - a Master Thesis project.

Guberina, Marko
BSc in Computing 2020 at the University of Zagreb, Croatia. MSc in Physics Engineering (Complex adaptive systems) 2022 at Chalmers. PhD student at the department since September 2022.

Supervised by Yiannis Karayiannidis and funded by ELLIIT. His research topic is control of robotic hand-arm coordination.

He was TA on the *Applied robotics* course and the *Basic* course.

For the RoboticsWeek he made a robotic handover demo (a robotic arm picked up candy from the table and handed it over to the kids).

In December he became a WASP-affiliated PhD student.

Hägglund, Tore
Professor, PhD (1984). Has been at the department since 1978 except for four years when he worked for ABB. Tore Hägglund is professor emeritus since August 2022.

Main research interests include process control, PID control, decentralized control, and monitoring and diagnosis.

Main research activities during the year have been feedforward control, and control loop decoupling. The research projects are presented on his personal web page at www.control.lth.se/personnel/.

Hansson, Jonas
MSc in Engineering Physics, LTH, 2020. PhD student since August 2020.

Jonas' main interest pertain to the fundamental limitations in the Control of large-scale and networked systems, which is lead by Emma Tegling with WASP funding. In particular he has investigated how heterogeneity impacts the spread of infectious diseases and methods for describing the transient behaviour of network dynamical systems. He has a special interest in multi-agent systems and the scalable control thereof.

He has been teaching assistant in the *Network Dynamics* course as well as the *Advanced Control* course.

Starting from December 2022 he is the leader of the WASP Cluster Complex Systems.

Throughout the year he has also been responsible for Seminar Announcements at the department.

Heimerson, Albin
MSc in Engineering Physics, LTH, 2018. PhD student since August 2018.

Albins research interests are towards ML/RL, looking at when they can be beneficial compared to classical control. He is also interested in techniques to improve existing models by learning only the missing dynamics.

He has been a teaching assistant in the *Real-Time Systems* course, the *Introduction to Machine Learning, Systems and Control* course for the Masters program as well as the *Basic course* in Automatic Control.

Heskebeck, Frida
MSc in Biotechnology 2019, Lund University, Since August 2019 a PhD student, working with Brain-Computer Interfaces (BCI).

Jia, Zheng
Zheng received the bachelor's degree in electronic engineering from The Hong Kong Polytechnic University in 2013 with first-class honors, and the master's degree in robotics, systems, and control from ETH Zurich in 2017. Zheng started as a PhD student in September 2021 and has been a WASP affiliated PhD student since November 2021.

Zheng has been a teaching assistant in the courses: *Applied Robotics*, *Project in Automatic Control* and *Mathematical Modeling*.

Zheng's research interests include force control, motion control and robotics. During the past year, Zheng has been active in the research project that combines Impedance Control and Model-Predictive Control for force-aware path following problems.

Johansson, Rolf
Professor, MD (1986), PhD (1983). Active at the department since 1979. In August 2021 he retired but is still supervising PhD students and engaged on part-time at the department.

Rolf Johansson's research interests are in system identification, robotics and nonlinear systems and automotive control.

Johnsson, Charlotta
Professor (2018), PhD (1999). Dean of Campus Helsingborg, Lund University (2021-) and Director of X-Lab, LTH (2020-).

Charlotta's main research interest covers Automation, Control and Operations. However, Charlotta is also involved in the research domains of Innovation and Entrepreneurship, Teaching and Learning in Higher Education, as well as Technology Management and Engineering Leadership.

She is the Chair of ISO TC184/SC5, hence actively working on standardisation activities for Smart Manufacturing and Industry 4.0. She is also the director for the makerspace X-Lab at LTH, an open innovation space for both students and colleagues at LTH.

During the year 2022, Charlotta has been a guest lecture in the course *Automation in Complex Systems* (given by the Department of Biomedical Engineering). Charlotta has also been involved in the PhD-courses *Research Methodology, Ethics and Innovation* and *Innovation and Value Creation in Research*. Charlotta has also given invited seminars to industry focusing on Industry 4.0/Smart Manufacturing.

Karayannidis, Yiannis
He received a Diploma in Electrical and Computer Eng. and a Ph.D. degree in Electrical Eng. from Aristotle University of Thessaloniki, Greece, in 2004 and 2009, respectively and became Reader (Docent) at Chalmers University of Technology in 2017. He was affiliated with KTH, Royal Institute of Technology (2011-2020) and Chalmers University of Technology(2015-2022). Associate Professor at the Department of Automatic Control in August 2022.

His research interests lie in the intersection of robotics and control systems currently focusing on force-based robot control and perception, manipulation of deformable objects, contact modeling for manipulation and dynamic trajectory generation for robotic systems.

During 2022, Yiannis was responsible for the undergraduate level course in Nonlinear Control and Servo Systems. He supervised two master projects and one Phd student at the Department of Automatic Control. He has also supervised four International PhD students, three of them were hosted at the Department of Automatic Control. He is also the main supervisor of three PhD students affiliated with Chalmers University of Technology.

Kjellqvist, Olle
Olle is a Ph.D student at the department since fall 2019. He got his M.Sc in engineering physics in 2018 at Lund University, and successfully defended his Licentiate thesis *on control and estimation of large and uncertain systems* this winter.

During the spring semester, he continued his research visit at California Institute of Technology where he was visiting professors Richard Murray and John Doyle working on robustness analysis, system level synthesis and learning optimal team decisions.

During the fall semester, he conducted lab sessions, exercises and seminars for the undergraduate students taking the *basic control course* and was lab responsible the the master's level course *Modeling and Learning from Data*.

Laban, Lara
MSc in Mechanical Engineering (Automatic Control with a focus on Computer Vision), at the University of Belgrade, Serbia. PhD student at the department since April 2022. She is supervised by Rolf Johansson, Anders Robertsson and Björn Olofsson from the Department of Automatic Control, with Lund School of Aviation (LUSA) funding and co-supervision of Johan Bergström and Rikard Tyllström. This project is a collaboration between Lund University School

of Aviation and the Department of Automatic Control (UAS@LU).

Her research topic: A research platform will be developed to demonstrate autonomous flight missions in an air traffic control environment with mixed autonomous, civil and military aviation under supervision of air traffic control (ATC). The research will focus on different aspects of autonomous flight, e.g., planning and control.

She is co-supervising a Master Thesis project by Anton Hässler. She made a UAV/drone demo for the Robotics Week using the DJI Matrice 100.

Since January 2023 she is a WASP-affiliated PhD student.

Lindberg, Johan

Johan has a MSc in engineering Physics (2020) and started as a PhD student at the department in September 2020.

His supervisor is Richard Pates and he works with scalable, decentralized control.

Johan's research interests are towards how decentralized control can be used in the electrical power grid. Especially how to keep it in balance when more power production comes from renewables, that are less predictable than traditional power production, and where the power is injected to the power grid through power electronics, instead of traditional synchronous machines.

During 2022 Johan was a teaching assistant in the bachelor course *Automatic Control, Basic Course* and in the master course *Automatic Control, Advanced Course*.

Maggio, Martina

PhD, 2012, Politecnico di Milano and is now Associate Professor. She is full-time professor at Saarland University, therefore on part-time leave from the department of Automatic Control.

Her research interests: Real-Time Control Systems. Martina has mainly two research interests. The first one has been the design of controllers for computing systems. Many components of a computing system can be designed as controllers: memory allocators, schedulers, and similar components. This is true also for distributed infrastructures like cloud computing facilities. The second research interest concerns the implementation of control systems and their real-time properties. In that respect, she has been working on what happens when a controller designed with given proven characteristics is implemented and runs in a real computing environment, where unpredictable workloads can lead to missing computational deadlines. She is supervising two PhDs; Claudio Mandrioli and Nils Vreman. She has also supervised many masters thesis at Saarland University.

Mandrioli, Claudio

Claudio has been PhD student at the Automatic Control department from 2018 to 2022.

He successfully defended his thesis titled *Control Perspective on the Testing of Feedback-Based Systems* on the 16th of December. The thesis leverages control theory to enhance the engineering process of testing Self-Adaptive Systems as well as Cyber-Physical Systems.

In 2022 he has been awarded the Frank Anger Memorial award that fosters interdisciplinary research across Embedded Systems and Software Engineering.

Between 2021 and 2022 he has been visiting for 6 months at the Software Verification and Validation Lab headed by Lionel Briand at the University of Luxembourg. In 2023 he will be starting as post-doc at the Software Verification and Validation Lab.

In 2022 Claudio has been involved in the supervision of the *Real-Time Systems projects* and in the teaching of the *Advanced Control course*..

Morin, Martin

MSc in Engineering Physics 2017, Lund University. PhD student at the department since 2017.

Research interests are within large scale optimization and monotone inclusion with previous work focusing on variance reduced stochastic first order methods.

Current research revolve around modeling of general algorithms for solving monotone inclusions with the aim of deriving sufficient

conditions for their convergence and examining their properties.

He defended his thesis, titled *Fixed Point Iterations for Finite Sum Monotone Inclusions*, in November.

Nilsson, Anders
PhD (2006), Research Engineer since 2010.

Spends most of the time looking after the department computers and their software. He also spends some time maintaining and developing the robotics lab.

Nishimura, Mika
Born in Japan. Administrator at the department since January 2014.

She handles Ladok (student administration system) for both students and PhD students. She has contact with the printing office about publications, and is responsible for purchase of office supplies, books and handles Lucat-catalogue system for the employees at the department. In addition, she reviews Lucris-research portal, updates LUP-student paper and parts of the web pages as well as other service-oriented tasks.

Norlund, Frida
Frida obtained her MSc in engineering physics from Lund University, 2022. Since September 2022 she is an industrial PhD student at the department.

She is employed by Boliden AB and her research interests are within data driven modeling of the flotation process.

Nyberg Carlsson, Max
MSc in Engineering Physics (2021) at LTH. PhD student since August 2021 as a part of an ELLIIT funded project. WASP affiliated as a part of class 2022.

Research interests include real-time systems and how the "infinite" resources from cloud computing can be exploited in a robust way.

Partook in creating a Julia port of the JitterTime toolbox.

Teaching duties during 2022 were *Real-Time Systems* in the spring and *Project in Automatic Control* in the fall.

Ohlin, David
MSc Engineering Physics (2021), LTH. PhD student since 2021, supervised by Emma Tegling. Part of the WASP NEST project Learning in Networks: Structure, Dynamics, and Control.

Current research focuses on data-driven methods for control and identification of large-scale networks. Interests also include network models of opinion dynamics.

Teaching responsibilities during 2022 included teaching assistance and course development of *Learning-Based Control*, as well as teaching assistance in the course *Network Dynamics*.

Olofsson, Björn
He obtained the M.Sc. in Engineering Physics in 2010 and the Ph.D. in Automatic Control in 2015, both from Lund University, and was appointed Docent at Linköping University in 2020. He has been with the department since 2010. He is since May 2022 a Senior Lecturer and since November 2022 Director of Undergraduate Studies.

He has broad research interests in autonomous motion planning and control for robots and vehicles. During the year, he has been involved in research projects within the ELLIIT Strategic Research Area, the Wallenberg AI, Autonomous Systems and Software Program, and a collaboration project with the School of Aviation at Lund University.

He has also taken active part in the teaching activities at the department. He was responsible for the course *Applied Robotics* during the fall semester. He was also acting as supervisor of several Master's Theses during the year. He is the co-supervisor of five PhD students at the department. He is in addition co-supervisor of one PhD student at Department Computer Science and two PhD students at the Division of Vehicular Systems, Linköping University.

Pates, Richard
Richard obtained the M.Eng degree in 2009 and PhD degree in 2014, both from the University of Cambridge. He is currently an Associate Professor at the Department of Automatic Control.

His research focus is on control system design for electrical power systems and autonomous vehicles. The vision is to build a modular theory of control system design that can be used to address the requirements of future large-scale interconnected systems.

Pigot, Henry
Henry (Harry) joined the department as a Project Assistant in 2018 and became a PhD student in 2019. He has an electrical engineering degree from the University of British Columbia in Vancouver, with a specialization in biomedical applications.

Harry's main interest is medical technology development. The focus of his thesis is applying control theory to improve the safety and efficacy of devices for evaluating heart organ function outside of the body. He works together with Kristian Soltesz, Ylva Wahlquist, and researchers at Igelösa Life Science AB.

In 2022, Harry published results from a preclinical evaluation of a heart evaluation system prototype, and began assembling and testing a new type of cardiac afterload designed to provide tighter control of organ evaluation for improved organ safety. The system aims to increase the supply of heart organs for transplant surgery. He also helped develop and teach a new iteration of the *Physiological Modelling and Control* course. At X-lab, LTH's co-creation and innovation space, Harry continues as a member of the leadership group, taking responsibility for student engagement by coordinating a group of student volunteers and organizing workshops.

Pisarevskiy, Alexander
DipEng in Optoelectronics (2009). Research Engineer since 2020.

Mainly participates in upgrading of lab equipment for education processes.

During 2022 he was also involved in tasks, dedicated to modernization of Jokab safety system for the RobotLab, application of Soft grippers in existing robotic systems and several master thesis projects.

Rantzer, Anders
Professor of Automatic Control since 1999 and head of department.

Anders is the main supervisor for several PhD students and postdocs. During 2022, he also developed and taught a new masters level course named *Learning-based Control*".

He has broad interests in modeling, analysis and synthesis of control systems, with particular attention to uncertainty, optimization, scalability and adaptation.

Rasmusson, Monika
She joined the department in August 2011 and as from March 2017, she took over as finance officer and is now responsible for year-end closing, budget, forecast and reporting, both internallly within the faculty and externally to sponsors.

As a part of the administrative team, her work includes backup function for her colleagues, editing the yearly Activity Report, among other administrative tasks.

She is a member of the Department Board and also a member of the nomination committee.

Renganathan, Venkatraman
Venkatraman is a postdoctoral fellow at the department of automatic control at Lund University. He holds a PhD from the University of Texas, Dallas, USA.

During 2022, Venkatraman taught a PhD course on Linear systems as the sole instructor. He supervised the Masters theses of two students as the main supervisor.

He was awarded the DAAD AI-Net Fellowship during October 2022 for research visits across German universities fostering new research collaborations in artificial intelligence for cyber-physical systems.

During 2022, he had submitted and got his research papers accepted into ACC 2023, ICRA 2023, ESA-GNC & ICATT 2023, IFAC 2023 conferences so far. He is actively working on regret analysis for learning based controllers such as minimax adaptive control and other robust control algorithms. He successfully contributed to the ESAi4GNC project through his design of learning based MPC for relaunch space vehicle.

Robertsson, Anders
Professor (2012), Associate Professor (2007), "Docent" (2005), Research Associate (May 2003), PhD (1999). Excellent Teaching Practitioner (ETP) in 2007.

His main interests are in nonlinear control, robotics and control of computing systems.

He is working on UAV-control within UAS@Lund, serial and parallel kinematic robots, sensor-data integration and force control of industrial robots in collaboration with ABB Robotics/ABB CRC and Cognibotics. The research has been conducted within the Robotics Lab, ELLIIT network, and the projects Smart Systems (SSF) and within a couple of projects related to construction robotics (VINNOVA and FORMAS).

He is manager for the RobotLab@LTH and the Center for Contruction Robotics, Faculty of Engineering, Lund University.

Rosdahl, Christian
MSc in Engineering Physics 2017, Lund University and PhD student at the department since September 2017.

He is part of the Wallenberg AI, Autonomous Systems and Software Program (WASP) and works on a project with focus on efficient learning of dynamical systems.

He presented his licensiate thesis, titled *Learning-based Controller Design with Application to a Chiller Process*, in October.

Ruuskanen, Johan
Graduated from Lund University with an MSc in Engineering Mathematics 2017, and has been a PhD student at the department since September 2017.

On November 18th, Johan defended his thesis titled: *Dynamical Modeling of Cloud Applications for Runtime Performance Management*.

Johan has been a part of the WASP research program within the Autonomous Clouds and Networks cluster, and has been supervised by Anton Cervin and Karl-Erik Årzén. His research interests includes performance modeling and autonomic computing for cloud application management.

Sadeghi, Hamed
MSc (2013) in Mechanical Engineering, PhD student since August 2016.

His research interest is in Large-scale Optimization and its vast areas of application. His research is a part of Large-scale Optimization and Control cluster within WASP-AS branch.

In December he defended his thesis *Efficient and Flexible First-Order Optimization Algorithms*.

Salt Ducaju, Julian
Julian has a MSc. in Aeronautical Engineering from Universidad Politecnica de Valencia (2018) and he did his master's thesis in the University of California, Berkeley with Professor Masayoshi Tomizuka as a visiting student researcher. Since February 2019 a PhD student at the department where he is an affiliated WASP-AS student.

The main focus of his research work has been in the fields of autonomous vehicles and robotics**.**

Soltesz, Kristian
He defended his PhD in Automatic Control at Lund University in 2013, based on research conducted at University of British Columbia. Since 2019 Kristian is Reader (Docent) in Automatic Control, with research focus on medical models and control systems.

He is the main supervisor of PhD students Ylva Wahlquist and Harry Pigot and Frida Norlund, co-supervisor for PhD student Martin Gemborn-Nilsson, and mentor for postdoc Jesper Sundell.

Kristian also serves as director of the Engineering Physics program in Lund (35 %), and is working for a research company (40 %), fi-

nanced by a Swedish foundation for strategic research mobility grant.

During 2022 Kristian has coordinated the inaugural ELLIIT focus period on data-driven modelling and learning for cancer immunotherapy. He is a member of the steering group of the LTH Engineering Health focus area, and the IEEE technical committee on Healthcare and Medical Systems. Locally, he serves as a member of the department board, and holds a coordinating role between research engineers and teachers at the department.

In 2022 Kristian taught a course in physiological models and computations, for which he has written the course material. He has also been involved as supervisor or examiner in several master thesis projects.

Sundell, Jesper
He joined the department as a postdoc in April 2022 to work in the project entitled Learning pharmacometric model structures from data.

Jesper holds a PhD in quantitative pharmacology with a focus on model-based drug development, which he obtained in 2021 at Gothenburg University.

Research interests include pharmacometrics, precision medicine and machine learning.

Tegling, Emma
She received her PhD in Electrical Engineering from KTH Royal Institute of Technology, Sweden, in 2019 and her BSc and MSc degrees in Engineering Physics in 2011 and 2013 from the same institute. Emma is a senior lecturer (associate professor) with a WASP (Wallenberg AI, Autonomous Systems and Software Program) professorship. She joined the department in 2020.

Her research revolves around analysis and control of network systems. Together with her research group, she is interested in fundamental questions regarding scalability, robustness and controllability of systems defined over networks, and in applications including energy systems and social networks. Emma is one of the leaders of the WASP NEST (Novelty, Excellence, Synergies and Teams) project on Learning in Networks, which is a collaboration with KTH and Uppsala university and co-organizes the ELLIIT focus period on Network Dynamics in Linköping to take place in 2023.

Emma is course responsible for the undergraduate level *basic* course in *Automatic Control*.

At the Department of Automatic Control, she is member of the Nomination Committee.

Tetov Johansson, Anton
Master of Architecture, 2021, LTH and Master of Advanced Studies in Architecture and Digital Fabrication, 2020, ETH Zürich.

Project assistant in the project *Biomimetic fabrication through robotic 3D printing*.

Anton has also been Technical Assistant in *Applied Robotics* and at the Robotics week.

Tufvesson, Pex
Pex graduated with a MSc in Electrical Engineering in 1997 from LTH, working as a chip designer on GPUs, supercomputing, communication systems, encryption and synthesizers.

He's founded startups doing wearables and child healtcare systems. Employed by Ericsson Research, and in 2021 he started as an industrial PhD student at the Department of Automatic Control.

He is part of the research group working with EEG-based Brain-Computer Interfaces led by Professor Bo Bernhardsson. His research is about real time online classification and signal analysis.

Upadhyaya, Manu
MSc in engineering physics, 2020, Lund University; MSc in finance, 2020, Lund University and BSc in mathematics, 2015, Lund University. PhD student since July 2020.

His research interests are in continuous optimization and its applications, e.g., machine learning, control, and finance. Currently, his focus is on the performance analysis of first-order algorithms for convex optimization problems.

During the year he has been TA in courses *Optimization for Learning* and *Network Dynamics*. He has also taken part in developing the course *Optimization for Learning*.

Vladu, Emil
MSc in Engineering Physics from Lund University, 2018. PhD student at the department since August 2019.

His supervisor is Anders Rantzer and his research project mainly concerns control in large-scale dynamic networks.

During the spring of 2022, he was a TA for the course *Control Theory*. During the autumn of 2022, he was a TA for the course *Nonlinear Control and Servo Systems*, in which he was also responsible for two of the three laboratory exercises as well as compiling the exam.

Voitenko, Volodymyr
PhD in Technical Sciences, Institute of Electrodynamics at the National Academy of Science, Ukraine. Radio-engineer (MSc, honors), Leningrad Electrical Engineering Institute, USSR. PhD in Technical Sciences, Docent, Associated Professor on the Department of Electronics, Automation, Robotics and Mechatronics at the Chernihiv Polytechnic National University (Ukraine).

During spring 2022: at the Chernihiv Polytechnic National University (Chernihiv, Ukraine) he was teaching: *Digital Image Processing, Pattern Recognition and Image Processing, Displaying Systems, Microcontrollers, Microprocessor Devices for Control and Information Processing, Electronic Support Systems for Scientific Experiments* at undergraduate level.

He has supervised Maksym Solodchuk (Chernihiv Polytechnic National University, Ukraine).

Until 24.02.2022 he worked at Chernihiv Polytechnic National University, Ukraine.

Vreman, Nils
Nils obtained a MSc (2018) from Lund University. He has been pursuing a PhD degree since August 2018.

The main focus of Nils' research has been on the analysis and synthesis of real-time control systems subject to computational faults and communicational faults, in particular systems where the computational faults follow a weakly-hard model.

During 2022, his research focus has been on designing tools and methodologies for analysing and improving the performance of real-time control systems subject to weakly-hard and stochastic fault models.

Additionally, he has been teaching: *Real-time Systems* and *Automatic Control Advanced Course*.

Wahlquist, Ylva
MSc (2019) and PhD student at the Department since May 2020.

Her research interests include pharmacometric modelling and control of hemodynamic parameters for intensive care and heart transplantation.

She works together with Henry Pigot and Kristian Soltesz in collaboration with the research company Igelösa Life Science.

In the spring of 2022, Ylva received a travel grant from the Royal Physiographical Society in Lund and visited Prof. Guy Dumont's group at the University of British Columbia, Canada. She has also participated in the ELLIIT focus period on *Data-driven modelling and learning for cancer immunotherapy* that took place in Lund in May.

During the year, Ylva has been a teaching assistant for the *Physiological Models and Computation* course and the *Process Control & Systems Engineering* course.

Westin, Eva
PhD in French linguistics. Administrator at Automatic Control since 2008 and administrative manager from December 2017 for the administrators and research engineers at the department.

She handles the overall responsibility of human resources, guests and conferences. She also handles part of the process for research studies.

Eva is part of the steering group for AI Lund. She is also part of the steering group for gender and equality issues at the Faculty of Engineering and a member of the LTH Board.

Eva is the health and safety representative substitute.

Wu, Dongjun
Dongjun joined the department as a postdoc since May 2022. He got his PhD degree from Université Paris-Saclay (Automatique) and Harbin Institute of Technology (Control science and engineering).

His research interests include control and analysis of monotone systems, optimal transport and optimization. He is currently working in the project Scalable Control of Interconnected Systems.

He is in charge of the PhD course *Optimal Control* in the coming semester.

Zilic, Tihomir
He obtained PhD (2010) in Control System Theory and MSc (2003) in Mechanical engineering from the Faculty of Mechanical Engineering and Naval architecture, University of Zagreb, Croatia. He has also worked as Assistant Professor (2015 -2019) at the Department of Robotics and Production System Automation, Faculty of mechanical engineering and naval architecture, Zagreb, Croatia.

He joined the Department of Automatic Control, LTH in October 2021 first as an intern, being support to the project course in Automatic Control and to the doctoral project in global navigation satellite system. From January 2022 to January 2023, he has worked as a project assistant at the SelectiCa project between food industry and University. In this project he has worked with image analysis, image recognition, eye-to-hand calibration for positioning and control of robot manipulator.

JÄLM@REGLER - THE GENDER EQUALITY, EQUAL OPPORTUNITIES, AND DIVERSITY GROUP AT THE DEPARTMENT

We would like to introduce you to Jälm@regler, the gender equality, equal opportunities, and diversity group at our department. This group was formed in early 2014 and since then has held around 20 seminars and workshops with invited speakers, covering a variety of topics from research to ergonomics, security, and implementation. Through these seminars, gender equality and diversity have become natural talking points in our coffee breaks, which we believe is key for addressing and improving these issues.

In 2022 we have also hosted PhD days and other events to promote connection and closeness among our colleagues. Additionally, we have a delegate from our department in the JäLM working group at LTH, Cecilia Edelborg.

Richard Pates | Henry Pigot | Cecilia Edelborg | Johan Lindberg | Anton Cervin

AWARDS

IFAC Technical Committée Award

Karl Johan Åström receives the award for control education life time achievement - *for educating and inspiring generations of control engineers around the world based on his outstanding books and publications, impactful educational materials and 'industry is my laboratory' concept and for explaining control ideas to non-specialists and applying control ideas in emerging new disciplines.*

Teaching Assistant of the Year

Olle Kjellqvist awarded TA of the year by mechanical engineering students.

SIGBED-SIGSOFT Award

Frank Anger Memorial Award is a student award in the name of the late Dr. Frank Anger that promotes cross-disciplinary research between embedded systems and software engineering. In 2022 Claudio Mandrioli received this reward.

Best Student Paper Award

Congratulations to Alex Martins who won the best student paper award at 6th IFAC Symposium on Telematics Applications, TA'2022, June 15-17th, 2022 – Nancy, France.

Pedagogical price - Engineering Faculty

Tore Hägglund got the pedagogical prize from the Engineering Student Union for the year 2022.

Gratitude received from Cherihiv

In December 12, 2022 Volodymyr Voitenko received a Gratitude of the Department of Education and Science of the Chernihiv Regional State Administration. *For many years of conscientious work, fruitful scientific and technical activity, and personal contribution to the training of highly qualified specialists.*

GRANTS

Travel grant from Royal Physiographical Society

Ylva Wahlquist received a travel grant from the Royal Physiographical Society and visited Professor Guy Dumont's group at the University of British Columbia, Canada, during a two month period.

Travel grant

Julian Salt received the RAS Student Travel Grant at IEEE International Conference on Automation Science and Engineering (CASE) 2022, Mexico City, Mexico.

Travel grant

Olle Kjellqvist received a workshop/travel support from IEEE CSS at the CDC Conference in Cancun, Mexico, December 2022.

ASSIGNMENTS

BOARD MEMBER

Årzén, Karl-Erik
Chair of the Research Management Group for the Wallenberg Autonomous Systems and Software Program (WASP).
Member of the WASP Executive Committee.
Member of Research Board for the Faculty of Engineering, Lund University.
Member of the IFAC Conference Board.

Como, Giacomo
Board member of the Excellence Project of the Department of Mathematical Sciences, Politecnico di Torino.

Eker, Johan
Chairman of the advisory board member for "Internet of Things and People" research center at Malmö University.

Johnsson, Charlotta
Board member of EFL (Executive Foundation Lund), Lund, Sweden.
Board member of Innovation Skåne, Sweden.
Board member of IUC Syd (Industriellt utvecklingscentrum Syd), Malmö, Sweden.
Board member of IUC Syd Lab, Lund, Sweden.
Other Board assignments in national and international companies.

Rantzer, Anders
Member of the steering committee for the International Symposium on Mathematical Theory of Networks and Systems.
Member of Editorial Board for the journal Annual Reviews in Control.
Member of WASP research management group for Mathematics in AI.

Robertsson, Anders
Board member for Centre for Engineering Education (CEE), Faculty of Engineering, Lund University.

Westin, Eva
Member of the steering group for AI Lund.
Member of the steering group for gender and equality issues at the Faculty of Engineering.
Member of the board at the Faculty of Engineering.

MEMBER OF INTERNATIONAL PROGRAM COMMITTEE (IPC)

Cervin, Anton
Member of the International Program Committee of the 34rd Euromicro Conference on Real-Time Systems (ECRTS'22).

Hägglund, Tore
Member of the IEEE International Conference on Emerging Technologies and Factory Automation, ETFA'2021, Västerås, Sweden.

Maggio, Martina
Member of DATE 2023 (PC in 2022).
Member of RTSS 2022.
Program chair of ECRTS 2022.

Rantzer, Anders
General Co-chair for the organization of European Control Conferenence 2024 in Stockholm.

Salt, Julian
Co-chair for the session *Collaborative Robots in Manufacturing* at IEEE International Conference on Automation Science and Engineering (CASE) 2022, Mexico City, Mexico.

OPPONENT AND MEMBER OF EXAMINATION COMMITTEE

Bernhardsson, Bo
Member of the evaluation committee for Johan Jönsson's dissertation, "A probabilistic Approach to Non-Markovian Impulse Control", at the Linnaeus University, March 17.

Cervin, Anton
Member of PhD examination committee of Johan Lidén Eddeland, Chalmers University of Technology, December 9.

Giselsson, Pontus
Member of PhD examination committee of Carl Jidling, Uppsala University, June 3.
Suppleant in PhD examination committee of Ganiele Gerosa, Lund University, April 26.
Member of PhD examination committee of Schervin Ahmadi, Linköping University, March 11.
Opponent Licentiate thesis of Erik Berglund, KTH, Stockholm, January 28.

Hägglund, Tore
Member of examination committee for PhD thesis *Design and Control of Integrated Continuous Processes for the Purification of Biopharmaceuticals*, by Joaquin Gomis Fons, Lund University, March 11.

Karayannidis, Yiannis
Opponent of Dipendra Subedi (University of Agder, Norway).
Member of the examination committee of Theodora Kastritsi (AUTH, Greece) in September.

Maggio, Martina
Reviewer of PhD thesis of Durgesh Singh, titled *Control Theoretic Approach for Performance Management of Web Services in Cloud Environment*.
Reviewer of PhD thesis of Tobias Stark, titled *Real-Time Exe- cution Management in the ROS 2 Framework*.

Olofsson, Björn

Member of the grading committee for PhD thesis *Pre-crash Motion Planning for Autonomous Vehicles in Unavoidable Collision Scenarios*. by Masoumeh Parseh on June 13, Department of Machine Design, KTH Royal Institute of Technology, Sweden.

Rantzer, Anders

External examinor for PhD dissertation at University of Cambridge, April 27.

Member of examination committe for PhD defence by Ingvar Max Ziemann, KTH, Stockholm, November 11.

ADVISORY COMMITTEES AND WORKING GROUPS

Årzén, Karl-Erik

Elected member of the Royal Swedish Academy of Engineering Sciences (IVA).

Como, Giacomo

Chair of the IEEE-CSS Technical Committee on Networks and Communications, since 2019.

Co-Organizer of the Workshop "Algorithmic Game Theory, Mechanism Design, and Learning" at Politecnico di Torino.

Eker, Johan

Project manager for WARA-Common and adjunct member of the WARA Management Group.

Organiser of the Real-time Cloud Workshop at ECRTS in Modena, June 2022.

Member of the IEEE Future Tech Summit Cloud Panel, August 2022.

Johnsson, Charlotta

Chair of ISO TC184/SC5 (Industrial Automation / Interoperability, integration and architectures for enterprise systems and automation applications).

Member in ISO SMCC (Smart Manufacturing Coordination Committee), reporting directly to ISO Technical Management Board.

Voting member in the standardization committee ISA95 and ISA88, and an information member in the standardization committee ISA99.

Board member for Diploma Engineering at University of Limerick, Ireland.

Member in SIS and SEK. She serves as the Swedish expert in the international IEC 62264, IEC 61512, ISO 22400 and ISO 15746 standards, as well as in the groups IEC AhG3, IEC TC65E AhG1, as well as in the joint committee IEC/TC65-ISO TC184 JWG21 (Reference Architecture for Smart Manufacturing).

Member of several boards and working groups at Lund University.

Rantzer, Anders

Member of review panel for completed projects funded by the European Research Council.

Member of the IEEE Control Systems Society Fellow Evaluating Committee.

Member Evaluation Committee for Wallenberg Academy Fellows.

Principal Investigator in the project "*AI for Guidance Navigation and Control*" funded by the European Space Agency.

Member of the Advisory Board for Lecture Notes in Control and Information Sciences at Springer Verlag Heidelberg.

Member of the IEEE Control System Society Technical Committee on Nonlinear Systems and Control.
Member of the IFAC Technical Committee on Nonlinear Systems.

Tegling, Emma
Chair for Chapter Activities with the IEEE Control Systems Society (CSS), and co-organized the inaugural world-wide event CSS Day in 2022.
Secretary of the European Control Association (EUCA).

OTHER ASSIGNMENTS

Årzén, Karl-Erik
Associate Editor for Real-Time Systems Journal.
Associate Editor for the Leibnitz Transactions on Embedded Systems (LITES).
Associate Editor for ACM Transactions of Cyber-Physical Systems.

Como, Giacomo
Associate Editor of the IEEE Transactions on Control of Network Systems and of the IEEE Transactions on Network Science and Engineering.
Guest Editor for Special Issue *Dynamics and Behaviors in Social Networks* for the IEEE Transactions on Control of Network Systems.
Guest Associate Editor for Special Section *Mathematical Modeling, Analysis, and Control of Epidemics* for the SIAM Journal on Control and Optimization.
Associate Editor of Automatica, since 2022.

Edelborg, Cecilia
Representative for Automatic Control in the Equality working group (JäLM) at the Faculty of Engineering.

Giselsson, Pontus
Editor (with A. Gibali and T. Humphries) of special issue in Journal of Applied Numerical Optimization, May.

Johnsson, Charlotta
Serving as the IFAC Liaison with IEC 65A.
Serving as a member in IEEE CSS industry Committee.

Karayiannidis, Yiannis
Associate Editor for IEEE Robotics and Automation Letters since 2018.
Associate Editor for IEEE RSJ International Conference on Intelligent Robots and Systems (IROS) since IROS20.
Associate Editor for European Control Conference (ECC) since ECC19.
Associate Editor for IEEE International Conference on Robotics and Automation (ICRA) since ICRA22.

Maggio, Martina
Associate editor for ACM Transactions on Embedded Computing Systems.
Associate editor for ACM Transactions on Cyber-Physical Systems.

Rantzer, Anders
Director of the ELLIIT Focus Periods.

Soltesz, Kristian
Director of the Engineering Physics program at Lund University.
CEO of AB Benoso (engineering consultancy) and GinkGo bikes (locally manufactured environment friendly transportation solutions).
Panel member as Expert Reviewer. European Science Foundation.
Steering group member of the Engineering Health LTH profile area.

Westin, Eva
Coordinator of the ELLIIT Focus Periods in Lund.

LONGER VISITS ABROAD

Agner, Felix
Felix spent two months in autumn 2022, in Toulouse for a research collaboration with CNRS.

Kjellqvist, Olle
During spring semester, Olle continued his research visit at California Institute of Technology where he was visiting professors Richard Murray and John Doyle working on robustness analysis, system level synthesis and learning optimal team decisions.

Maggio, Martina
In April 2020, Martina Maggio started a double appointment as full professor at the Department of Computer Science of Saarland University in Germany. During 2022 she had only 20% duty at the Department of Automatic Control, Lund University.

Mandrioli, Claudio
October 2021 through March 2022, Claudio has been visiting during 6 months the Software Verification and Validation Lab headed by Lionel Briand at the University of Luxembourg. The purpose of the visit was to foster interdisciplinary research across control and software engineering.

Wahlquist, Ylva
Beginning of 2022, during a two month period, Ylva visited Professor Guy Dumont's group at the University of British Columbia, Canada working on pharmacological precision medicine models.

LECTURES BY OUR PERSONNEL OUTSIDE THE DEPARTMENT

Årzén, Karl-Erik

Modeling, Control and Learning for Improved Cloud Predictability, Keynote address, 2022 IEEE International Conference on Service-Oriented System Engineering (SOSE), Newark, CA, USA, August 17.

Modeling, Control and Learning for Improved Cloud Predictability. ELLIIT Distinguished Lecture, Linköping University, December 12.

Bernhardsson, Bo

Hur skattar man effekten av lockdown och andra NPI:er. Lecture given at a the workshop *Pandemi-modeller för framtiden*, arranged by Gothenburg University, May.

Como, Giacomo

Optimal Interventions in Network Games @ ETH, June 16. Invited talk.

Dynamic Pricing and Heterogeneities in Traffic Networks@ ETH, April 12. Invited talk.

Eker, Johan

WASP cloud course. Guest lecture in May.

CLONAR – Cloud Native Real-Time Systems. Invited talk, Stuttgart, 6-9 September.

Godoy, Boris

Estimation of radiation sources : What's next ? From Max. likelihood to (generalized) Additive Point Source Localization (APSL). Presentation at ELLIIT Annual Workshop 2022.

Giselsson, Pontus

Advances in Operator Splitting. Invited talk at EUROPT 2022, Lisbon, Portugal, July 29-30.

Invited session: Continuous Optimization: Theory and Applications. 15th Viennese conference on Optimal Control and dynamical Games, Vienna, Austria, July 12-15.

Speaker in online weekly optimization seminar for mathematical optimization community. One World Optimization Seminar Series, January 24.

Hägglund, Tore

A simple and efficient PID control loop decoupler. Nordic Process Control Workshop, Luleå, Sweden, March 18.

PID controller design. Invited lecture. University of Almeria, Spain. April 20.

Ratio control and mid-ranging control. Invited lecture. University of Almeria, Spain. April 20.

An industrial control loop deccoupler for process control applications. Invited lecture. University of Almeria, Spain. April 21.

Some practical control issues. Invited lecture. University of Almeria, Spain. April 21.

Johnsson, Charlotta

Smart Manufacturing Standardization – issues and trends. Future Factory Technology Conference, JeJu Island South Korea, November.

Smart Manufacturing. Digital presentation for ELLIIT Tech Talks, October.

Key Performance Indicators for Smart Manufacturing. Virtual presentation at Coperman conference, October 13.
Metaverse and Smart Manufacturing. IE University Metaverse meeting, October.
ISO TC184/SC5 Integration and interoperability in manufacturing. Australia Automation Stakeholders Forum, August 18.
The golden standard. Invited talk at Forum för Standardisering, June 16.
Smart manufacturing. Invited presentation for ISO JTC1/SC40, June 13.
Standarder som möjliggörare för Smart industri. Invited presentation Prekam, May 19.

Karayiannidis, Yiannis
Robotic Manipulation of Deformable objects. Invited talk for the 3rd workshop organized in October, in connection to IROS 22 in Kyoto, Japan.

Kjellqvist, Olle
Infinite-Horizon SLS. CDC Workshop: System Level Synthesis: New Frontiers in Distributed Control, December 5, Cancun, Mexico.

Maggio, Martina
Control in the Presence of Deadline Misses: Weakly-Hard and (towards) Probabilistic Models. Invited presentation.
Control Systems in the presence of Computational Problems. Invited presentation in the SIC seminar series.
Control Systems in the presence of Computational Problems. Invited presentation in the Tecosa seminar series.

Rantzer, Anders
Minimax Adaptive Control for a Finite Set of Linear Systems. Seminar at University of Cambridge, April 28.
Towards Scalable Adaptive Control Plenary lecture at Reglermöte 2022, Luleå, June 8.
Nonlinear Optimal Control for Large-scale and Adaptive Systems. Invited virtual seminar IFAC/IEEE webinar series on Nonlinear Control Systems, June 15.
Robust and Adaptive Control for Large-scale Systems. Invited virtual seminar at Peking University, June 22.
Quadratic Inequalities in Learning for Control. Plenary lecture at 17th IEEE International Conference on Control and Automation, Neaples, June 29.
Towards Robust and Adaptive Control for Large-scale Systems. Plenary lecture at 10th IFAC Symposium on Robust Control Design ROCOND 2022, Kyoto, Japan, September 1.
Robust and Adaptive Control for Large-scale Systems}. Invited virtual seminar at Beijing Institute of Technology, October 11.
Scalable Adaptive Control. Invited lecture at ELLIIT focus period workshop in Linköping, November 1.
Synthesis of Minimax Adaptive Controller for a Finite Set of Linear Systems. Oral presentation at 61st IEEE Conference on Decision and Control, Cancun, Mexico, December 7.
Explicit Solution to Bellman Equation for Positive Systems with Linear Cost. Oral presentation at 61st IEEE Conference on Decision and Control, Cancun, Mexico, December 9.

POPULAR SCIENCE PRESENTATIONS

Johnsson, Charlotta

Standards and Control, C Johnsson and M Bauer in a digital presentation for Dept of Automatic Control, October.

X-Lab tar fram studenternas kreativa sida, article by Future By Lund, November 14.

Voitenko, Volodymyr

Flydde kriget i Ukraina – fick miljonanslag till drönarforskning by Jan Olsson, LUM Magazine, November 3.