Abstracts

Control Design for a MEMS Accelerometer with Tunneling Sensing
Karl Astrom (Lund University)

Quantum tunneling provides an extremely sensitive position measurement, it permits sensing with a resolution of the order of tens of picometers. Design of MEMS accelerometers based on tunneling is presented. The design is challenging because the devices are subject to random disturbances such as: Brownian motion, Johnson-Nyquist
noise, and tunneling noise. The devices also have resonances with very low damping. The goal of the design is to make an instrument with a good frequency response and the effects of disturbances should be attenuated efficiently. Results from analysis, design and experiments will be presented. The major part of the work has been done in Professor Kimberly Turner's laboratory at the University of California Santa Barbara.

Linear dynamic models and mixed frequency data
Manfred Deistler (TU Wien), BDO Anderson, M. Deistler, L. Koelbl

This paper is concerned with the problems of identifiability and estimation of the parameters of a high frequency multivariate autoregressive or ARMA model from mixed frequency time series data. We demonstrate identifiability for generic parameter values using the (mixed frequency) population second moments of the observations for the AR case as well as for the ARMA case, where the MA order is smaller than or equal to the AR order. In addition we display a constructive algorithm for the parameter values and establish the continuity of the mapping attaching the high frequency parameters to the directly observed population second moments. The cases of stock and flow variables, as well as of general linear transformations of high frequency data, are treated. Finally, with an emphasis on the AR case, we discuss how our identifiability results can be used for parameter estimation based on the sample second moments.

Autonomous yet safe operation of complex interconnected systems
Rolf Findeisen (University of Magdeburg), Sergio Lucia, Markus Kögel, Pablo Zometa, Tobias Bäthge, Bruno Morabito

Advancements in communication and computation have lead to an increasingly connected world - large interconnections of cyber-physical systems. Formerly separately designed systems are becoming part of larger systems, which need to be designed such that an optimal, yet flexible behavior is achieved while guaranteeing safety and reliability. As shown in this talk, predictive control is well suited to tackle these challenges. It allows to take preview information of future demands and disturbances into account, while being able to satisfy constraints on states and parameters, which enables safe and reliable operation. Specifically, we present the concept of contract based predictive control, which provides means towards flexible, yet reliable distributed and hierarchical control. We outline how the concept of contract based control can be expanded to the use of models of different granularity in the predictions. The findings will be underlined considering examples from building control and control of autonomous vehicles.

LASSO MPC: A summary of my PhD research

Marco Gallieri (McLaren Applied Technologies)

Model Predictive Control (MPC) is a relatively mature and established technology based on online (or offline) optimisation of a control input sequence and a particular cost function through model-based prediction of the system trajectory. LASSO, also known as L1-regularised least squares, is a statistical technique used in machine learning to obtain sparse solutions to a fitting problem. LASSO MPC employs the LASSO cost function to obtain sparse input sequences (as well as their derivatives). Sparsity is proven in the actuators' domain for LTI systems although it can also occur through time. Beside this, stability results are obtained for PWA systems by means of two different formulations, one of them relying on a Minkowski terminal cost function. A method for computing the regularisation penalty is proposed to have preferred and auxiliary actuators, the latter being used only when the control error is large. The intrinsic robustness of the approach is shown for a tracking problem with soft constraints by means of set theoretic control. The approach is demonstrated on the problem of ship roll reduction with rudder and fins.

Identification of dynamical networks

Michel Gevers (Catholic University of Louvain), joint work with Alexandre Bazanella

We consider networks of dynamical systems in which the node signals are connected by edges made up of linear time-invariant dynamical systems, and in which the externally signals may comprise both known excitation signals and noise signals. One important problem is the identifiability of the whole network from measured signals: which prior information on the structure of the network and which experiment design can lead to a unique reconstruction of the network structure? Another imporant problem is the identification of a particular module (i.e. dynamical link) within the network: which excitation conditions are required for the consistent estimation of such module? We provide sufficient conditions for the first problem and a new and very simple solution for the second problem.

Network inference: from theory to applications in biology

Jorge Goncalves (University of Luxembourg)

A major goal of biological sciences is the identification of regions in genetic networks that underpin responses to stimuli, with the potential to identify drug targets or differences between cell types. This talk will describe recent developments, both from theoretical and application point of view, for the identification of dynamical biological networks. Theoretically, it gives conditions for network identifiability of networks with deterministic or stochastic inputs. For identification, it considers recent developments of efficient algorithms that impose sparsity constraints on the network and model complexity. Then, the talk describes the application of control systems tools, such as system identification and the gap metric, to improve our understanding of circadian clocks in Arabidopsis thaliana. In particular, this work is interested in explaining alterations in circadian clock period in the toc1-1 mutant and in response to the drug nicotinamide. Finally, the talk discusses the gap between theory and application and some of the theoretical challenges in biology.

Tight Global Linear Convergence Rate Bounds for Operator Splitting Methods

Paul Goulart (University of Oxford)

We establish necessary and sufficient conditions for linear convergence of operator splitting methods for convex optimization problems where the associated fixed-point operator is averaged. We also provide a tight bound on the achievable convergence rate. Most existing results establishing linear convergence in such methods require restrictive assumptions regarding strong convexity and smoothness of the constituent functions in the optimization problem. However, there are several examples in the literature showing that linear convergence is possible even when these properties do not hold. We provide a unifying analysis method for establishing linear convergence based on linear regularity and show that many existing results are special cases of our approach.

On a class of global optimization methods for model reduction and system identification.

Bernard Hanzon (University College Cork), the presentation is based on joint work with several co-authors including R. Peeters, M. Olivi, Th. Ribarits, W. Scherrer.

Model order reduction and system identification problems for linear systems are often cast as optimization problems, where the criterion characterizes goodness-of- fit or the quality of the predictions generated by the model etc. However finding the optimum of such a criterion is a non-trivial matter and often local search methods are employed, or other heuristic methods, often based on approximations. In both cases it would still be of interest to be able to compare the outcomes to the global optimizer of an accepted criterion such as least squares or maximum likelihood, etc. In previous work (with Jan Maciejowski and others) we have considered algebraic approaches to some of these global optimization problems. However these methods will not be (practically) applicable in many cases. Here we follow a different approach. In many cases it turns out to be possible to split the optimization problem into two steps: One “partial optimization” step in which (typically for a given reachable pair) a convex (quadratic or more complicated) optimization problem is solved, which is “easy”, and a second step in which one optimizes the “concentrated” or “partially optimized” criterion over a set of which the closure is compact. If we can show that the resulting criterion is Lipschitz continuous over the compact set and Lipschitz constant(s) can be determined, then the global optimum exists and can be determined with arbitrary precision by systematically searching through the compact set. With the increase of computing power the application of these ideas seem to become more realistic now.

We will consider the H_2 model order reduction problem, where the theoretical results required have been know already for quite a while, and the maximum likelihood problem for Gaussian linear systems for which a solution to the problem of finding an appropriate compactification is proposed.

The compactification in this case is obtained by embedding the collection of row spaces of related reachability matrices into an appropriate Grassmann manifold.

If time permits remarks about application to model reduction and system identification problems with constraints will be made (esp non-negativity constraints).

Disturbance models for offset-free generalised internal model control
William Heath (University of Manchester), Gabriele Pannocchia, Marina Polignano

It is standard to impose offset-free action in model predictive control with an augmented model including disturbance dynamics. By analogy we propose a generalisation of the internal model control (IMC) structure that includes an observer generating both state and disturbance estimates. Stable offset-free action can be guaranteed with a particular rotation matrix and tuning procedures closely aligned to standard IMC. The approach is general and may be applied to open-loop unstable plants and to plants with open-loop poles at the origin. It may be interpreted as a generalisation of the Youla parametrisation to an augmented plant model that is observable but not controllable. The standard Youla parameterisation emerges as a special case with a specific deadbeat observer.

Predictive Demand Response for Commercial Buildings
Colin Jones (EPFL)

Commercial buildings have significant flexibility in how and when they consume energy, and this freedom can be put to good use by grid operators managing the stability of the grid. This talk will discuss demand response for buildings, or the throttling of power consumption in reaction to signals sent by the grid operator. By shifting energy consumption in time, these techniques can be seen as utilizing the thermal inertia of buildings as a form of virtual electrical storage. In the first part of the talk, we will introduce and analyse a hybrid storage system that combines the best properties of electrical batteries, commercial buildings and generation re-scheduling to better provide balancing services at multiple time scales. In the second part, we will examine the current Swiss markets and utilize the developed methodology to determine the financial benefit to participation in the secondary ancillary services market, competing directly against the large-scale generators who traditionally provide these services. The resulting experiments and simulations demonstrate that commercial buildings can profitably compete today.

Optimal Control of Multiprocessor Systems
Eric Kerrigan (Imperial College, London)

We will address the problem of scheduling a set of real-time computing tasks on a multiprocessor system, while minimizing the energy used for computation. We will present a novel algorithm, which is based on solving a suitably-defined optimal control problem, that can achieve as much as an 80% energy saving compared to the state of the art.

Stability and instability in gradient dynamics

<u>I. Lestas</u> (University of Cambridge)

Finding the saddle point of a concave-convex function is a problem that is relevant in many applications in engineering and economics and has been addressed by various communities. It includes, for example, optimization problems that are reduced to finding the saddle point of a Lagrangian. The gradient method, first introduced by Arrow, Hurwicz and Uzawa has been widely used in this context as it leads to decentralized update rules for network optimization problems.

Nevertheless, in broad classes of problems there are features that render the analysis of the asymptotic behaviour of gradient dynamics nontrivial. In particular, even though for a strictly concave-convex function convergence to a saddle point via gradient dynamics is ensured, when this strictness is lacking, convergence is not guaranteed and oscillatory solutions can occur. Furthermore, when the subgradient method is used to restrict the dynamics in a convex domain, the dynamics become non-smooth in continuous time, thus increasing significantly the complexity in the analysis, which is reflected in both the early work of Arrow, Hurwicz and Uzawa and also more recent studies.

In this talk we present various results that address these issues. In particular, we first consider the gradient method applied on a general concave-convex function in an unconstrained domain, and show that despite the nonlinearity of the dynamics the trajectories converge to solutions that satisfy a linear ODE that is explicitly characterized. For the subgradient method we show that despite the non-smooth character of these dynamics the limiting behaviour is given by the solutions of one of an explicit family of smooth differential equations. This therefore allows to remove the complications associated with non-smooth analysis, and prove convergence for broad classes of problems.

Model Predictive Control for tracking periodic signals

<u>Daniel Limon</u> (University of Seville)

This talk is devoted to present recent results of our group on stabilizing predictive controllers for tracking arbitrary periodic signals that may vary along the time. This issue appears naturally in relevant control problems as, for instance, when the economically optimal operation of the plant is not to remain at a given steady-state but to follow a non-steady trajectory, often periodical, due to periodic disturbances or variations of the unitary economic costs.

This control technique is based on the extension of the idea of artificial setpoint introduced in the MPC for tracking approach to deal with the case of periodic signals. This has also been adapted to the case of economic optimization of periodic systems as well as systems with algebraic equations and additive uncertainty. Applications to water distribution networks and microgrids will be presented.

Event-triggered Sequence-based Anytime Control as an Event-triggered Markov Jump System
LING Keck Voon *(Nanyang Technological University)*

In embedded and networked control systems, the amount of computing resources available may be time-varying due to multi-tasking requirements and measurements may be unavailable due to packets drop-out, or network congestion. To deal with these situations, one can employ a sequence-based anytime control (SAC) algorithm. The main idea of SAC is to, when computing resources and measurements are available, compute a sequence of tentative control inputs and stored them in a buffer for potential use in the future. To conserve computing and network resources, the SAC scheme could be event-triggered resulting in an event-triggered sequence-based anytime control (E-SAC) algorithm.

State-dependent Random-time Drift (SRD) approach is often used to analyse and establish stability properties of such E-SAC algorithm. However, using SRD, the analysis quickly becomes combinatoric and hence difficult to extend to more sophisticated E-SAC.

In this talk, we propose a new method based on Markov jump system. Through the proposed Markov jump system description of E-SAC, existing stability conditions for E-SAC are recovered. In addition, the proposed technique systematically extends to a more sophisticated E-SAC scheme for which, until now, no analytical expression had been obtained.

Regularization and orthonormal basis functions in linear regression output error methods for linear system identification
Lennart Ljung *(Linkoping univeristy)*

Orthonormal basis function expansion, like Laguerre polynomials, have proven quite useful for estimation of linear systems. It combines the useful features of being linear regressions, and using fewer parameters to cover long impulse responses than simple FIR models. In this presentation we show the links between such expansions and basic L2 norm regularization.

Real-time NMPC strategies for vehicle stability at the limits of handling
Stefano Longo *(Cranfield University)*

In this talk I will discuss real-time implementable optimal constrained control strategies for stabilizing a vehicle near the limit of lateral acceleration. A nonlinear four-wheel vehicle model coupled with a nonlinear tyre model is used. The NMPC strategies are compared in terms of closed-loop performance and computational complexity. The control algorithms are implemented in a dSpace real-time hardware-in-the-loop system, which is the de-facto standard for industrial vehicle control development.

Control of Populations
John Lyegeros (ETH Zurich)

Many large scale systems involve the interaction of a number of agents with loosely coupled dynamics and decisions. Examples include transportation systems, consumer demand response in electricity grids, emergency evacuation of buildings, and even education. In all these cases agents locally optimize their decisions, but their eventual well being depends on the decisions of all other agents. For such systems it is typically impractical to impose a centralized control structure for a number of reasons, including computational and communication limitations and privacy concerns. Instead one can consider providing suitable information to the agents and imposing an appropriate penalty/reward scheme to steer the overall population using macroscopic commands, so that it exhibits a desirable macroscopic behaviour. In this talk we will discuss how such control structures can be developed by adopting a aggregative game perspective, based on convergence results in operator theory. The discussion will be motivated by applications of population control to consumer electricity demand response schemes and transportation.

Jan Maciejowski's Impact on Control Research and Education
Manfred Morari (ETH Zurich)

In this talk I will highlight some of Jan's contributions over the course of more than three decades - from computer-aided design via multivariable frequency domain methods to robust model predictive control. I will also direct attention to his two textbooks which appeared at critical junction points to shape the evolution of our field. Finally, I will acknowledge the long-term impact Jan had on the thinking and work in our group.

Single Molecule Microscopy: use of balanced realizations for location estimation
Raimund J. Ober (University of Texas at Dallas)

Microscopy is probably the most important tool for the analysis of fundamental biomedical processes within cells such as the transport of therapeutic agents. Image analysis is a central component of single molecule based super resolution microscopy. For example, in localization based super resolution microscopy the improvement in resolution over conventional techniques depends crucially on the quality of the image analysis. Here we show how state space identification approaches, such as those pioneered by J. Maciejowski can be used to carry out the essential step in single molecule microscopy, the estimation of the locations of the single molecules in the images.

Modelling and Control of Timed Discrete Event Systems with Standard Synchronisation Rules and Set-Based Constraints
Joerg Raisch (TU Berlin), Laurent Hardouin and Bertrand Cottenceau

Timed discrete event systems that are exclusively governed by standard synchronisation rules (i.e., for all $k \geq l$, occurrence k of event e2 is at least t units of time after occurrence $k - l$ of event e1 with t, k, l ∈ N0) have been widely investigated. It is well known that the behaviour of this class of systems is linear in suitable dioid frameworks as, e.g., the (max,+)-algebra, and a variety of modelling and control methods is available for such systems. In this talk, we will discuss the extension of modelling and optimal (in the sense of just-in-time) control methods to timed discrete event systems that are characterised by standard synchronisation rules, but are subject to the additional restriction that certain events may only occur in externally imposed ultimately periodic sets. Such phenomena frequently arise in multi-layer systems, where the evolution of a top-layer system may invoke ultimately periodic restrictions for the bottom-layer system. To illustrate the obtained results, a simple road network example with traffic lights will be considered.

Predictive Control for Robot Motion

Arthur Richards (University of Bristol)

This talk will consider the application of Model Predictive Control (MPC) for robot navigation. MPC is a natural choice for this problem given the need for dynamic re-planning subject to dynamics and environmental constraints. Examples from flying and driving robots will be used to show how formal results from MPC can improve robot behaviour. Tuning guidelines will be deduced from experience, identifying how decision-making capability influences overall robot performance.

Why should we trust a robot in the operating theatre?

Paul Roberts (Cambridge Medical Robotics)

Historically, robotic systems used in an industry are designed to be rigid, fast and precise: a necessity for applications from precision welding, finishing and complex assembly. But the rapid, and precise movement makes most industrial robots intrinsically unsafe for humans to work with, and would therefore not be suitable for use in an operating theatre. However, in the last 20 years, robotically-assisted surgery has been revolutionising how surgery is performed. Surgical robots are becoming commonplace in operating theatres resulting in approximately 5% of all keyhole surgical procedures are now performed robotically.

Yet current keyhole surgery robotic technology is limited. Typically, safety is ensured by careful choice of robot kinematics, which can be design-limiting. Only recently has technology allowed for the implementation of patient-safe impedance control algorithms, that facilitate truly collaborative operation of these robotic systems. Such technology has the potential to result in full adoption of robotic systems in surgery. Synthesising compliance in robotic manipulators allows serial manipulators to work in close proximity with humans, even with unconscious patients during surgical procedures. We will describe the current state of the art in synthesising multi-dimensional compliance in arbitrary reference frames, and describe how such algorithms are being used in the world's most advanced robotic systems for keyhole surgery.

The proposed ideas illustrate the recent technical developments in the robotic space, and the future collaborative robotic technology that is transforming robotically-assisted surgery, but is it enough for me to trust a robot to operate on my reproductive organs?

Optimal Move Blocking Strategies for Computationally-Efficient Model Predictive Control
Rohan Shekhar (University of Melbourne)

Model Predictive Control (MPC) has captured the interest of control practitioners in recent times, owing to its intuitive formulation and unique constraint handling ability. However, its utility for systems with fast dynamics and high sampling rate requirements is currently limited. Such systems generally require long prediction horizons for guaranteeing constraint satisfaction and delivering adequate controller performance, necessitating the solution of a computationally-complex online optimisation problem at each MPC iteration.

This talk will introduce the notion of move blocking as a means for reducing the computational burden of MPC. It will be shown how move blocking structures parameterising the predicted input sequence can be optimised using mixed-integer programming to reduce online complexity and preserve or improve the controller's domain of attraction, whilst maintaining desirable recursive feasibility guarantees. Numerical examples will be used to demonstrate the computational speedup and improvement in domain of attraction volume resulting from the optimisation technique.

Decentralised Design and Distributed Control for Power Systems
Glenn Vinnicombe (University of Cambridge)

We present a novel decentralised condition for checking the small signal stability of a power system with arbitrary components. The network is first torn into a collection of subnetworks, one for each bus together with the transmission lines it is connected to, with the buses at the far end of the line replaced by an "evil twin" of the retained bus. If each of these subnetworks satisfies a certain robust stability condition, with a certificate it shares with its neighbours, then the entire network is guaranteed to be small signal stable. The evil twin represents the worst case behaviour of the rest of the network, with the constraint that it too must satisfy the robust stability condition. Now, in order to check the stability of a single operating condition it might be simpler to assemble the equations for the whole network; the utility of the present result is in the local design controllers and the checking of contingencies. Although inherently conservative, the resulting bounds are often comparable with the results of direct computation (This is joint work with Richard Pates).