ERNSI 2021 PROGRAM

IN MEMORY OF RIK

Monday, September 20

08h15-08h30: ERNSI Workshop 2021 opening in memory of Rik

08h30-09h00: regular talk 1: **Asymptotic theory for regularized system identification; empirical Bayes hyper-parameter estimator,** *Tianshi Chen (The Chinese University of Hong Kong)*, [Chair: A. Chiuso]

09h00-09h30: regular talk 2: **Bayesian frequentist bounds for machine learning and system identification**, *A. Scampicchio (University of Padova)*, [Chair: H. Hjalmarsson]

09h30-09h50: coffee break

09h50-10h20: regular talk 3: **Single module identifiability in linear dynamic networks with partial excitation and measurement**, *S. Shi (TU Eindhoven)*, [Chair: X. Bombois]

10h20-10h50: regular talk 4: **Optimal identification experiment design to improve the detection of the topology of a dynamic network**, *X. Bombois (CNRS-Ecole Centrale Lyon)*, [Chair: P. van den Hof]

10h50-11h10: **discussion** [Chairs: A. Chiuso, H. Hjalmarsson, X. Bombois, P. van den Hof]

11h10-11h30: **poster teaser A** [Chair: M. Gilson Bagrel]

11h30-12h30: **poster session A** [Chair: M. Gilson Bagrel]

12h30-14h00: lunch

14h00-15h00: invited talk 1: **Fast and furious methods for real-time inference in SLAM**, *Arno Solin (Aalto University)*, [Chair: T. Schön]

15h00-15h30: regular talk 5: **Physics-informed learning for identification of a residential building's thermal behavior**, *P. Kergus (Lund University)*, [Chair: M. Schoukens]

15h30-15h50: **discussion** [Chairs: M. Schoukens, T. Schön]

15h50-16h20: coffee break

16h20-16h40: **poster teaser B** [Chair: M. G. Mercère]

16h40-17h40: **poster session B** [Chair: M. G. Mercère]

Tuesday, September 21

08h30-09h00: regular talk 6: **Time series forecasting and anomaly detection with residual temporal convolutional networks**, *L. Zancato (University of Padova)*, [Chair: R. Smith]

09h00-09h30: regular talk 7: **Direct data-driven design of explicit predictive controls**, *S. Formentin (Politecnico de Milano)*, [Chair: R. Toth]

09h30-09h50: coffee break

09h50-10h20: regular talk 8: **Kernel-based system identification with manifold regularization: a Bayesian perspective**, *M. Mazzoleni (Università degli Studi di Bergamo)*, [Chair: J. Lataire]

10h20-10h50: regular talk 9: **Surface identification through rational approximation of the back-scattering of an electromagnetic planar wave**, *P. Asensio (INRIA Sophia)*, [Chair: J. Schoukens]

10h50-11h10: **discussion** [Chairs: R. Smith , R. Toth, J. Lataire, J. Schoukens]

11h10-11h30: **poster teaser C** [Chair: M. Döhler]

11h30-12h30: **poster session C** [Chair: M. Döhler]

12h30-14h00: lunch

14h00-15h00: invited talk 2: **On the stability and the uniform propagation of chaos properties of ensemble Kalman-Bucy filters**, *Pierre Del Moral (INRIA Bordeaux)*, [Chair: L. Mevel]

15h00-15h30: regular talk 10: **Identification with frequency domain side information**, *M. Khosravi (ETH, Zürich),* [Chair: M. Enqvist]

15h30-15h50: coffee break

15h50-16h20: regular talk 11: **Gene expression modelling from cell population snapshot data using optimal mass transport**, *F. Lamoline (University of Luxembourg)*, [Chair: L. Baratchart]

16h20-16h50: regular talk 12: **On data informativity in direct simulation problems**, *A. Iannelli (ETH Zürich)* [Chair: B. Wahlberg]

16h50-17h10: **discussion** [Chairs: L. Mevel, M. Enqvist, L. Baratchart, B. Wahlberg]

17h10-17h20: ERNSI Workshop 2021 closing

TALK 1
CODE: IT01

Title: Fast and furious methods for real-time inference in SLAM

Author: Arno Solin

Abstract: Probabilistic inference offers principled and well-understood tools for sensor fusion in applications such as simultaneous localization and mapping (SLAM). However, practical constraints often hinder leveraging the 'best' or 'right' ways to do things. In applications, we typically resort to linearisation, Gaussian approximations, or only forward filtering approaches to meet real-time or computational budget constraints. This talk discusses (with examples) how these limiting boundaries can and even should be pushed to provide more accurate, reliable, and useful solutions to tracking and SLAM applications.

TALK 2
CODE: IT02

Title: On the stability and the uniform propagation of chaos properties of ensemble Kalman-Bucy filters

Author: Pierre Del Moral

Abstract: The Ensemble Kalman filter is a sophisticated and powerful data assimilation method for filtering high dimensional problems arising in fluid mechanics and geophysical sci- ences. This Monte Carlo method can be interpreted as a mean-field McKean-Vlasov type particle interpretation of the Kalman-Bucy diffusions. Besides some recent advances on the stability of nonlinear Langevin type diffusions with drift interactions, the long-time behaviour of models with interacting diffusion matrices and conditional distribution interaction functions has never been discussed in the literature. One of the main contributions of the talk is to initiate the study of this new class of models. The talk presents a series of new functional inequalities to quantify the stability of these nonlinear diffusion processes. The second contribution of this talk is to provide uniform propagation of chaos properties as well as Lp-mean error estimates w.r.t. the time horizon.

TALK 1
CODE: RT01

Title: Asymptotic theory for regularized system identification; empirical Bayes hyper-parameter estimator

Author: T. Chen

Abstract: Regularized system identification is the major advance in system identification in the last decade. Although it has achieved great success, it is far from complete and there are still many key problems to be solved. One of them is the asymptotic theory, which is about convergence properties of the model estimators as the sample size goes to infinity. The existing related results for regularized system identification are about the almost sure convergence of various hyper-parameter estimators. A common problem of those results is that they do not contain information on the factors that affect the convergence properties of those hyper-parameter estimators, e.g., the regression matrix. In this paper, we try to tackle this kind of problems for the regularized finite impulse response model estimation with the empirical Bayes (EB) hyper-parameter estimator. In order to expose those factors, we study the convergence in distribution of the EB hyper-parameter estimator to its limit, and the asymptotic distribution of its corresponding model estimator to the true model parameter. For illustration, we run Monte Carlo simulations to show the efficacy of our obtained theoretical results.

TALK 2
CODE: RT02

Title: Bayesian frequentist bounds for machine learning and system identification

Authors: A. Scampicchio, G. Baggio, A. Caré, G. Pillonetto

Abstract: Estimating a function from noisy measurements is a crucial problem in statistics and engineering, with an impact on machine learning predictions and identification of dynamical systems. In view of robust control design and safety-critical applications such as autonomous driving and smart healthcare, estimates are required to be complemented with reliable uncertainty bounds around them. Most of the available results are derived by constraining the estimates to belong to a deterministic function space; however, the returned bounds often result overly conservative and, hence, of limited usefulness. An alternative is to use a Bayesian framework. The regions thereby obtained however require complete specification of prior distributions whose choice may significantly affect the probability of inclusion. This study presents a framework for the effective computation of regions that include the unknown function with exact probability. In this setting, the users not only have the freedom to modulate the amount of prior knowledge that informs the constructed regions but can, on a different plane, finely modulate their commitment to such information. The result is a versatile certified estimation framework capable of addressing a multitude of problems, ranging from parametric estimation (where the probabilistic guarantees can be issued under no commitment to the prior) to non-parametric problems (that call for fine exploitation of prior information).

TALK 3
CODE: RT03

Title: Single module identifiability in linear dynamic networks with partial excitation and measurement

Author:S. Shi

Abstract: Identifiability of a single module in a network of transfer functions is determined by the question whether a particular transfer function in the network can be uniquely distinguished within a network model set, on the basis of data. Whereas previous research has focused on the situations that all network signals are either excited or measured, we develop generalized analysis results for the situation of partial measurement and partial excitation. As identifiability conditions typically require a sufficient number of external excitation signals, this work introduces a novel network model structure such that excitation from unmeasured noise signals is included, which leads to less conservative identifiability conditions than relying on measured excitation signals only. More importantly, graphical conditions are developed to verify global and generic identifiability of a single module based on the topology of the dynamic network. Depending on whether the input or the output of the module can be measured, we present four identifiability conditions which cover all possible situations in single module identification. These conditions further lead to synthesis approaches for allocating excitation signals and selecting measured signals, to warrant single module identifiability. In addition, if the identifiability conditions are satisfied for a sufficient number of external excitation signals only, indirect identification methods are developed to provide a consistent estimate of the module. All the obtained results are also extended to identifiability of multiple modules in the network.

TALK 4
CODE: RT04

Title: Optimal identification experiment design to improve the detection of the topology of a dynamic network

Authors: X. Bombois and H. Hjalmarsson

Abstract: In this talk, we propose a methodology to detect the topology of a dynamic network that is based on the analysis of the uncertainty of an estimate of the static characteristic of the matrix of transfer functions between the external excitations and the node signals. We also show that the reliability of the proposed network topology detection methodology can be improved by an appropriate design of the experiment leading to the estimate of the static characteristic.

TALK 5
CODE: RT05

Title: Physics-informed learning for identification of a residential building's thermal behavior

Author: P. Kergus

Abstract: As space heating represents a large share of total energy use, thermal networks, i.e. district cooling or heating networks, would be able to increase the efficiency of the energy system in an economic way. Thanks to the natural inertia of heat exchanges, these networks can offer flexibility. In order to explore this feature, it is important to model building's thermal behavior in order to enable the use of demand-side management control strategies. In this work, such models are built through a physics-informed learning based approach.

TALK 6
CODE: RT06

Title: Time series forecasting and anomaly detection with residual temporal convolutional networks

Authors: L. Zancato, A. Achille, G. Paolini, A. Chiuso, S. Soatto

Abstract: We present a residual-style architecture for interpretable forecasting and anomaly detection in multivariate time series. Our architecture is composed of stacked residual blocks designed to separate components of the signal such as trends, seasonality, and linear dynamics. These are followed by a Temporal Convolutional Network (TCN) that can freely model the remaining components and can aggregate global statistics from different time series as context for the local predictions of each time series. The architecture can be trained end-to-end and automatically adapts to the time scale of the signals. After modeling the signals, we use an anomaly detection system based on the classic CUMSUM algorithm and a variational approximation of the f-divergence to detect both isolated point anomalies and change-points in statistics of the signals. Our method outperforms state-of-the-art robust statistical methods on typical time series benchmarks where deep networks usually underperform. To further illustrate the general applicability of our method, we show that it can be successfully employed on complex data such as text embeddings of newspaper articles.

Talk 7
CODE: RT07

Title: Direct data-driven design of explicit predictive controls

Authors: A. Sassella, V. Breschi, S. Formentin

Abstract: In this talk, we deal with constrained predictive control of linear time-invariant (LTI) systems. Specifically, we discuss how explicit predictive laws can be learnt directly from data, without the need to identify the system to control. To this aim, we resort to the Willems' fundamental lemma, and we show how the explicit controller can be derived from data either starting from the explicit MPC formulas or based on the existing data-driven implicit predictive solutions. The resulting law turns out to be a piece-wise affine controller coinciding with the solution of the original MPC problem in case of noiseless data. The use of regularization is finally discussed for the case of noisy measurements, where the proposed method reveals itself as a computationally efficient alternative to the state-of-the-art predictive controls. The effectiveness of the proposed approach is illustrated on a variety of simulation case studies.

Talk 8
CODE: RT08

Title: Kernel-based system identification with manifold regularization: a Bayesian perspective

Authors: M. Mazzoleni, A. Chiuso, M. Scandella, S. Formentin, F. Previdi

Abstract: Kernel methods for system identification is an active area of research. Essentially, these techniques are regularized approaches to learning an unknown input-output mapping. Tikhonov regularization is the most common regularization term: however, other formulations are possible. One of these is manifold regularization, where it is assumed that regressors are connected via a graph, and the aim is to penalize function variations between connected regressors. In this talk, I will first review the concepts of manifold regularization and graph signal processing. Then, I will present a nonparametric Bayesian interpretation of kernel-based function learning with manifold regularization. It is shown that manifold regularization corresponds to an additional likelihood term derived from noisy observations of the function gradient along the regressors graph. The derived interpretation allows the tuning hyperparameters of the method by a suitable empirical Bayes approach. The effectiveness of the method in the context of dynamical system identification is evaluated on a simulated linear system and on an experimental switching system setup.

TALK 9
CODE: RT09

Title: Surface identification through rational approximation of the back-scattering of an electromagnetic planar wave

Author: P. Asensio, L. Baratchart, J. Leblond, M. Olivi, F. Seyfert

Abstract: By measuring the scattered electromagnetic field produced by a plane wave on a smooth object at various frequencies, and then performing rational or meromorphic approximation of the transfer function, we consider the issue identifying the shape of the object from the recovery of some characteric singularities (which are poles because the object is smooth, but typically infinite in number). This technique can also be used to identify certain physical characteristics of the object for nondestructive testing.

TALK 10
CODE: RT10

Title: Identification with frequency domain side information

Author: M. Khosravi, R. Smith

Abstract: In the identification of dynamical systems, in addition to the measurement data, we might be given side information about the underlying system. The origin of this side information can be the physics or the nature of the system, e.g., RC circuits are positive systems. Also, this side information can be due to the observed behavior from data or past experiments. For example, a neuron converges gradually to a periodic spiking behavior when it is subject to a constant current. One other source of this side information can be examples with a similar structure, e.g., unknown friction nonlinearities at the joints of a pendulum do not change the equilibrium points. For the linear systems, the side information can be about various frequency domain properties such as the DC-gain, the H-infinity norm, or the dissipativity of the system. When it is required to employ this information in the identification problem, the main concerns are the correct incorporation of the given side information and also obtaining a tractable identification scheme. In this work, we employ the regularized system identification framework and formulate the problem as a convex optimization in a reproducing kernel Hilbert space where suitable constraints are introduced to capture the side information. We investigate the analytic properties of this convex program and introduce a solution heuristic for solving this optimization problem. Finally, the efficacy and tractability of the method are verified by several numerical examples.

TALK 11
CODE: RT11

Title: Gene expression modelling from cell population snapshot data using optimal mass transport

Authors: F. Lamoline, A. Aalto, I. Haasler, J. Karlsson, J. Goncalves

Abstract: Modelling gene expression is a central problem in systems biology. Accurate predictive models provide powerful tools for understanding cellular mechanisms and exploring the regulatory relations between genes. Perturbations of these regulatory structures affect the cellular functions. The ability to predict the effects of these perturbations is critical for finding sources of complex diseases and developing new treatments. Recently, single-cell techniques have enabled sequencing at the level of individual cells for a large number of cells at a time. Unfortunately, the cells are destroyed in the measurement process, and so the data consist of population snapshots at different times. Traditional methods aim at modelling from time series data and cannot utilise the

full information in the richer single-cell data. Therefore, these new sequencing techniques have raised the need of tailored computational methods for modelling the gene expression from single-cell data. In this presentation we introduce new methods based on the 18th century problem of optimal mass transport. The idea consists in tracking the evolution of the distribution of cells over time and finding the dynamical system that minimises the transport cost between consecutive time points. The performance of the methods is compared in numerical experiments.

TALK 12

CODE: RT12

Title: On data informativity in direct simulation problems

Authors: A. Iannelli, M. Yin, R. Smith

Abstract: The work investigates the notion of data informativity in simulation problems where future system's trajectories are predicted directly from data (and not by identifying first a model). The problem is framed in the context of the Willems' Fundamental Lemma, which provides excitation requirements such that the subspace of input/output trajectories of the system coincides with the span of certain noise-free data matrices. We first present, in the case of noise-free data, weaker excitation requirements tailored to the specific input signal of which we want to simulate the response. Then, the case where the data matrices are built using noisy trajectories is considered, and an input design problem based on a recently proposed maximum likelihood estimator (i.e. the Signal Matrix Model) is defined. The objective function is formulated from a Bayesian viewpoint by leveraging the concept of mutual information, and the implications of using Hankel or Page matrix representations on data informativity are investigated. Numerical examples show the impact of the designed input on the predictive accuracy for different simulation problems and matrix structures.

Poster session A (14 posters)

POSTER 1
CODE: PA01

Title: Identification of physiological lung parameters using the forced oscillation technique

Authors: A. Marchal, A. Keymolen, G. van Dijk, J. Lataire, G. Vandersteen

Abstract: Medical doctors only have access to limited information about the patient's respiratory system when ventilating a patient. Only a first order model is used for the patient's respiratory system for patient ventilation applications where a patient's breathing is assisted or taken over by a machine. We propose the use of frequency domain identification along with the Forced Oscillation Technique (FOT, also referred to as oscillometry techniques) to provide more physiological parameters linked to the patient's lung condition. A constant phase model is used which is known to deliver a wider set of parameters which are physiologically interpretable and can now be parametrically identified for patients being ventilated. First results on a healthy subject are provided. The design of the excitations used is also detailed. It requires the spectral separation of the controlled excitation and the patient's estimated breathing. The latter is indeed modelled as a disturbance in the low frequency range. Additionally, the SNR is typically very low, making the identification challenging.

POSTER 2
CODE: PA02

Title: Dynamic inversion based estimation of COVID-19 epidemiological data

Authors: B. Csutak, T. Péni, G. Szederkényi

Abstract: Estimating the non-measurable epidemiological data of COVID-19 pandemic is addressed in this work. For this, a nonlinear compartmental model describing the transmission dynamics of the virus is used. Assuming that only the number of hospitalized patients are available for measurement, a dynamic inversion based estimator is designed first to determine the number of latent infected individuals. In the next step, this estimation is used to determine the other states, i.e. the number of people in other compartments, by a state observer. In the possession of the full state information it is possible to track the time dependent reproduction numbers via a recursive least squares estimate. The results obtained are validated by detailed analysis on the basis of the available data in the literature.

POSTER 3
CODE: PA03

Title: Temperature dependent parameter estimation of Li-ion batteries

Authors: A. Pózna, K. Hangos, A. Magyar

Abstract: The identification of thermoelectric electrical vehicle battery model is addressed in this work. The basis of the proposed method is a two level estimation procedure where the first level is a series of parameter estimations of the key battery parameters at different temperatures. On the second level the thermal characteristics of the key battery parameters are fitted on the temperature dependent parameter estimates. The proposed method can be used as a computationally effective way of determining the key battery parameters at a given temperature from their actual estimated values and from their

previously determined temperature dependence. This makes the method attractive for applications like battery management systems, etc. Te results are validated by simulation experiments involving battery models of different complexity.

Poster 4
CODE: PA04

Title: Identification of the low speed steering dynamics of an autonomous car from real and simulation data

Authors: G. Rödönyi, G. Beintema, R. Tóth, M.Schoukens, D. Pup , A. Kisari, Z. Vígh, P. Kőrös, A. Soumelidis, J. Bokor

Abstract: Identification of the steering dynamics of an autonomous car prototype is addressed based on measured and simulated data taken at low speed conditions. At low speed with high steering angles, nonlinear effects coming from the wheel settings through the variation of the pneumatic trail drive the system close to the boundary of its stability region where the effects of disturbances amplify. Model identification is even more challenging by the unknown structure of the steering assist unit used as the steering actuator. In this presentation several data driven methods are compared showing the good approximation capabilities and the efficiency in dynamic system identification of a neural network based subspace-encoder that can be utilised in model predictive control. Furthermore, simulation studies show how powerful the black-box linear parameter-varying (LPV) identification tools are in comparison with first principle models.

Poster 5
CODE: PA05

Title: A simplified frequency domain approach for local module identification in dynamic networks

Authors: P. Csurcsia, K. Ramaswamy, J. Schoukens, P. Van den Hof

Abstract: In classical approaches of dynamic network identification, in order to identify a (sub)system (module) embedded in a dynamic network, one has to formulate a MISO identification problem that requires identification of a parametric model for all the modules constituting the MISO setup - including the noise model - and determine their model orders. This requirement leads to model order selection steps for modules that are of no interest to the experimenter which increases the computational complexity for large-sized networks. In this work, we provide a two-step identification approach to avoid these problems. The first step involves performing a nonparametric indirect approach for a MISO identification problem to get the non-parametric frequency response function estimates and its variance as a function of frequency. In the second step, the estimated FRF of the target module is smoothed using a parametric frequency domain estimator with the estimated variance from the previous step as the non-parametric noise model. The developed approach is practical with weak assumptions on noise, uses already available toolboxes, requires a parametric model only for the target module of interest, and uses a non-parametric noise model to reduce the variance of the estimates.

Poster 6
CODE: PA06

Title: Identification of nonlinear system linearized around a trajectory by Gaussian process

Authors: S. Ebrahimkhani, J. Lataire and R. Pintelon

Abstract: The identification of nonlinear systems linearized around a time-varying trajectory is considered. The first step is applying an excitation signal containing a slow-large signal and a fast-small signal to the system. After linearizing the nonlinear system around the large signals, the obtained system is a linear parameter varying (LPV) system. The scheduling variable vector of this LPV system is the vector of large input-output signals. Parameter-varying (PV) coefficients of this LPV system are identified by a Gaussian process using frequency-domain input-output measurements. Because these PV coefficients are the elements of the gradient vector of the nonlinear system, so a matrix-valued curl-free kernel is used to model the PV coefficients of this LPV system. This kernel ensures that the estimated LPV model is a gradient of an unknown nonlinear system. A simulation example is presented to demonstrate the performance of the proposed LPV estimator.

Poster 7
CODE: PA07

Title: A novel deep neural network architecture for non-linear system identification

Authors: L. Zancato, A. Chiuso

Abstract: We present a novel Deep Neural Network (DNN) architecture for non-linear system identification. We foster generalization by constraining DNN representational power. To do so, inspired by fading memory systems, we introduce inductive bias (on the architecture) and regularization (on the loss function). This architecture allows for automatic complexity selection based solely on available data, in this way the number of hyper-parameters that must be chosen by the user is reduced. Exploiting the highly parallelizable DNN framework (based on Stochastic optimization methods) we successfully apply our method to large scale datasets.

Poster 8
CODE: PA08

Title: Shaping multisine excitation for closed-loop identification of a mechanical transmission

Authors: B. Boukhebouz, G. Mercère, M. Gossard, E. Laroche

Abstract: In robotic systems, saturations on current and voltage are active in inner control loops. Consequently, on the one hand, high amplitudes of the excitation should be avoided when we aim at finding the underlying linear system in some frequency spectrum, because they can lead to saturation and introduce distortions in the estimated FRF. On the other hand, the need to properly excite all the robot dynamics requires large amplitude within the frequency band of interest. In this work, we present a multisine excitation design method to improve the quality of the estimated FRF in presence of saturation on the control signal and in a closed-loop setup. The method is based on the shaping of the multisine excitation that allows improving the Crest Factor of the control signal. The perspectives are to synthesize non-conservative model-based controller for a ball-screw cable actuator.

Poster 9
CODE: PA09

Title: Willems' fundamental lemma based on second-order moments

Author: M. Ferizbegovic

Abstract: We propose variations of Willems' fundamental lemma that utilize second-order moments such as correlation functions in the time domain and power spectra in the frequency domain. We believe that using a formulation with estimated correlation coefficients can reduce noise in the data, and it is suitable for data compression. Also, the formulations in the frequency domain can enable modeling of a system in a frequency region of interest.

POSTER 10
CODE: PA10

Title: Uncertainty quantification of input matrix and transfer function estimates in subspace identification

Authors: S. Greś, M. Döhler, L. Mevel

Abstract: The transfer function of a linear mechanical system can be defined in terms of the quadruplet of state-space system matrices (A,B,C,D) that can be identified from input and output measurements with subspace-based system identification methods. While the estimation of the quadruplet has been well studied in the literature, a practical algorithm for quantification of its estimation errors is missing. In this work, explicit expressions for the covariance related to matrices (B,D) are developed that can be easily computed based on sample covariances related to the measured inputs and outputs. The proposed schemes are validated on simulated data of a mechanical system and are applied to laboratory measurements of a plate.

POSTER 11
CODE: PA11

Title: A layer potential approach to functional and clinical brain imaging

Authors: M. Nemaire, J. Marmorat, J. Leblond, J. Badier

Abstract: in this work we consider the issue of identifying foci of electric activity in the human brain. We regard this as an inverse source recovery problem for L2 vector-fields normally oriented and supported on the grey/white matter interface, which together with the skull and cererospinal fluid form a non-homogeneous layered conductor. In the quasi-static approximation to Maxwell's equation, we approach this inversesource problem for EEG and MEG data. The electric data is measured in points lying both inside and outside the conductor, while the magnetic data is measured only point-wise outside. The problem is ill-posed and a Tikhonov regularization is used on triangulations of the interfaces and a piecewise linear model for the current on the triangles.
Both in the continuous and discrete formulation the electric potential is expressed as a linear combination of double layer potentials, while the magnetic flux density in the continuous case is a vector-surface integral whose discrete formulation features single layer potentials. A main feature of our approach is that these contributions can be computed exactly. Also, when dealing with Cauchy transmission problems for electric potential across interfaces, the normal derivatives at the interfaces of discontinuity of the electric conductivities are computed directly from the resulting solution. This reduces the computational complexity of the problem as we do not need to propagate these derivatives. Because of the connection between the magnetic flux density and the electrical potential, coupling the EEG and MEG data is straightforward, leading us to a unified approach that uses only single and double layer potentials. We provide numerical examples.

POSTER 12
CODE: PA12

Title: Parameter Estimation and identification of Mostar Hydroelectric Plant using PMU and synthetic data

Authors: M. Podlaski, X. Bombois, L. Vanfretti

Abstrat: The new advancements in renewable power generation such as hydroelectric power and their control systems helps create a resilient power grid and reach emission reduction goals. Simulation-based studies are indispensable in determining which technologies have the most benefit to the grid and identifying potential dynamic impacts of integrating these resources with the bulk electric grid. Having accurate models of conventional synchronous generation models is crucial with rapid integrating of inverter-based resources, such as wind and solar generation, as they have a significant impact on power system stability characteristics and performance under disturbances. In this work, PMU data collected during commissioning tests for a hydroelectric plant is used to estimate the parameters and identify the plant's model for the controllers and generator using nonlinear grey box models. The identification of the plant's components have deficiencies in exciting certain functions, so synthetic data is then used to show methods to excite and identify all functions in the models.

POSTER 13
CODE: PA13

Title: Identification of Non-linear Differential-Algebraic Equations Disturbed by Stochastic Processes

Authors: M. R.-H. Abdalmoaty, O. Eriksson, R. Bereza, D. Broman, H. Hjalmarsson

Abstract: Differential-algebraic equations (DAEs) arise naturally as a result of equation-based object-oriented modeling. Such models often contain unknown parameters that have to be identified using measured data. A challenge with the identification of physical systems is the effect of unknown disturbances. If such disturbances are ignored during the identification procedure, one can obtain poor parameter estimates. This issue has been addressed for non-linear state-space models using particle filters. However, to use such methods for non-linear DAEs, one has to re-write the model on state-space form, which is especially challenging for models with disturbances. To the best of the authors' knowledge, there are no general methods successfully dealing with parameter estimation for this type of model. In this work, we propose a simulation-based prediction error method for non-linear DAEs where disturbances are modeled as continuous-time stochastic processes. We assume that the model can be simulated using available DAE solvers. For particle filter methods, random variations in the minimized cost function due to the nature of the algorithm can make optimization difficult. A similar phenomenon occurs with our method, and we explicitly consider how to sample the underlying continuous-time disturbance to mitigate this issue. Our method is tested on a simulated pendulum example, which suggests that our method provides consistent parameter estimates.

POSTER 14
CODE: PA14

Title: Parameter Estimation of Parallel Wiener-Hammerstein Systems by Decoupling their Volterra Representations

Authors: P. Dreesen, M. Ishteva

Abstract: Nonlinear dynamic systems are often approximated by a Volterra series, which is a generalization of the Taylor series for systems with memory. However, the Volterra series lacks physical interpretation. To take advantage of the Volterra representation while aiming for an interpretable block-oriented model, we establish a link between the Volterra representation and the parallel Wiener-Hammerstein model, based on decoupling of multivariate polynomials. The true link is through a constrained decoupling model with (block-)Toeplitz structure on the factors and sets of identical internal branches. The solution of the modified decoupling problem then reveals directly the parameters of the parallel Wiener-Hammerstein model of the system. However, due to the uniqueness properties of the plain decoupling algorithm, even if the structure is not imposed, the method still leads to the true solution (in the exact case).

Poster session B (14 posters)

Poster 1
CODE: PB01

Title: Identifying faults in closed-loop systems

Authors: K. Classens, W. (Maurice) Heemels, T. Oomen

Abstract: Fault detection is essential in production machines to facilitate maintenance and minimize operational downtime. The aim of this poster is to illustrate a systematic procedure from closed-loop identification to accurate nullspace-based fault diagnosis, accounting for the influence of noise and interaction in multivariable closed-loop controlled systems. The influence of noise and interaction on the model estimate and fault diagnosis system are investigated using closed-loop operators.

Poster 2
CODE: PB02

Title: A scalable multi-step least squares method for network identification with unknown disturbance topology

Author: S. Fonken, K. Ramaswamy, P. Van den Hof.

Abstract: Identification methods for dynamic networks typically require prior knowledge of the network and disturbance topology, and often rely on solving poorly scalable non-convex optimization problems. While methods for estimating network topology are available in the literature, less attention has been paid to estimating the disturbance topology, i.e., the (spatial) noise correlation structure and the noise rank. In this work we present an identification method for dynamic networks, in which an estimation of the disturbance topology precedes the identification of the full dynamic network with known network topology. To this end we extend the multi-step Sequential Linear Regression and Weighted Null Space Fitting methods to deal with reduced rank noise, and use these methods to estimate the disturbance topology and the network dynamics. As a result, we provide a multi-step least squares algorithm with parallel computation capabilities and that rely only on explicit analytical solutions, thereby avoiding the usual non-convex optimizations involved. Consequently we consistently estimate dynamic networks of Box Jenkins model structure, while keeping the computational burden low. We provide a consistency proof that includes path-based data informativity conditions for allocation of excitation signals in the experimental design. Numerical simulations performed on a dynamic network with reduced rank noise clearly illustrate the potential of this method.

Poster 3
CODE: PB03

Title: Dynamical system identification from video data using subspace encoders

Authors: G. Beintema, R. Toth, M. Schoukens

Abstract: The increased availability of cameras for modeling dynamical systems and other spatial data sources such as PDE simulations and LIDAR, motivated us to develop the subspace encoder method. This method is able to efficiently estimate nonlinear state-space models directly from video data without requiring any manual video processing. The proposed method combines truncated simulation loss with a subspace encoder to estimate the initial states. We show the successful application of the proposed method to simulation studies and real-world experiments illustrating the computational efficiency and flexibility of the proposed method when using neural networks as a function approximator.

Poster 4
CODE: PB04

Title: Accurate $H\infty$-norm estimation via finite-frequency norms of local parametric models

Authors: P. Tacx, T. Oomen

Abstract: $H\infty$ norm estimation is crucial for robust control design. This paper aims to develop an algorithm to estimate the $H\infty$ norm accurately and reliably using limited data and limited user intervention. Traditional algorithms to determine the $H\infty$ norm rely on at-grid frequency information based on frequency response data which leads to a potentially large inter-grid error. In this paper, a local parametric modeling approach is used to improve the at-grid frequency content and to estimate the inter-grid behavior. The main idea is to estimate the global $H\infty$ norm through local finite-frequency $L\infty$ norm computation of local parametric models through the generalized KYP lemma. A simulation example shows the effectiveness of the proposed algorithm.

Poster 5
CODE: PB05

Title: Non-causal regularized least-squares for continuous-time system identification with band-limited input excitations

Authors: R. González, C. Rojas, H. Hjalmarsson

Abstract: In continuous-time system identification, the intersample behavior of the input signal is known to play a crucial role in the performance of estimation methods. One common input behavior assumption is that the spectrum of the input is band-limited. The sinc interpolation property of these input signals yields equivalent discrete-time representations that are non-causal. This observation, often overlooked in the literature, is exploited in this work to study non-parametric frequency response estimators of linear continuous-time systems. We study the properties of non-causal least-square estimators for continuous-time system identification, and propose a kernel-based non-causal regularized least-squares approach for estimating the band-limited equivalent impulse response. The proposed methods are tested via extensive numerical simulations.

Poster 6
CODE: PB06

Title: Control and Estimation of Ensembles via Structured Optimal Transport

Authors: I. Haasler, J. Karlsson, A. Ringh

Abstract: The optimal transport problem is to find a mapping that moves the mass between two distributions, while minimizing the total transport cost. We describe how optimal transport can be used to formulate and solve optimal control problems and state estimation problems for ensembles of dynamical systems. Based on this we provide a duality result between control and estimation for multiagent systems similar to the classical result by Kalman.

Poster 7
CODE: PB07

Title: Dual adaptive model predictive control using application-oriented set membership identification

Author: A. Parsi, A. Iannelli, R. Smith

Abstract: Adaptive model predictive control (MPC) is a control algorithm which can be applied to linear dynamical systems affected by uncertain parameters in the state space matrices and exogenous disturbances. In this technique, a tube MPC approach is used to guarantee constraint satisfaction and set-membership identification is used to reduce model uncertainty online. In this work, we propose an application- oriented dual adaptive MPC scheme to address the exploration-exploitation trade-off that is inherent in the control of uncertain systems. The effect of future control inputs on parameter identification is modeled using a parameter estimate, which provides a prediction of the next state measurement. The predicted state measurement is then used to construct a non-falsified set of parameters, called the predicted parameter set. The evolution of state trajectories within the prediction horizon for all the parameters in the predicted parameter set is bounded by a predicted state tube. The MPC cost is defined as a worst-case cost over the predicted state tube, thereby modeling the performance improvement achieved by identifying smaller parameter sets. The advantages of the proposed method over non-dual adaptive MPC approaches are demonstrated using a simulation study.

POSTER 8

CODE: PB08

Title: Necessary graph condition for local network identifiability

Authors: A. Legat, J. Hendrickx

Abstract: This work focuses on the generic identifiability of dynamical networks with partial excitation and measurement: a set of nodes are interconnected by transfer functions according to a known topology, some nodes are excited, some are measured, and only a part of the transfer functions are known. Our goal is to determine whether the unknown transfer functions can be generically recovered based on the input-output data collected from the excited and measured nodes. We propose a decoupled version of generic identifiability that is necessary for generic local identifiability and might be equivalent as no counter-example to sufficiency has been found yet in systematic trials. This new notion can be interpreted as the generic identifiability of a larger network, obtained by duplicating the graph, exciting one copy and measuring the other copy. We establish a necessary condition for decoupled identifiability in terms of vertex-disjoint paths in the larger graph, and a sufficient one.

POSTER 9

CODE: PB09

Title: Distance correlation screening for separable decompositions of MIMO non-linear systems

Authors: P. Wachel, K. Tiels, M. Filinski

Abstract: We propose a new structure exploration technique developed for the multiple-input multiple-output dynamical systems with finite memory. The algorithm applies distance correlation screening for preselection of those system inputs that contribute to the consecutive system outputs and estimates projection coefficients, sensitive to the existence of additive system sub-characteristics. Hence, the method allows for exploration of the internal system structure and thus may support further modelling or identification tasks. A numerical experiment illustrates the ability of the proposed approach to indicate which of the system inputs contribute to which outputs and illustrates the ability of the approach to detect separable lower-dimensional sub-characteristics in the system.

POSTER 10
CODE: PB10

Title: Identification of nonlinear systems using LPV model identification around a time-varying trajectory

Authors: S. Ebrahimkhani, J. Lataire, R. Pintelon

Abstract: Generally, real dynamical systems are nonlinear and suffer from modeling uncertainties and noise. Obtaining an accurate model of these systems is the first step for designing a high-performance control system, analysis, prediction, and or monitoring the health condition of such systems. This research deals with the identification of the nonlinear system. In this research the structure of the nonlinear system is unknown. Then the nonlinear system is linearized around a time-varying trajectory which leads to an LPV system. Once the LPV system is identified, by symbolic integration the nonlinear model can be reconstructed. In this research, a frequency-domain Curl-free LPV estimator is developed in which the estimated LPV model is the gradient of an unknown nonlinear system. Using the curl-free LPV estimator ensures that the reconstructed nonlinear system is unique, while it uses fewer unknown parameters with respect to the standard LPV estimator. The uniqueness of the reconstructed nonlinear model enables the identification of nonlinear and LPV models at the same time. A numerical example is presented to show the effectiveness of the proposed approach.

POSTER 11
CODE: PB11

Title: Regularized switched system identification: a statistical learning perspective

Authors: L. Massucci, F. Lauer, M. Gilson

Abstract: This talk deals with the identification of hybrid dynamical systems that switch arbitrarily between modes. Switched system identification is a challenging problem, for which many methods were proposed over the last twenty years. Despite this effort, estimating the number of modes of switched systems from input–output data remains a nontrivial and critical issue for most of these methods. A novel method from statistical learning including regularized models, and more precisely based on structural risk minimization, is presented. It relies on minimizing an upper bound on the expected prediction error of the model.

POSTER 12
CODE: PB12

Title: Excitation allocation for generic identifiability of linear dynamic networks with fixed modules

Authors: H. Dreef, S. Shi, X. Cheng, M. Donkers, P. Van den Hof

Abstract: Identifiability in dynamic networks, where node signals are interconnected through modules that represent linear time-invariant systems, depends on which nodes are subject to external excitation signals. It is typically desirable to allocate a minimal number of excitation signals to satisfy identifiability conditions in order to minimize impact on the operation of the network. In this work, we show that the presence of fixed modules, i.e., the ones that are known a priori and thus nonparametrized, reduces the required number of excitation signals to achieve an identifiable network model set. We develop a graphical method to allocate a minimal number of excitation signals for generic identifiability of a network model set in the presence of fixed modules. Furthermore, an algorithm is proposed that performs this graphical method in a systematic fashion.

Poster 13
CODE: PB13

Title: Improved Experiment Design for the Identification of Complex Real-World Systems

Authors: Fredrik Ljungberg, Stefanie Zimmermann, Martin Enqvist

Abstract: The formal problem of optimal experiment design for identification of nonlinear systems is often hard to solve. This holds especially if the system under consideration shows significant nonlinear behavior, and if it has many input signals, which lead to many degrees of freedom in the experiment design. In this work, experiment design for two complex real-world systems is explored. The main idea is to reduce the design problem to choosing the best combination of simpler excitation signals out of a pre-defined set of candidate excitations. Even though this approach will fail to guarantee optimality in a wide sense, this work shows that the experiment design can be improved in terms of shorter experiment execution times and more accurate identification results. An existing approach to this problem is adapted and discussed for two applications: A frequency-domain identification approach for industrial manipulators and a time-domain instrumental variable approach for the identification of marine systems. The effectiveness of the improved experiment design is demonstrated both using simulated and real data.

Poster 14
CODE: PB14

Title : Long-term individual household electrical consumption forecasting

Authors : L. Botman, B. De Moor

Abstract : Electrical load forecasting has been a challenge for a long time. Two dimensions can be considered: the horizon (i.e. the length of the forecast in the future) and the granularity (i.e. a geographical specification). Another relevant parameter is the sampling time, which can vary from per second to yearly values, and which is strongly linked with the horizon dimension. If the electrical consumption of a city has to be predicted ten years ahead, an hourly forecast would not be relevant. We focus on the prediction of the monthly electrical consumption of individual household for the entire next year. We work with 3000 half hourly sampled time series over a period of one year, which contain household load consumption values. The algorithm is a hybrid method that consists of multiple steps applied sequentially. These steps involve data pre-processing (data aggregation and normalization), data augmentation, k-means clustering, median prediction, and smoothing. The prediction is based on the clustering results and using a ratio approach. The method reaches state-of-the-art accuracy and was one of the top three forecasting solutions (out of 71 participants) in the Technical Challenge of the IEEE Computational Intelligence Society. The method is also highly scalable thanks to the low computational power and the small amount data necessary, i.e., the algorithm is able to predict one year ahead even with only a couple of months of historical consumption data. Nor weather data, nor household attributes are required. We now want to investigate the short-term forecasting of individual households. However, one additional challenge has to be taken into account: there is a very high uncertainty in the data, due to (almost) unpredictable human behavior.

Poster session C (14 posters)

Poster 1
CODE: PC01

Title: Local identification in physical networks

Authors: E. (Lizan) Kivits, P. Van den Hof

Abstract: Physical dynamic networks most commonly consist of interconnections of physical components that can be described by diffusive couplings. These diffusive couplings imply that the cause-effect relationships in the interconnections are symmetric and therefore physical dynamic networks can be represented by undirected graphs. This poster shows how the symmetric structure can be utilized for identification of local dynamics in physical dynamic networks.

Poster 2
CODE: PC02

Title: Bayesian tensor network-based Volterra system identification

Author: E. Memmel

Abstract: High-order discrete nonlinear multiple-input multiple output (MIMO) Volterra system identification problems can be solved by Tensor Network-based iterative algorithms. We combine this approach with a probabilistic Bayesian interpretation of the iterative alternating linear scheme, and obtain an estimate about the accuracy of the Volterra coefficients. This estimate can then also be used to provide confidence bounds on the predictions.

Poster 3
CODE: PC03

Title: Large-Scale nonlinear system identification with Fourier features and tensor decompositions

Author: F. Wesel

Abstract: Random Fourier features provide a way to tackle large-scale machine learning problems with kernel methods. Their slow Monte Carlo convergence rate has motivated the research of deterministic Fourier features whose approximation error decreases exponentially with the number of frequencies. However, due to their tensor product structure these methods suffer heavily from the curse of dimensionality, limiting their applicability to two or three-dimensional scenarios. In our approach we overcome said curse of dimensionality by exploiting the tensor product structure of deterministic Fourier features, which enables us to represent the model parameters as a low-rank tensor decomposition. We derive a monotonically converging block coordinate descent algorithm with linear complexity in both the sample size and the dimensionality of the inputs for a regularized squared loss function, allowing to learn a parsimonious model in decomposed form using deterministic Fourier features.

Poster 4
CODE: PC04

Title: Decoupling multivariate functions using a nonparametric filtered tensor decomposition

Authors: J. Decuyper, K. Tiels, S. Weiland, M. Runacres, J. Schoukens

Abstract: Multivariate functions emerge naturally in a wide variety of data-driven models. Popular choices are expressions in the form of basis expansions or neural networks. While highly affective, the resulting functions tend to be hard to interpret, in part caused by the large number of required parameters. Decoupling techniques aim at providing an alternative representation of the nonlinearity. The so-called decoupled form is often a more efficient parameterisation of the relationship while being highly structured, favouring interpretability. In this work a novel algorithm, based on filtered tensor decompositions of first order derivative information is used. The method finds direct applications in, i.a. the fields of nonlinear system identification and machine learning

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Poster 5
CODE: PC05

Title: What is the Koopman form of nonlinear systems with inputs?

Authors: L. Cristian Iacob, R. Tóth, M. Schoukens

Abstract: In recent years, the Koopman framework has become a popular approach used to obtain linear surrogate models of nonlinear dynamical systems. The main concept is to lift the nonlinear state space through so called observable functions, resulting in a linear space (generally infinite dimensional), where the observable dynamics are governed by the Koopman operator. In its original formulation, autonomous systems were solely treated, however, recent developments have extended the concepts for systems with inputs. In continuous time representations, through the use of the chain rule and the properties of the time derivative, the corresponding Koopman form of the nonlinear system can be derived with relative ease. Most system identification techniques, however, are generally designed for discrete time formulations. Nonetheless, a method to derive the Koopman model of a discrete time nonlinear system has been lacking, as particular forms (generally LTI) are usually assumed, without a formal proof of their validity. To address this, using the Fundamental Theorem of Calculus, we present a method to derive the Koopman model associated to a nonlinear discrete time system. In the present poster, we will focus on control affine nonlinear systems, showcasing a motivating example.

Poster 6
CODE: PC06

Title: Cooperative system identification via correctional learning

Authors: I. De Miranda De Matos Lourenco, B. Wahlberg

Abstract: We consider a cooperative system identification scenario in which an expert agent (teacher) knows a correct, or at least a good, model of the system and aims to assist a learner-agent (student), but cannot directly transfer its knowledge to the student. For example, the teacher's knowledge of the system might be abstract or the teacher and student might be employing different model classes, which renders the teacher's parameters uninformative to the student. We propose correctional learning as an approach to the above problem: suppose that in order to assist the student, the teacher can intercept the observations collected from the system and modify them to maximize the amount of information the student receives about the system. We formulate a general solution as an optimization problem, which for a multinomial system instantiates itself as an integer program. Furthermore, we obtain finite-sample results on the improvement that the assistance from the teacher results in (as measured by the reduction in the variance of the estimator) for a binomial system. We illustrate the proposed algorithms and verify the theoretical results that have been derived.

Poster 7
CODE: PC07

Title: Signal matrix model in simulation, signal denoising and control design

Author: M. Yin, A. Iannelli, R. Smith

Abstract: In large-scale complex systems, conventional system identification approaches may fail to obtain a compact parametric model of the systems reliably. Instead, abundant data are available to help us understand the behaviors of the systems directly. In this poster, we will introduce the signal matrix model, a novel type of implicit non-parametric models built directly from data. Each column of the signal matrices contains a signal trajectory obtained from data, possibly with singular value decomposition for data compression. In the noise-free case, it is known that all trajectories of linear systems within a finite horizon can be described by the signal matrix, when the data are sufficiently informative. This motivates applications in data-driven simulation and control. This poster discusses the extension of this idea to the noisy case with statistical tools. We focus on the applications of simulation, signal denoising, and optimal control design with signal matrix models containing noisy data. The simulation problem aims at finding a linear combination of signal matrix columns compatible with the known initial conditions and inputs by maximum likelihood estimation. It maximizes the conditional probability density of observing the trajectory estimate given the combination. The signal matrix model is also able to obtain statistically optimal trajectory estimates from any combination of partial and stochastic information about the trajectory. Such information includes prior knowledge of the trajectory in simulation, noisy signal measurements in signal denoising, and control objectives with reference trajectories in optimal control design. Maximum a posteriori estimation is conducted to combine a linear combination of signal matrix columns and the information about the trajectory. The linear combination is considered as hyperparameters here and optimized by the empirical Bayes method. It will be demonstrated by numerical examples that the signal matrix model is effective in providing a reliable non-parametric model in these applications.

Poster 8
CODE: PC08

Title: Nonlinear model estimation via linearization around large signals

Authors: M. Sharabiany, J. Lataire, R. Pintelon

Abstract: Linearization of a system around a constant operating point has been known for a long time as an efficient, well-established and reliable approach for the control and identification of nonlinear systems. The derived LTI (linear time-invariant) system parameters depend on the underlying nonlinear system and the operating point itself. It is also possible to linearize the system around a variable operating point. Similarly, the derived linear system depends on aforementioned two factors . The difference is that the variable operating point gives a time-varying linear system instead of an LTI one.\\

This LTV (linear time-varying) system enables us to estimate the corresponding nonlinear system along that operating point. The key issue is that the coefficients of any linearized system, constructed around an operating point, are the gradient of the nonlinear system evaluated at that operating point. This gradient is a vector function and is the same as the LTV model parameters. So, having estimated the LTV coefficients and having known the variable operating point itself, one can proceed to model the gradient of the nonlinear system along the variable operating point. Finally, one can integrate the acquired gradient model to have a nonlinear model of the initial system. This nonlinear model needs another estimation step which refines the model parameters further.

Poster 9

CODE: PC09

Title: Multi-armed bandit schemes for adaptive model predictive control

Authors: P. Wachel and C. Rojas

Abstract: We propose a novel approach to introduce adaptation in model predictive control (MPC) by considering a finite set of possible models and the usage of adversarial multi-armed bandits theory to develop adaptation. Under weak assumptions, we then establish theoretical bounds on the performance of the proposed algorithm and show its empirical behaviour via simulation examples.

Poster 10
CODE: PC10

Title: Incorporating prior knowledge in kernel-based estimators: a frequency domain approach

Authors: N. Hallemans, R. Pintelon and J. Lataire

Abstract: Nonparametric kernel-based modelling of dynamical systems offers important advantages over other nonparametric techniques; the estimate is a continuous function, the model complexity is continuously tuneable, and stability, causality and smoothness are imposed on the impulse response estimate. However, for lightly damped systems, most of the existing kernel-based approaches for estimating the impulse- or frequency response function fail because classical kernels are not appropriate for describing lowly damped resonances. By introducing the superposition of different kernels, carrying prior knowledge about the resonant poles of the system, we make the kernel-based modelling of lightly-damped systems possible with high-accuracy. We use a frequency domain local rational modelling technique as preprocessing step to determine the most dominant poles, and include these as prior knowledge in the kernels. The performance of the new kernel is demonstrated on a highly resonating simulated system and compared to the state of the art nonparametric frequency domain approaches.

Poster 11
CODE: PC11

Title: Estimating Koopman operators for data driven control

Authors: F. Zanini, A. Chiuso

Abstract: The Koopman operator framework allows for an alternative description of a nonlinear dynamical system, in a linear but infinite-dimensional fashion. This is accomplished by considering the evolution of scalar-valued functions of the state, rather than the state itself. When learning the Koopman operator from data, it is necessary to maintain a finite-dimensional approximation: Extended Dynamic Mode Decomposition is a standard technique that relies on a fixed dictionary of functions. The latter can be improved by adding regularisation, which allows the procedure to deal with noise in measurements, and by performing the estimation in Reproducing Kernel Hilbert Spaces, that corresponds to consider an infinite-dimensional dictionary of functions. This estimator of the dynamics can also be extended to non-autonomous systems, allowing for predictions which take into account the control variable. By considering the evolution of the cost of the system over time, it is then possible to retrieve an estimation of the performances obtained by a particular control scheme. The control parameter can be iteratively adjusted following the descent direction of the overall cost, thus improving step by step both the controller, aimed at minimising the cost, as well as the predictions, since more and more data will be collected.

POSTER 12
CODE: PC12

Title: Robust-control-relevant experiment design and system identification

Authors: N. Dirkx, T. Oomen

Abstract: The robust performance of model-based controllers hinges on the quality of the identified model set. The aim of this poster is to achieve high-performance robust control through a robust-control oriented experiment design and system identification approach. First, a specific nonnormalized coprime factorization is selected to establish a transparent connection to the robust control criterion, the identification criterion, and the experiment design criterion. This result is exploited in a two-stage coprime factor identification algorithm to achieve optimal identification of robust-control-relevant model sets. Furthermore, a robust-control-relevant experiment design algorithm is presented that enables identification of minimum-size model sets within experimental constraints. Application to a wafer stage system confirms that the presented approach enables high-performance robust control.

POSTER 13
CODE: PC13

Title: A recursive algorithm to compute a numerical basis of the null space of the block Macaulay matrix

Authors: C. Vermeersch, B. De Moor

Abstract: Although the null space of the block Macaulay matrix yields numerical results that are exact within machine precision, the block Macaulay matrix algorithm suffers from a troublesome, large computational complexity.
The main culprit of this large computational complexity is the construction of a numerical basis of this null space. Therefore, we propose a new, recursive algorithm to determine a numerical basis, which exploits the sparsity and structure of the (banded) Toeplitz-like block Macaulay matrix. Moreover, an adaptation of the recursive algorithm that avoids the explicit construction of the block Macaulay matrix has a big memory advantage over the more conservative approach. To reveal the structure of the null space, i.e., to identify the linearly independent rows of the numerical basis and to split the affine solutions from the solutions at infinity, we can even employ a second recursive orthogonalization algorithm. Together, these two recursive orthogonalization algorithms achieve considerable improvements over the standard approach, both in computation time and required memory. A particular example is the identification of a small ARMA(1, 1) model via the block Macaulay matrix: the recursive (sparse and structured) approach computes a numerical basis 300 times faster than its standard (dense and unstructured) counterpart.

POSTER 14
CODE: PC14

Title: Length of stay prediction in a simulated hospital environment using transfer learning

Authors: L. Naomi Wamba Momo, N. Moorosi, E. Nsoesie, B. De Moor

Abstract: The demand for healthcare is gradually on a rise worldwide. Provision of compassionate, accessible and high quality of care within cost containments requires efficient planning by hospital management systems, hours or days ahead. Such planning systems can be built by predicting the bed occupancy of each patient within the hospital by monitoring their length of stay (LoS). In a real-hospital setting, patients are admitted to different medical units based on comorbidities, admission complaints, etc. Preceding authors have shown that units of admissions effectively reflect different patient behaviors

and should be taken into account when modelling. In other to mimic the real hospital setting and provide more granular information to the hospital management system, we developed an efficient LoS prediction mechanism that could be deployed within a hospital at low-cost while taking into account patient specificities within their admission units. In this work, we extract the first 24 hours of data from 89,123 patients from eICU Collaborative Research Database. The singularity of these patients across the eight ICU units they are admitted to results in varying input sizes and dimensions. By employing a long short-term memory network (that learns the temporal dynamics in patient information) and transfer learning techniques (to initiate model training), we are able to learn both the shared (across medical units) and specific (within units) characteristics of all patients, resulting into a robust, accurate and hospital adapted model. Overall, the model achieves better prediction in a less amount time even in instances of varying input dimensions between the source and target domains. For example when applying transfer learning, up to two hours of training are saved for patients admitted to neurological ICU.