PID'12
Book of Abstracts

IFAC Conference on Advances in PID Control
Brescia (Italy)
March 28-30, 2012

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Welcome to PID'12

On behalf of the National Organizing Committee and of the International Programme Committee it is my pleasure to welcome you to the IFAC Conference on Advances in PID Control, held at the University of Brescia, Italy, on March 28-30, 2012.
PID controllers are undoubtedly the most employed controllers in industry. The previous meeting dedicated to PID controllers was organised by IFAC in 2000 in Terrassa (Spain). That workshop was a great success and it has given a significant impulse in the research in PID controllers, as witnessed by the large number of papers published in the last ten years on this subject. The present edition of the conference brings together academic and industrial experts in the field coming from all over the world in order to present the recent research developments in the design of PID controllers. More than 120 papers will be presented during the meeting in regular and poster sessions. Further, a panel session has been organized where representatives of important PID manufacturers and end-users will give their opinionS on the future perspective of PID controllers.
Last but not least, the program includes three plenary sessions where leading researchers from academia and industry will discuss the most recent advances in PID control. I would like to express my thanks to all participants: to the authors, whose high-quality work is the essence of the conference, and to all the members of the International Program Committee and of the Organizing Committee who did their best to set the scene for a successful event. I wish you a pleasant stay in Brescia, city of art and culture in one of the most important industrial districts of Europe, and I wish you a fruitful and inspiring meeting. I trust that you will leave the PID'12 conference with a wealth of new knowledge and ideas in addition to building on your professional networks and friendships.

Antonio Visioli
University of Brescia
National Organizing Committee Chair

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WePl: Signal Filtering in PID Control (Plenary Session) 9.00-10.00, Sala Consiliare

Chair: Sebastian Dormido *UNED (E)*

Tore Hägglund *Lund University (S)*

The major input signals entering the PID controller are: the setpoint, the process output, and measurable load disturbances. By feeding these signals through suitable filters before they enter the PID controller, the properties of the feedback loop can be improved significantly. This presentation will treat setpoint handling, feedforward from load disturbances, TITO control, noise filtering, and process dynamics compensation.

Biography

Tore Hågglund is professor in automatic control at Lund University in Sweden. His main research interests include PID control, process control, monitoring and diagnosis, and industrial implementation and applications. Tore Hågglund has written several books about PID and process control, has worked at ABB for four years, and holds several patents in the area.

WeA1: Design of PID Control Systems I
10.30-12.30, Sala Consiliare

Chair: Karl Johan Åström — *Lund University (S)*
Co-Chair: Willy Wojsznis — *Emerson Process Management (USA)*

Intelligent PID product design

Willy Wojsznis — *Emerson Process Management (USA)*
Terry Blevins — *Emerson Process Management (USA)*
John Caldwell — *Emerson Process Management (USA)*
Peter Wojsznis — *Emerson Process Management (USA)*
Nixon Mark — *Emerson Process Management (USA)*

This paper outlines intelligent PID design for DCS. The design includes a PID algorithm with diverse standard options and algorithm extensions for wireless/event-driven control and for surge control. The core of the PID intelligence is adaptive process modeling based on model switching and parameter interpolation. The developed process model is applied to loop tuning, adaptive control, loop performance evaluation and valve diagnostics. A user-friendly interface provides insight into a loop's current state and history events. The interface also provides advice about how to improve loop performance.

Unified PID tuning approach for stable, integrative and unstable dead-time processes

Julio Normey-Rico — *Federal University of Santa Catarina (BR)*
Jose Luis Guzman — *University of Almeria (E)*

This paper presents a unified approach for tuning PID controllers for stable, integrative and unstable dead-time processes. The approach is based on a PID approximation of the Filtered Smith Predictor that allows to control this kind of processes looking for a trade-off between performance and robustness. The proposed control tuning method is simple to analyze and use. Cases studies are included to illustrate the advantages of the proposed tuning rules. Furthermore, comparisons with other existing methods are presented to show that the proposed unified method provides promising results.

Design and analysis of IMC based PID controller design for unstable systems for enhanced closed loop performance

A.V.N.L Anusha — *National Institute of Technology, Tiruchirappalli (IND)*
Seshagiri Rao Ambati — *National Institute of Technology, Tiruchirappalli (IND)*

In this paper, design of PID controller is analyzed for unstable second order processes with time delay based on IMC method and H2 minimization. A new desired closed loop transfer function is obtained based on which the PID controller is designed. Maclaurin series is used to approximate the controller expression as a PID controller. Improved closed loop performances are achieved with the proposed method when compared to the recently reported methods in the literature. Comparative analysis has also been carried out with modified Smith predictor schemes and showed that the proposed method is superior. Further, an analysis is carried out based on maximum sensitivity for arriving at systematic guidelines for selection

of the closed loop tuning parameter which is essential for unstable systems. The bounds for this tuning parameter are analyzed using the maximum sensitivity.

Criteria and trade-offs in PID design

Olof Garpinger — *Lund University (S)*
Tore Hägglund — *Lund University (S)*
Karl Johan Åström — *Lund University (S)*

Control design is a rich problem which requires that many issues such as load disturbances and set-point responses, model uncertainty, and measurement noise are taken into account. These issues are discussed for design of PI and PID controllers. The purpose is to give insight into the different criteria and their trade-offs, not to give specific tuning methods.

Design of adaptive I-PD control for systems including time lag

Tsuyoshi Shiota — *Keio University (J)*
Hiromitsu Ohmori — *Keio University (J)*

Proportional-Integral-Derivative (PID) controllers are undoubtedly the most employed controllers in industry. Also, since the so called exact model matching is impossible in the actual realities, the partial model matching from the lowest order term to as higher the term as possible is adopted by Kitamori. This controller has a structure which cousists of information about the controlled object and the reference model. PID can be obtained after some manipulation from the original solution. Thus a problem arises which is the superior, the original one or PID. In this paper, we propose adaptive I-PD controller using augmented error method for SISO systems. In addition, we show the effectiveness of the proposed method by the simulation result.

Robust semi-automatic design of PID controllers for systems with time delay

Guillermo P. Falconí — *Technische Universität München (D)*
Jürgen E. Ackermann — *DLR (D)*

In this paper an extension of the Matlab-tool PIDrobust is presented. This tool calculates the entire set of PID controllers that stabilizes a set of linear systems with time delay simultaneously. On this basis an iteratively algorithm is used to improve σ-stability in order to assist operators. At the end of the process the operator is able to judge the results and interactively choose a controller. This tool needs much less computational effort than other optimization methods and achieves similar performance. It is can also be used for tuning robust controllers by means of the parameter space approach.

WeA2: FRIT PID Design (Invited Session)
10.30-12.30, Aula N8

Chair: Toru Yamamoto — *Hiroshima University (J)*
Co-Chair: Osamu Kaneko — *Kanazawa University (J)*

PFC design via FRIT approach and adaptive PID control system design for discrete-time systems

Ikuro Mizumoto — *Kumamoto University (J)*
Taro Takagi — *Kumamoto University (J)*

This paper deals with a design problem of an adaptive PID control for discretetime systems with a parallel feedforward compensator (PFC) which is designed for making the augmented controlled system ASPR. A PFC design scheme by a FRIT approach with only using an input/output experimental data set will be proposed for discrete-time systems in order to design an adaptive PID control system. Furthermore, the effectiveness of the proposed PFC design and an adaptive PID control method will be confirmed through numerical simulations for an uncertain discrete-time system.

Fictitious reference tuning using information in frequency domain

Yoshihiro Matsui — *Tokyo National College of Technology (J)*
Tomohiko Kimura — *Tokyo National College of Technology (J)*
Kazushi Nakano — *The University of Electro-Communications (J)*

In this paper, an application method of Fictitious Reference Iterative Tuning (FRIT), which has been developed for controller gain tuning for single-input single-output systems, to state feedback gain tuning for single-input multivariable systems is proposed. Transient response data of a single-input multivariable plant obtained under closed-loop operation is used for model matching by the FRIT in time domain. The data is also used in frequency domain to estimate the stability and to improve the control performance of the closed-loop system with the state feedback gain tuned by the method. The method is applied to a state feedback control system for an inverted pendulum with an inertia rotor and its usefulness is illustrated through experiments.

Online controller tuning via FRIT and recursive least-squares

Yuji Wakasa — *Yamaguchi University (J)*
Kanya Tanaka — *Yamaguchi University (J)*
Yuki Nishimura — *Yamaguchi University (J)*

This paper proposes an online type of controller parameter tuning method by modifying the standard fictitious reference iterative tuning method and by utilizing the so-called recursive least-squares (RLS) algorithm, which can cope with variation of plant characteristics adaptively. As used in many applications, the RLS algorithm with a forgetting factor is also applied to give more weight to more recent data, which is appropriate for adaptive controller tuning. Moreover, we extend the proposed method to online tuning of the feed-forward controller of a two-degree-of-freedom control system. Finally, numerical examples are provided to illustrate the effectiveness of the proposed method.

A design of nonlinear PID controller with neural net based FRIT

Yoshihiro Ohnishi — *Ehime University (J)*
Shin Wakitani — *Hiroshima University (J)*
Toru Yamamoto — *Hiroshima University (J)*

Some design schemes of model-free controllers which do not require any system models have been considered in the last decade. FRIT(Fictitious Reference Iterative Tuning) method that directly computes the control parameters from the operating data have been proposed as the one of model-free controllers. FRIT has some useful practical features. One is that it does not require system identification. Another is that the control parameters can be directly computed using only a set of closed loop input/output data and the desired output signal. The calculations of the control parameters needs the optimization of the cost functions. The ordinary approach is the gradient method. However, this calculations derives only linear parameters. Therefore, the applications of FRIT are limited for linear systems. In this paper, a new approach to the discrete FRIT-based nonlinear PID control is proposed. The neural network is utilized for the optimization of FRIT. PID parameters are adequately adjusted corresponding to the nonlinear properties. The conventional schemes by using the neural networks require the information of system Jacobian to update weighting factors. This proposed method can calculate the control parameters without the information of system Jacobian or system parameters except for the information about the time-delay.

FRIT based PID parameter tuning for linear time delay systems - simultaneous attainment of models and controllers -

Osamu Kaneko — *Kanazawa University (J)*
Yusuke Wadagaki — *Kanazawa University (J)*
Shigeru Yamamoto — *Kanazawa University (J)*

In this paper, we provide a new method of the PID parameter tuning for time-delay systems by utilizing the fictitious reference iterative tuning (FRIT), which is a controller tuning method enabling us to obtain the desired parameter with only one-shot experimental data. Here, by relating the conventional PID controller to the internal model controller (IMC), we show that PID parameters obtained as the result of the FRIT yield not only a desired controller but also a mathematical model of the controlled time delay system. In order to show the validity of the proposed method, we give an illustrative example.

PID controller tuning based on disturbance attenuation FRIT using one-shot experimental data due to a load change disturbance

Shiro Masuda — *Tokyo Metropolitan University (J)*

A direct design approaches based on input-output measurements with no need for help from a plant model have attracted attention from several researchers. We have recently proposed such a disturbance attenuation FRIT method using input-output data generated by disturbances. The approach has advantages that it can tune PID gains to improve feedback properties, such as disturbance attenuation. Furthermore, the method has been applied to PID control gain tuning. The method tunes PID gains using one-shot experimental data generated by a known step-type disturbance added at the input signal. However, additive known step-type signal implies a test signal to identify the characteristic of the control systems, so the case where the method can be applied may be restricted. The paper, therefore, gives a tuning method using a one-shot experimental data generated by a load change. Such a disturbance has a possibility that the data can be collected during a full operation. The proposed method can be realized by estimating the magnitude of an impulse and step signal for a load change disturbance from one-shot

experimental data. The proposed method realizes the approach by modeling a load change disturbance as a linear combination of a step signal and an impulse signal, where the weighting parameters are unknown. The paper also gives the way how unknown parameters are estimated from the one-shot initial input-output data. Finally, this paper shows the efficiency of the disturbance attenuation FRIT through the experimental result of a helicopter attitude control model when the disturbance is known or correctly estimated.

WeB1: Design of PID Control Systems II
13.30-15.30, Sala Consiliare

Chair: Robin de Keyser — *Ghent University (B)*
Co-Chair: Manuel Berenguel Soria — *University of Almería (E)*

Design of feedback control for underdamped systems

Damir Vrancic — *J. Stefan Institute (SLO)*
Paulo Moura Oliveira — *University of Tras-os-Montes e Alto Douro (P)*

In practice, there are several processes which are exhibiting oscillatory behaviour. Some representatives are disk-drive heads, robot arms, cranes and power-electronics. One of techniques, aimed at reducing the oscillations, is Posicast Input Command Shaping (PICS) method. The paper combines the PICS method and Magnitude Optimum Multiple Integration (MOMI) tuning method for PID controllers. The combination of both methods significantly improves the speed and stability of the closed-loop tracking responses. Moreover, the proposed approach is relatively simple for implementation in practice and can be used either on process time-response data or on the process model in frequency-domain.

Laboratory essay with online back-calculation anti-windup scheme for a MTG system

Antônio Miguel Salla Neto — *Federal University of Santa Catarina (BR)*
Thaise Damo — *Federal University of Santa Catarina (BR)*
Antonio Coelho — *Federal University of Santa Catarina (BR)*

This paper describes a lecture based on a laboratory experiment of the under-graduate course of Control and Automation Engineering at the Federal University of Santa Catarina. The goal is to show to the students the differences, codes and performance of tuning methods for the PID controller implemented with online back-calculation anti-windup scheme applied to a MTG (motor+tacogenerator) plant. The assessed system is used in many activities of a laboratory discipline of Feedback Systems. The whole study is conducted with a real plant instead of relying on computational numerical simulation. Analyzed tuning methods are: Ziegler-Nichols, Chien-Hrones-Reswick, Åström-Hägglund, AMIGO. Finally, the PID, tuned by the Internal Model Control (IMC), is also evaluated for different filter design parameters. The online experiment gives a better understanding, for the students, of how different tuning methods modify the system stability and the magnitude of the control signal.

Improvements on the filtered Smith predictor using the Clegg integrator

Jose Carlos Moreno — *University of Almeria (E)*
Jose Luis Guzman — *University of Almeria (E)*
Julio Elias Normey-Rico — *Federal University of Santa Catarina (BR)*
Alfonso Baños — *University of Murcia (E)*
Manuel Berenguel — *University of Almeria (E)*

This paper presents a non-linear control scheme to deal with dead-time (DT) processes where small rise times are required. The control scheme is based on the combination of two strategies appeared in the

literature to deal with DT processes, the Filtered Smith Predictor (FSP), which is a Smith Predictor (SP) including a filter to improve the robustness, and the PI+CI, a PI with a partial reset action on the control signal when the process output is equal to the reference input. In the proposed strategy, the reset action allows to achieve very small rise times with small overshoots, improving the results from FSP. On the other hand, the use of the robust predictor allows to deal with the dead time in a better and systematic way than the PI+CI with variable reset ratio and variable reset band does.

Oscillation shaping in uncertain linear plants with nonlinear PI control: analysis and experimental results

Alessandro Pilloni — *University of Cagliari (I)*
Alessandro Pisano — *University of Cagliari (I)*
Elio Usai — *University of Cagliari (I)*

Linear systems controlled by a nonlinear version of the PI algorithm are under study. The modified PI controller in question is known in the literature as the Super–Twisting (STW) algorithm (see Levant (1993)), and it belongs to the family of second order sliding mode controllers. The considered closed–loop system exhibits self–sustained stable oscillations (chattering) when the relative degree of the linear plant is higher than one (see Boiko and Fridman (2005)) and it is the task of the present paper to present a systematic yet simple procedure for tuning the STW algorithm parameters in order to obtain pre–specified frequency and magnitude of the resulting chattering oscillation. The proposed methodology is based on the Describing Function (DF) approach. The approach is theoretically illustrated and verified by means of, both, simulation analysis and experiments carried out by making references to a DC motor.

The next generation of relay-based PID autotuners (part 1): some insights on the performance of simple relay-based PID autotuners

Clara Mihaela Ionescu — *Ghent University (B)*
Robin De Keyser — *Ghent University (B)*

The paper presents theoretical insights which might lead to further development of improved relay-based PID autotuners. The analysis is based on the first generation of autotuners, namely the widely used Åström-Hägglund relay-feedback tuner. The analysis is accompanied by illustrative examples. The performance of the autotuners is evaluated against a reference PID controller which is designed using computer aided design tools and assuming full knowledge of the system's transfer function. The paper is concluded by pointing towards some ideas to design a more generally valid version of the PID autotuner.

The next generation of relay-based PID autotuners (part 2): a simple relay-based PID autotuner with specified modulus margin

Robin De Keyser — *Ghent University (B)*
Oana-Lucia Joita — *Technical University of Cluj-Napoca (RO)*
Clara Mihaela Ionescu — *Ghent University (B)*

The purpose of this paper is to present the development and evaluation of a novel PID autotuner. Based on prior art results, the algorithm uses the location of the critical point and the value of the critical frequency of the process to impose a user specified robustness on the closed loop. It is shown that the method is easy to apply with few choices left for the user. Nevertheless it is quite successful on systems which are relevant from process engineering point of view.

WeB2: Software Tools for PID Control (Invited Session)
13.30-15.30, Aula N8

Chair: Jose Luis Guzman — *University of Almería (E)*
Co-Chair: Tore Hägglund — *Lund University (S)*

Data-driven robust PID tuning toolbox

José David Rojas — *Universitat Autònoma de Barcelona (E)*
Ramon Vilanova — *Universitat Autònoma de Barcelona (E)*

In this paper, a toolbox is presented for the parameter tuning of PID controllers based on the Virtual Reference Feedback Tuning. The VRFT is a data-driven methodology that uses only data to find the parameters of the controller. In order to add robustness to the design, a test is proposed and implemented in the tool that use an approximation of the multiplicative uncertainty in an "Internal Model Control" like framework to check if the controller found is robustly stable.

Software for PID design: benefits and pitfalls

Olof Garpinger — *Lund University (S)*
Tore Hägglund — *Lund University (S)*
Lars Cederqvist — *Swedish Nuclear Fuel & Waste Management Company (S)*

The most common PID design methods in industry are based on formulas. This article will present some major advantages of instead using the power of computer based softwares for PID controller design. The Matlab based software used in this work was developed in 2007 and derives robust, IAE minimizing, PID controllers. The experiences of using this software are collected in this article and include control signal activity limitation due to measurement noise, controller design on an industrial Friction Stir Welding process and fast controller design for large batches of processes. It is shown that the properties of the software make it suitable for design of PID controllers and in PID research. There are, however, some possible design pitfalls that the user needs to be aware of. Some of these are presented as well.

I-PIDtune: an interactive tool for integrated system identification and PID control

Jose Luis Guzman — *University of Almeria (E)*
Daniel Rivera — *Arizona State University (USA)*
Manuel Berenguel — *University of Almeria (E)*
Sebastián Dormido — *UNED (E)*

This paper describes i-pIDtune, an interactive software tool that integrates system identification and PID controller design. The tool supports experimental design and execution under plant-friendly conditions, high-order ARX estimation, and control-relevant model reduction leading to models that comply with the IMC-PID tuning rules. All these stages are depicted simultaneously and interactively in one screen. Thus, i-pIDtune allows to display both open- and closed-loop responses of the estimated models and important control-relevant validation criteria, what enables the user to readily assess how design variable choices, control performance requirements and model error can impact the achievable closed-loop performance from a restricted complexity model estimated under noisy conditions.

Object-oriented modelling of industrial PID controllers

Alberto Leva — *Politecnico di Milano (I)*
Marco Bonvini — *Politecnico di Milano (I)*
Martina Maggio — *Politecnico di Milano (I)*

This paper presents a library of (PID) controller models adopting the object-oriented approach, and written in Modelica. Peculiar to this work is that controllers are represented both as dynamic continuous-time and digital models, achieving consistence between the two and accounting for the functionalities of typical industrial implementations. This allows the designer to use realistic controllers, maintaining the possibility of choosing the continuous-time or digital (event based) representation. The former allows for example for variable-step simulation, to the advantage of efficiency, while the latter represents very realistically the actual control system's operation, clearly at the cost of more simulation time. Beside standard PI and PID controls, in this work also autotuning is (initially) considered, and some application examples are reported to show how the presented library can ease system studies involving (PID) controls.

A toolbox for robust PID controller tuning using convex optimization

Mehdi Sadeghpour — *EPFL (CH)*
Vinicius De Oliveira — *EPFL (CH)*
Alireza Karimi — *EPFL (CH)*

A robust PID controller design toolbox for Matlab is presented in this paper. The design is based on linearizing or convexifying the conventional non-convex constraints on the classical robustness margins or H_∞ constraints. Then the existing optimization solvers can be used to compute the controller parameters. The software can be used in a wide range of controller design problems, including multi-model systems and gain-scheduled controllers. The models can be parametric or non-parametric while the software is compatible with the output data of the identification toolbox of Matlab. Three illustrative examples exhibit convenience of working with the developed commands.

An interactive software tool for the study of event-based PI controller

Sebastián Dormido — *UNED (E)*
Manuel Beschi — *University of Brescia (I)*
José Sánchez — *UNED (E)*
Antonio Visioli — *University of Brescia (I)*

The paper describes an interactive tool focused on the study of a new family of event-based PI controller. Most research in control engineering considers periodic or time-driven control systems. Eventbased control is particularly a very promising alternative when systems with reduced computation and communication capacities are considered. For event-driven controllers it is the occurrence of an event, instead of the autonomous progression of the time what decides when the signal sampling should be made. The tool has been developed using Sysquake, a Matlab-like language with fast execution and excellent facilities for interactive graphics. The highly visual and strongly coupled nature of event based control system is very amenable to interactive tools. The tool presented in this paper enables to discover a myriad of important properties of these systems.

WeC1: Robustness Issues in PID Control
16.00-18.00, Sala Consiliare

Chair: Sigurd Skogestad *NTNU (N)*
Co-Chair: Peter Hansen *(USA)*

Parametric robustness

Peter Hansen *(USA)*

Gain and time-constant factors shift the inverse process relative to its feedback controller. A new robustness plot cross-graphs these shift factors that take the loop to the stability boundary as a function of frequency.

Comparison between robust PID and predictive PI controllers with constrained control signal noise sensitivity

Per-Ola Larsson *Lund University (S)*
Tore Hägglund *Lund University (S)*

A performance comparison between PID and predictive PI (PPI) controllers, i.e., two different prediction methods, is presented. Optimization of controller and measurement filter parameters, considering load disturbance rejection, robustness and noise sensitivity, is performed for a batch of industrially representative processes. For a majority of the processes and the constraints chosen, results show that the performances of the controllers are similar. However, the PID controller yields better performance for processes where increased phase and gain may be achieved over a wider frequency interval than what is possible by the PPI controller.

A look into robustness/performance and servo/regulation issues in PI tuning

Salva Alcántara *Universitat Autònoma de Barcelona (E)*
Ramon Vilanova *Universitat Autònoma de Barcelona (E)*
Carles Pedret *Universitat Autònoma de Barcelona (E)*
Sigurd Skogestad *NTNU (N)*

This paper addresses the model-based tuning of Proportional-Integral (PI) controllers focusing on the robustness/performance and servo/regulation trade-offs. First, a tuning rule is derived analytically by solving a simple H_∞ weighted sensitivity problem, where the weight is chosen so that two design parameters permit to adjust the considered conflicting objectives. This way, the resulting tuning expressions show clearly how the controller's parameters should be changed to shift each trade-off, giving insight into the tuning task. Then, we proceed to study the two trade-offs at hand and the interplay between them.

Fragility-rings - a graphic tool for PI/PID controllers robustness-fragility analysis

Victor Alfaro — *Universidad de Costa Rica (CR)*
Ramon Vilanova — *Universitat Autonoma de Barcelona (E)*

The aim of the paper is to present the Delta 20 Fragility-Rings plot and its use for robustness-fragility analysis of proportional integral (PI) and proportional integral derivative (PID) controllers. Using the Delta 20 Fragility Index and the Nyquist plot it shows the areas on the $L(j\omega)$ plane corresponding to robustness-fragile, robustness-non-fragile and robustnessresilient controllers providing a visual aid for evaluation of the controller robustness-fragility when its parameters are perturbed.

Robustness considerations on PID tuning for regulatory control of inverse response processes

Víctor M. Alfaro — *Universidad de Costa Rica (CR)*
Pedro Balaguer — *Universitat Jaume I de Castelló (E)*
Orlando Arrieta — *Universitat Autònoma de Barcelona (E)*

In general, to control industrial processes that show an inverse response output is difficult. This difficulty arises because achievable performance and robustness levels are competing factors that the designer has to deal with. In this paper we focus on proportional integral derivative (PID) control of inverse response processes, in particular with the Direct Synthesis design for disturbance rejection DS-d tuning method of Chen and Seborg. The paper presents equations that link the control system design performance parameter (closedloop control system speed) with its minimum robustness level, measured with the maximum sensitivity MS , for the mentioned tuning method. In this way, the proposed result allows to obtain robust PID control systems with MS ≤ 2 for inverse response processes. The examples show the effectiveness of the proposed design parameter lower limit estimation for the DS-d tuning method.

Robust gain-scheduled smith PID controllers for second order lpv systems with time varying delay

Vicenç Puig — *UPC (E)*
Yolanda Bolea — *UPC (E)*
Joaquim Blesa — *UPC (E)*

In this paper, a new approach to design a robust gain scheduled linear parameter varying (LPV) PID controller with pole placement constraints (through LMI regions) is proposed for LPV systems with second order structure and time-varying delay. The controller structure includes a Smith predictor, real time estimated parameters that schedule the controller and Smith predictor (using the known part of the delay) and unstructured dynamic uncertainty which covers the delay uncertainty. Finally, the proposed control technique is validated in a real case study based on a piece of a sewer system.

WeC2: Multivariable PID Control (Invited Session)
16.00-18.00, Aula N8

Chair: Johannes Van Dijk — *University of Twente (NL)*
Co-Chair: Manuel Gil Ortega — *Universidad de Sevilla (E)*

Model order reduction for decentralized PID control design on TITO processes

Pedro Balaguer — *Universitat Jaume I de Castelló (E)*
Julio Ariel Romero — *Universitat Jaume I de Castelló (E)*

The decentralized PID control design of multivariable processes is an appealing approach due to its practical applicability and the existence of a good theoretical basis. However, although industrial processes may be modeled using simple first order and second order models, in decentralized control, the models increase their complexity due to loop interaction, compromising the applicability of existing PID tuning rules. In fact, even inverse response behavior may appear due to loop interaction. The contribution of the article is twofold. First, we derive conditions to assess the inverse response behavior of reduced effective transfer functions. As a result, we know when tuning rules for first order and minimum phase second order models are suited for decentralized control tunning. Secondly, at the sight of matrix transfer function parameters, we derive simplified models in a straightforward way. The results are useful for decentralized MIMO process control design using simple tuning rules derived for first order and second order systems.

Extending the AMIGO PID tuning method to MIMO systems

Julio Ariel Romero — *Universitat Jaume I de Castelló (E)*
Pedro Balaguer — *Universitat Jaume I de Castelló (E)*

In this paper a methodology for tuning decentralised PID is proposed, which is based on the AMIGO method for SISO systems. The study addresses MIMO systems with transfer matrix made up of first-order with time delay models that describe a large number of industrial processes. The proposed approach is evaluated by means of simulation studies that show the results of its application to several systems.

Minimum-time rest-to-rest feedforward action for PID feedback MIMO systems

Luca Consolini — *Università di Parma (I)*
Gabriele Lini — *Università di Parma (I)*
Aurelio Piazzi — *Università di Parma (I)*
Antonio Visioli — *University of Brescia (I)*

In this paper we present a methodology for the design of a feedforward control law to be applied to a closed-loop PID-based control system for a multi-input multi-output process in order to achieve a minimum-time rest-to-rest transition of the system from an equilibrium point to another subject to constraints on both the control and process variables. In particular, the proposed approach uses decentralized PID controllers which can be designed by any of the conventional methods, such as, for example, those aiming at rejection of load disturbances. Then, the closed-loop generalized bang-bang command input vector is determined

by applying a linear programming approach in order to minimize the rest-to-rest output transitions. Conditions for the constraints for which the problem admits a solution are given. Simulations for a two-inputs two-outputs plant highlight the effectiveness of the approach.

Analytical one parameter method for PID motion controller settings

Johannes Van Dijk — *University of Twente (NL)*
Ronald Aarts — *University of Twente (NL)*

In this paper analytical expressions for PID-controllers settings for electromechanical motion systems are presented. It will be shown that by an adequate frequency domain oriented parametrization, the parameters of a PID-controller are analytically dependent on one variable only, the cross-over frequency of the open loop transfer function. Analytical expressions are derived that relate the cross-over frequency clearly to the performance criteria for the closed loop system. In this paper the latter is shown in detail for servo problems. The effectiveness of the outlined approach is demonstrated by experimental results that were obtained from a two DOF tilting mirror system.

Robust PID control of the quadrotor helicopter

Ramon Andres Garcia — *Universidad de Sevilla (E)*
Francisco Rodriguez Rubio — *Universidad de Sevilla (E)*
Manuel Gil Ortega — *Universidad de Sevilla (E)*

In this paper a robust PID control strategy via affine parametrization is designed for an multivariable nonlinear unmanned aerial vehicle. The robustness of the controlled system is assured by using the H_∞ norm of the weighted complementary sensitivity function. Simulation results carried out using a complete nonlinear model are shown, wherein the performance achieved with this control strategy is shown.

2-DOF decoupling controller formulation for set-point following on decentraliced PI/PID MIMO systems

Ramon Vilanova — *Universitat Autònoma de Barcelona (E)*
Reza Katebi — *University of Strathclyde (GB)*

This paper presents a formulation for the inclusion of the second degree of freedom for MIMO system for decoupling purposes. The proposal is specially effective when combined with decentralized feedback controllers. Loop interaction is of the major problems in the control of MIMO systems, as interaction can be considered as a disturbance coming from all other loops, the design of the decentralized feedback controller is better understood as a disturbance rejection design. In this approach the set-point tracking capabilities may be not as good as expected. The proposed Two-Degree-of-Freedom (2-DoF) formulation provides a complement to the existing controller that can be automatically determined in terms of the available process and feedback controller information.

WePS: Applications of PID Controllers (Poster Session) 10.00-18.00, Poster Area

Chair: Alf J. Isaksson — *Linköping University (S)*
Co-Chair: Reza Katebi — *University of Strathclyde (GB)*

Wind turbine control using PI pitch angle controller

Abdulhamed Hwas — *University of Strathclyde (GB)*
Reza Katebi — *University of Strathclyde (GB)*

This paper suggests two methods to calculate the gains of a proportional-Integral pitch angle controller for a 5 MW wind turbine. The first method is analytical and the second one is based on simulation. Firstly, the power coefficient characteristics for different pitch angles are calculated. Secondly, the output powers vs. rotor speed curves from cut-in to cut-out wind speeds are simulated. The results from first and second analyses used to find the control gains at different wind speeds. Finally, the results are compared using a wind turbine model to determinate turbine's tracking characteristic.

FPAA-based PI controller for DC servo position control system

Somanath Majhi — *IIT Guwahati (IND)*
Virendra Kotwal — *IIT Guwahati (IND)*
Utkal Mehta — *Faculty of Technology, Changa (IND)*

In this paper, the real-time application is implemented for a DC servo position control system using Field Programmable Analog Array (FPAA) technology. An automatic tuning technique based on relay feedback is successfully implemented for obtaining the dynamics of a plant. A non-iterative tuning formulae is used in order to reduce the control efforts and to obtain the desired position. Results of real-time hardware-in-the-loop evaluation, obtained when running the on-line relay feedback test together with initial PI settings and improved response with updated settings, are reported.

Adaptive control system based on linear control theory for the path-following problem of a car-like mobile robot

Jose Luis Sanchez-Lopez — *Polytechnic University of Madrid (E)*
Pascual Campoy — *Polytechnic University of Madrid (E)*
Miguel Angel Olivares-Mendez — *Polytechnic University of Madrid (E)*
Ignacio Mellado-Bataller — *Polytechnic University of Madrid (E)*

The objective of this paper is to design a path following control system for a car-like mobile robot using classical linear control techniques, so that it adapts on-line to varying conditions during the trajectory following task. The main advantages of the proposed control structure is that well known linear control theory can be applied in calculating the PID controllers to fulfil control requirements, while at the same time it is flexible to be applied in non-linear changing conditions of the path following task. For this purpose the Frenet frame kinematic model of the robot is linearised at a varying working point that is calculated as a function of the actual velocity, the path curvature and kinematic parameters of the robot, yielding a transfer function that varies during the trajectory. The proposed controller is formed

by a combination of an adaptive PID and a feed-forward controller, which varies accordingly with the working conditions and compensates the non-linearity of the system. The good features and flexibility of the proposed control structure have been demonstrated through realistic simulations that include both kinematics and dynamics of the car-like robot.

Dual-space feedforward control of a redundantly actuated parallel manipulator for very high speed applications

Guilherme Sartori-Natal — *LIRMM (F)*
Ahmed Chemori — *LIRMM (F)*
Micaël Michelin — *LIRMM (F)*
François Pierrot — *LIRMM (F)*

This paper deals with dual-space control of R4 redundantly actuated parallel manipulator for very high acceleration applications. This controller consists in a PID in the Cartesian space complied with a feedforward of the desired acceleration in both Cartesian and articular spaces for tracking performance improvements: models show that this "dual-space" control strategy is an efficient way to implement computed torque control. For comparison purposes, experiments were made with a Cartesian PID until 20G. Experimental results show that the proposed control scheme is considerably better than the PID in the Cartesian space, and that a good tracking performance could be achieved even for the very high acceleration of 40G (equivalent to more than 425 pick-and-place cycles per minute).

Practical control of surge tanks suffering from frequent inlet flow upsets

Peter Rosander — *Linköping University (S)*
Alf J. Isaksson — *Linköping University (S)*
Johan Löfberg — *Linköping University (S)*
Krister Forsman — *Perstorp AB (S)*

In the presence of frequent inlet flow upsets, tuning of averaging level controllers is typically quite complicated since not only the size of the individual steps but also the time in between the subsequent steps need to considered. One structured way to achieve optimal filtering for such a case is to use Robust Model Predictive Control. The robust MPC controller is, however, quite computationally demanding and not easy to implement. In this paper two linear controllers, which mimic the behavior of the robust MPC, are proposed. Tuning guidelines to avoid violation of the tank level constraints as well as to achieve optimal filtering are presented.

Controller design methods for driving systems based on extensions of symmetrical optimum method with DC and BLDC motor applications

Stefan Preitl — *Politehnica University of Timisoara (RO)*
Alexandra-Iulia Stinean — *Politehnica University of Timisoara (RO)*
Radu-Emil Precup — *Politehnica University of Timisoara (RO)*
Zsuzsa Preitl — *Budapest University of Technology and Economics (H)*
Emil Petriu — *University of Ottawa (CDN)*
Claudia-Adina Dragos — *Politehnica University of Timisoara (RO)*
Mircea-Bogdan Radac — *Politehnica University of Timisoara (RO)*

The paper gives design methods dedicated to speed control of Direct Current (DC) and Brushless Direct Current (BLDC) motors in the framework of servo systems. Two design approaches are offered for

position and speed control of servo systems with inner current control loops. The PI and PID controllers in these approaches are tuned on the basis the Extended Symmetrical Optimum method and of the double parameterization of Symmetrical Optimum method. Cost-effective features are ensured by simple controller designs and easy implementations, and they are illustrated by means of a case study that includes simulation results. A two-degree-of-freedom interpretation is given. A BLDC motor application applied to mechatronic systems is presented.

Pressure control of a large scale water network using integral action

Gerard Sanz *UPC (E)*
Ramon Pérez *UPC (E)*
Ricard Sánchez *UPC (E)*

This paper presents a study of the effect of performing different control structures on a large scale water network. The aim is to keep network pressures stable and to their minimum in order to increase network efficiency and reduce leakage loss. One and two actuators pressure control is presented, including split range pressure control, all based on PID family. Simulations are performed using a simulation model of a real network (Demand Management Area situated in Barcelona). Resulting pressures of different control structures are compared. Subsequently, some leakages are introduced to the network to conclude which pressure control structure minimizes best the water loss. Finally, some discussions of the benefits of using each control structure are presented.

Two DOF fuzzy gain scheduling PI for combustion turbogenerator speed control

Arnulfo Rodriguez-Martinez *Institute of Electrical Research (MEX)*
Raul Garduno-Ramirez *Institute of Electrical Research (MEX)*

This paper presents two realizations a 2-DOF PI fuzzy gain-scheduling controller for wide- range speed control of combustion turbogenerators. The 2-DOF scheme allows independent tuning of the reference tracking and the disturbance rejection characteristics for the controlled system. Then, the fuzzy approach extends these characteristics all over the operating space of the combustion turbogenerator. Both realizations can be inserted into the speed control loop of existing control systems without degrading performance. Once in the loop, the controllers can be progressively tuned on-site, based on the inspection of speed responses. The proposed 2-DOF PI fuzzy gain-scheduling control schemes are suitable for application on actual combustion turbogenerators

Fault-tolerant fuzzy gain-scheduled PID for a quadrotor helicopter testbed in the presence of actuator faults

Mohammad Hadi Amoozgar *Concordia University (CDN)*
Abbas Chamseddine *Concordia University (CDN)*
Youmin Zhang *Concordia Univeristy (CDN)*

In the current study, an adaptive PID controller is proposed for fault-tolerant control of a quadrotor helicopter system in the presence of actuator faults. A fuzzy inference scheme is used to tune in real-time the controller gains. Tracking errors and change in tracking errors are used in this fuzzy scheduler to make the system act faster and more effectively in the event of fault occurrence. Two fault scenarios are investigated: the loss of control effectiveness in all actuators and the loss of control effectiveness in one single actuator. The proposed adaptive PID controller is compared with the conventional one

through an experimental application to a quadrotor helicopter testbed at the Department of Mechanical and Industrial Engineering of Concordia University. The obtained results show the effectiveness of the proposed method.

A multilevel coordinated control strategy for energy conservation in wastewater treatment plants

Angelo Dainotto — *University of Florence (I)*
Giacomo Barni — *University of Florence (I)*
Francesca Giaccherini — *University of Florence (I)*
Valeria Magnolfi — *University of Florence (I)*
Stefano Marsili-Libelli — *University of Florence (I)*
Irene Simonetti — *University of Florence (I)*

Wastewater treatment is an energy-intensive process pursuing two objectives: pollution abatement and energy conservation. To achieve these goals automatic control must be applied. This paper describes the performance improvement obtained by the coordinated automation of some basic process operations. Starting with the basic dissolved oxygen control, coordinated control actions are then introduced and their performance assessed. After discussing the design alternatives, the performance of the best combination is selected on the basis of energy conservation, provided that the effluent quality meets the environmental standards. It is shown that a combination of properly tuned PID and fuzzy regulators considerably improves the energy efficiency of the process.

Application of a supervised improved PID for the scheduling of energy feeding in a PV - battery system

Lucio Ciabattoni — *Università Politecnica delle Marche (I)*
Gianluca Ippoliti — *Università Politecnica delle Marche (I)*
Matteo Cavalletti — *Energy Resources SPA (I)*
Marco Rocchetti — *Energy Resources SPA (I)*
Sauro Longhi — *Università Politecnica delle Marche (I)*

This paper deals with the development of a PID control architecture for better utilization of the storage battery connected to a PhotoVoltaic (PV) Plant. The problem of the stochastic nature of the PV plant is overcomed scheduling the power feeding of the electric line. A neural network is used to derive the one-day-forecast of the PV production and a supervised PID controller is proposed to control the charge and discharge current reference to the battery, that is used as an energy buffer. The communication between all the parts of the system and the supervisor controller is made via TCP/IP protocol. The Energy Resources company has supported the experimentally tests of the proposed solution on a 14 KWp PV plant and a lithium battery pack.

Head pressure minimization of a visbreaking column through an advanced PID controllers architecture

David Barchiesi — *Università Politecnica delle Marche (I)*
Giacomo Astolfi — *Università Politecnica delle Marche (I)*
Silvia Maria Zanoli — *Università Politecnica delle Marche (I)*

In this paper an advanced PID control architecture developed to minimize the head pressure of a visbreaking column is presented. The implemented control strategy has been designed through an advanced

interconnection of PID controllers typically used in industrial processes: cascade control, feedforward control and override control. In order to correctly identify the interactions of the key variables, a RGA analysis has been performed. The proposed control system has been previously tested on simulation, thus been able to evaluate its performances in terms of robustness, stability and rejection of the main disturbances of the process. The results on the plant of the column optimization confirmed its effectiveness in the minimization of the head pressure. In this way, the new controller guaranties an increase of the separation between the heavy and light components and an increase of the extraction of the valuable products like gasoline and Light GasOil. The application of the proposed control architecture has allowed reaching an important economic recovery.

A cascade PID-PD controller for a hybrid piezo-hydraulic actuator in camless internal combustion engines

Paolo Mercorelli *Leuphana Universität Lüneburg (D)*

This paper deals with a hybrid actuator composed by a piezo and a hydraulic part and with a cascade PID-PD control structure for camless engine motor applications. The idea is to use the advantages of both, the high precision of the piezo and the force of the hydraulic part. In fact, piezoelectric actuators (PEAs) are commonly used for precision positionings, despite PEAs present nonlinearities, such as hysteresis, saturations, and creep. In the control problem such nonlinearities must be taken into account. In this paper the Preisach dynamic model with the above mentioned nonlinearities is considered together with a cascade PID-PD controller which is realized through sliding surfaces. Simulations with real data are shown.

PID controller design for "in vitro" exposure system at mobile phone frequencies

Raffaele Iervolino *Università Federico II, Napoli (I)*
Rita Massa *Università Federico II, Napoli (I)*

In the recent years, the analysis of the possible dangerous biological effects of electromagnetic fields at mobile phone frequencies has become of relevant interest for the scientific community. The availability of a controlled exposure system may help in performing meaningful experiments. To this aim, a suitable PID control is designed starting from a mathematical model of the exposure system. Both the structure and the parameters of the proposed model are derived directly from the experimental results. The effectiveness of the controller is also demonstrated via experimental evaluations.

Thursday (March 29)

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(Plenary Session)</td></tr>
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of PID Controllers I
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Applications</td><td>Benchmark for PID'12
(Invited Session)</td></tr>
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<tr><td>13.30–15.30</td><td>Optimization Methods in
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ThPl: Optimal PI-Control and Verification of the SIMC Tuning Rule (Plenary Session)
8.30-9.30, Sala Consiliare

Chair: Ramon Vilanova *Universitat Autònoma de Barcelona (E)*

Sigurd Skogestad *NTNU (N)*

Major advances that improve control in the process industry have been made over the last ten years in the basic PID technology of modern distributed control systems. This paper addresses the impact that international standards have on control implementation and the tools utilized in industry for monitoring and commissioning PID control. Examples are used to illustrate how new technologies, such as model switching for process identification, have allowed manufacturers to introduce a new level of ease-of-use in tools developed for on-demand and adaptive tuning. This paper discusses PID modifications that improve the speed of recovery from process saturation conditions that are common in industrial applications. Also, details are provided on PID modifications that enable effective control with non-periodic measurement updates by wireless transmitters. Finally, prospective future directions for industrial PID controllers are sketched.

Biography

Sigurd Skogestad received his Ph.D. degree from the California Institute of Technology, Pasadena, USA in 1987. He has been a full professor at Norwegian University of Science and Technology (NTNU), Trondheim, Norway since 1987 and he was Head of the Department of Chemical Engineering from 1999 to 2009. He is the principal author, together with Prof. Ian Postlethwaite, of the book "Multivariable feedback control" published by Wiley in 1996 (first edition) and 2005 (second edition). He received the Ted Peterson Award from AIChE in 1989, the George S. Axelby Outstanding Paper Award from IEEE in 1990, the O. Hugo Schuck Best Paper Award from the American Automatic Control Council in 1992, and the Best Paper Award 2004 from Computers and Chemical Engineering. He was an Editor of Automatica during the period 1996-2002. His research interests include the use of feedback as a tool to make the system well-behaved (including self-optimizing control), limitations on performance in linear systems, control structure design and plantwide control, interactions between process design and control, and distillation column design, control and dynamics.

ThA1: Non-Standard PID Applications
10.00-12.00, Sala Consiliare

Chair: Alberto Leva — *Politecnico di Milano (I)*
Co-Chair: Daniel Sbarbaro — *Universidad de concepcion (RCH)*

A nonlinear PI controller for optical tweezers system

Daniel Sbarbaro — *Universidad de concepcion (RCH)*
Carlos Toro — *Universidad de Concepcion (RCH)*

Positioning an optical tweezer is a complex task due to the inherent nonlinear characteristic of the process and the multiple disturbances that affect its behavior. In this work, a nonlinear PID controller is proposed to address the challenges posed by this task. The control scheme is designed to minimize the effect of uncertainties and external forces that perturb the system. The stability of the closed loop system is analyzed by using standard Lypaunov theory. Some numerical simulations illustrate the robustness of the proposed control scheme under random thermal and constant perturbations.

Closed-loop anesthesia in children using a PID controller: a pilot study

Kristian Soltesz — *Lund University (S)*
Klaske Van Heusden — *University of British Columbia (CDN)*
Guy Dumont — *University of British Columbia (CDN)*
Tore Hagglund — *Lund University (S)*
Christian Petersen — *BC Children's Hospital (CDN)*
Nicholas West — *BC Children's Hospital (CDN)*
Mark Ansermino — *BC Children's Hospital (CDN)*

The first study with a PID controller based automatic drug delivery system for propofol anesthesia in children is presented. It is shown that a robustly tuned PID controller is capable of delivering safe and adequate anesthesia. The design process of the control system is reviewed. Results are discussed and compared to those of two previous studies in adults.

Acoustic impedance matching using loop shaping PID controller design

Michail Pelegrinis — *The University of Sheffield (GB)*
Simon Pope — *The University of Sheffield (GB)*
Steve Daley — *University of Southampton (GB)*

For several decades Proportional-Integral-Derivative control (PID) has been successfully used for a wide variety of industrial processes and remains the most used method. Recent work concerning the tuning of PID control coefficients has been proven to provide both robust and near-optimal performance using a Frequency Loop Shaping (FLS) procedure. The FLS tuning method minimizes the difference between the actual and the desired target loop transfer function. Such a control design procedure is ideal for problems in which the desired closed loop frequency response is predetermined over a specific frequency band. This paper explores the possibilities and trade-offs of applying the FLS control strategy in Active Noise Control (ANC) problems. The use of the FLS design is ideal for the problem of noise suppression

in ducts, because the required acoustic impedance for the elimination of reflecting sound waves in the one-dimensional case is well defined. Hence, by controlling locally the reflecting boundary structure, a global cancelation of the undesired noise can be accomplished.

A PI-based control structure as an operating system scheduler

Martina Maggio — *Politecnico di Milano (I)*
Federico Terraneo — *Politecnico di Milano (I)*
Alessandro Vittorio Papadopoulos — *Politecnico di Milano (I)*
Alberto Leva — *Politecnico di Milano (I)*

Many functions of operating systems are keen to be realised as feedback controllers. Doing so has a non negligible design impact, but also a significant payoff in terms of simplicity and generality. This paper presents a complete operating system scheduler, at present implemented in a microcontroller kernel, entirely composed of a PI-based control structure. The proposed scheduler is experimented with in several load conditions. In all of them, it performs in a comparable manner with respect to the classical (i.e., not control-based) policy optimised for that condition, as long as design assumptions such as schedulability are met. In addition, if some off-design situation is encountered, the proposed controlbased scheduler definitely outperforms those not conceived as controllers.

Robust and gain-scheduled PID controller design for condensing boilers by linear programming

Vinicius De Oliveira — *EPFL (CH)*
Alireza Karimi — *EPFL (CH)*

This paper addresses the water temperature control in condensing domestic boilers. The main challenge of this process under the controller design perspective is the fact that the dynamics of condensing boilers are strongly affected by the demanded water flow rate. Two approaches are presented in this paper. First, a robust PI controller is designed that stabilizes and achieves good performance for closed-loop system for a wide range of the water flow rate. Then, it is shown that if the water flow rate information is used to update the controller gains, a technique known as gain-scheduled control, the performance can be significantly improved. Several models of a boiler in different water flow rate are identified in collaboration with Honeywell, and the effectiveness of the results are illustrated by simulation.

PI controller for electron density control in low pressure plasma

Yang Zhang — *Dublin City University (IRL)*
Bernard Keville — *Dublin City University (IRL)*
Cezar Gaman — *Dublin City University (IRL)*
Anthony Holohan — *Dublin City University (IRL)*
Stephen Daniels — *Dublin City University (IRL)*

This paper reports a PID control application for real-time feedback control of electron density, ne , in a low pressure, capacitively coupled plasma chamber. Experimental results are presented which demonstrate that a PI controller enables effective control of electron density when radio frequency power is used as an actuator. A hairpin resonator probe is used to measure the electron density, when the resonator is placed in plasma, its characteristic resonance frequency in vacuum shifts to a higher value. From the frequency shifts, electron density can be easily determined. Actuation and data acquisition are briefly outlined.

ThA2: Benchmark for PID'12 (Invited Session)
10.00-12.00, Aula N8

Chair: Fernando Morilla — *UNED (E)*
Co-Chair: Antonio Coelho — *Federal University of Santa Catarina (BR)*

Benchmark for PID control based on the boiler control problem

Fernando Morilla — *UNED (E)*

This paper describes the benchmark proposed for the IFAC Conference on Advances in PID Controllers (PID'12) at the end of july 2011. It is expected that this benchmark allows researchers to test their recent developments in the design of PID controllers. Two approaches to the boiling process were provided; the first ready to test a multivariable PID controller and the second ready to test PID controller, both with or without feedforward. Nevertheless, the boiler control systems described in this paper are ready to test other multivariable control strategies. The full documentation about the benchmark was linked from the website PID'12 and will remain in www.dia.uned.es/ fmorilla/benchmarkPID2012.

Multivariable PID control by inverted decoupling: application to the benchmark PID 2012

Juan Garrido — *Universidad de Cordoba (E)*
Francisco Vázquez — *Universidad de Cordoba (E)*
Fernando Morilla — *UNED (E)*

This paper deals with the boiler control problem proposed as a benchmark for the IFAC Conference on Advances in PID Controllers (PID'12). This boiling process is a multivariable nonlinear system that shows interactions and is subjected to input constraints. As proposal, in this work, a PID control by inverted decoupling with feedforward compensation is developed. The design simplicity and easiness of implementation are highlighted. Experiment simulations considered in the benchmark show that the proposed design achieves better performance indexes than those of the reference cases.

Application of data-driven loop-shaping method to multi-loop control design of benchmark PID 2012

Masami Saeki — *Hiroshima University (J)*
Kyosuke Ogawa — *Hiroshima University (J)*
Nobutaka Wada — *Hiroshima University (J)*

In this paper, an MIMO boiler control problem of Benchmark PID 2012 is studied, and a multi-loop PID control system is designed by our data-driven loop-shaping method. Our method is applicable to non-minimum phase or time-delay SISO plants very easily especially for stable plants, and a good disturbance rejection can be attained with a specified stability margin. The boiler model has non-minimum phase and integrating properties. A two step design procedure is newly presented so that our design method can be applied to integrating processes. The multi-loop controller consists of one PID and one PID-PD controllers, and each PID controller is designed by using a one-shot input-output response around the operating point. The control performance is considerably improved compared with a conservative initial PID gain.

PID controller design for MIMO systems by applying balanced truncation to integral-type optimal servomechanism

Yoshimasa Ochi *National Defense Academy (J)*

A closed-loop balanced truncation technique has been applied to an integral-type optimal servomechanism (IOS) expressed in graph-operator form of normalized right coprime factorization to produce a reduced-size state-feedback gain matrix, which is then converted into proportional-derivative (PD) gain matrices. On the other hand, the states of the integral of control error in the IOS are not truncated, so that the feedback gain matrix of the IOS for the states becomes the integral (I) gain matrix. All the design procedure is completed with the state-space approach, which is convenient especially in dealing with multiple-input multiple-output (MIMO) systems. Application of the proposed method to the boiler system of the PID '12 benchmark problem demonstrates the effectiveness of the design method.

Model-free adaptive PID controllers applied to the benchmark PID'12

Antonio Silveira *Federal University of Santa Catarina (BR)*
Antonio Coelho *Federal University of Santa Catarina (BR)*
Francisco Gomes *Federal University of Juiz de Fora (BR)*

Many tuning strategies for PID control algorithms have been proposed in the literature depending on modeling choice from heuristics, physical laws and/or experimental essays. In this paper, the properties of three model-free adaptive PID control design conceptions, known as direct PID control, are investigated and implemented. The recursive least squares estimator is used to identify the PID controller gains without the knowledge of the plant mathematical model. The tuning strategies of the direct PID controller are applied to the boiler control system proposed by Fernando Morilla (UNED, Spain) as a benchmark problem for the 2012 IFAC Conference on Advances in PID Controllers.

Multivariable PI control for a boiler plant benchmark using the virtual reference feedback tuning

José David Rojas *Universitat Autònoma de Barcelona (E)*
Fernando Morilla *UNED (E)*
Ramón Vilanova *Universitat Autònoma de Barcelona (E)*

In this work, the Virtual Reference Feedback Tuning is applied to the control of a boiler plant benchmark. Only data (without any modelling step) was used to compute a series of PI controllers for both a decentralized and a complete multi-loop control strategies. When compared with other PI controllers, it was found that a better tuning of the controller was achieved yielding better closed-loop results. The original VRFT method was enhanced with a series of constraints during the optimization process that allows the user to select the position of the zero of the controller.

ThB1: Optimization Methods in PID Control
13.30-15.30, Sala Consiliare

Chair: Ioan Dumitrache — *University "Politehnica" of Bucharest (RO)*
Co-Chair: Mikulas Huba — *Slovak University of Technology in Bratislava (SK)*

Spectral abscissa minimization when algebraic control of unstable LTI-TDS

Libor Pekar — *Tomas Bata University in Zlin (CZ)*
Roman Prokop — *Tomas Bata University in Zlin (CZ)*
Pavel Navratil — *Tomas Bata University in Zlin (CZ)*

Optimal pole assignment minimizing the spectral abscissa when algebraic control of linear time-invariant time delay systems (LTI-TDS) is focused in this paper. We concentrate on algebraic controller design approach in the RMS ring resulting in delayed controllers as well. In the case of unstable delayed plants, the use a simple feedback loop results in a characteristic quasipolynomial instead of polynomial is obtained which means that the closed loop has an infinite spectrum. Thus, it is not possible to place all feedback poles to the prescribed positions exactly by a finite number of free controller parameters. The pole placement problem is translated to the minimization of the spectral abscissa which is a nonsmooth nonconvex function of free parameters in many cases. We initially solve the problem via standard quasi-continuous shifting algorithm followed by a comparative utilization of three iterative optimization algorithms; namely, Nelder-Mead algorithm, Extended Gradient Sampling Algorithm and Self-Organizing Migration Algorithm. Simulation control of an unstable LTI-TDS - the roller skater on the swaying bow - serves as an illustrative example for the algebraic control with the spectral abscissa minimization.

A two-stage optimization PID algorithm

Gisli Herjolfsson — *Univsersity of Iceland (IS)*
Anna Soffía Hauksdóttir — *University of Iceland (IS)*
Sven Þ. Sigurðsson — *University of Iceland (IS)*

A two-stage PID algorithm is proposed with focus on fulfilling some important general requirements such as settling time, overshoot, size of control signal, disturbance rejection and robustness. The proposed method has two main goals. The first is to create an automatic PID computing algorithm giving decent results for a great variety of systems with different design requirements and different practical requirements. The second goal is to ensure that users with only a basic knowledge of automatic control systems can use the method. The proposed method is tested on 35 well known benchmark examples that have various difficulties of control.

GMV-PID controller design with gradient method for the energy weighting factor in nonlinear plants

Antonio Silveira — *Federal University of Santa Catarina (BR)*
Antonio Coelho — *Federal University of Santa Catarina (BR)*
Francisco Gomes — *Federal University of Juiz de Fora (BR)*

Since the PID tuning formula of Ziegler-Nichols step test, perhaps the best known, the process control literature is still showing lots of PID control schemes to improve the closed-loop stability. In this paper, using the relationship between the PID and generalized minimum variance (GMV) controller and adjusting online the control weighting factor by an adaptive learning algorithm of first-order (gradient method), a new control design is investigated. Besides, the control algorithm is gathering the direct estimation technique, with the covariance resetting procedure based on the weighted prediction error, to deal with nonlinear plants. Numerical and practical experiments are shown to evaluate the behavior of the proposed GMV-PID control design.

Online tuning of PID controller for linear SISO system with random communication delay by using genetic algorithms

Adrian-Bogdan Hanchevici — *University "Politehnica" of Bucharest (RO)*
Ioan Dumitrache — *University "Politehnica" of Bucharest (RO)*

In this paper we propose a control strategy for linear SISO systems in the presence of random communication delay. We have included the communication delay in the process model. This control strategy makes use of the several process models and based on the differences between each of them and real process, the PID controller is tuned. The tuning is made online, while the system is operational and for this are used the genetic algorithms. Simulation and implementation results are presented. The results show great performance improvement when the online tuning of the PID controller is used. The authors present the implementation for an axis of a 3D crane and using the Ethernet communication network.

A multi-objective optimization design methodology for SISO PID controllers

Gilberto Reynoso-Meza — *Universitat Politèctica de València (E)*
Xavier Blasco — *Universitat Politècnica de València (E)*
Javier Sanchis Saez — *Universitat Politècnica de València (E)*
Sergio García-Nieto — *Universitat Politècnica de València (E)*

By today, PI-PID controllers remain as reliable control solutions in a wide variety of industrial applications. Several tuning techniques have been designed and proposed successfully over the years. However the difficulty for tuning procedures increase as multiple requirements and criteria to evaluate the closed loop performance are demanded to be fulfilled. In this work, a multi-objective optimization design methodology is applied to the SISO benchmark for PID control based on the Boiler Control Problem. The main advantage of a multi-objective design methodology, is the capacity to perform an analysis on the trade-off among objectives.

Setpoint versus disturbance responses of the IPDT plant

Mikulas Huba — *Slovak University of Technology in Bratislava (SK)*

This paper considers PI controller tuning for Integral Plus Dead Time plant (IPDT) by new Matlab/Simulink tool based on the performance portrait method. It enables to guarantee transient responses with specified deviations from ideal shapes at the plant output and input and to fulfill additional optimality specification, defined in terms of the minimal IAE (Integral of Absolute Error) values weighted for the setpoint and disturbance steps. As the ideal step responses at the plant output monotonic transients are considered, whereas at the plant input one-pulse responses consisting of two monotonic intervals are required. As an introduction to new generation of robust tuning approaches, optimal nominal tuning is firstly treated.

ThB2: Event Based PID Control (Invited Session)
13.30-15.30, Aula N8

Chair: José Sánchez — *UNED (E)*
Co-Chair: Karl Henrik Johansson — *KTH Royal Institute of Technology (S)*

Stability analysis of PID controlled local model networks

Christian Mayr — *Vienna University of Technology (A)*
Christoph Hametner — *Vienna University of Technology (A)*
Martin Kozek — *Vienna University of Technology (A)*
Stefan Jakubek — *Vienna University of Technology (A)*

This paper addresses closed-loop stability analysis of PID controlled local model networks. The proposed method allows to investigate exponential or asymptotic stability of the closed-loop system. For this purpose a common quadratic Lyapunov function is used as stability criterion. Due to the fact that the Lyapunov approach requires a state-space model a suitable closed-loop state-space system with integration of the controller parameters is introduced. An example demonstrates the effectiveness of the proposed method.

Decentralised control of a quadruple tank plant with a decoupled event-based strategy

Jesús Chacón Sombría — *UNED (E)*
José Sánchez Moreno — *UNED (E)*
Antonio Visioli — *University of Brescia (I)*
Sebastián Dormido Bencomo — *UNED (E)*

In this work we focus on the development of a software tool, which allows users to perform experiments with event-based PI controllers in a multivariable system composed of four coupled tanks. The quadruple tank plant allows the student of control engineering to experiment and obtain an intuitive knowledge about multivariable systems (systems with more than one inputs and more than one outputs), to study the differences between the minimum phase and non-minimum phase behaviours and the difficulties in control that arise in the latter case, and all this with the motivation that the experiments can be done not only in simulation but with a real plant. The control system provides the possibility of using a decoupling net between the controllers and the actuators, which can have a direct or inverse scheme, and which can be used to reduce the effect of the interactions between inputs and outputs. Finally, we present a set of results illustrating the possibilities of the application to investigate the performance of the event-based controller together with a decoupling strategy.

Event-triggered PI control subject to actuator saturation

Daniel Lehmann — *KTH Royal Institute of Technology (S)*
Karl Henrik Johansson — *KTH Royal Institute of Technology (S)*

Event-triggered control aims at reducing the communication load over the feedback link in networked control systems by adapting the information exchange to the current needs. This paper firstly extends

a common approach to event-triggered control by incorporating a PI controller and by showing the setpoint-tracking properties of the extended scheme. Second, it investigates the consequences of actuator saturation on the behavior of the event-triggered PI-control loop. Simulations show that the effect of actuator saturation depends on the selection of the event threshold which might even destabilize the closed-loop system due to integrator windup. Finally, anti-windup techniques are discussed to overcome this problem.

On the stability of an event-based PI controller for FODPT processes

Manuel Beschi — *University of Brescia (I)*
Sebastian Dormido — *UNED (E)*
José Sanchez — *UNED (E)*
Antonio Visioli — *University of Brescia (I)*

This paper deals with the stability of an event-based proportional-integral controller. In particular, necessary and sufficient conditions on the controller parameters for the existence of equilibrium points without limit cycles are given for a first-order-plus-dead-time process. Practical issues related to the controller implementation are also addressed. The presented conditions enable a simpler tuning of the controller. Simulation and experimental results are provided as illustrative examples.

A self-triggered PI controller for processes with deadtime

Ubaldo Tiberi — *KTH Royal Institute of Technology (S)*
Carl-Fredrik Lindberg — *ABB Corporate Research (S)*
Alf Isaksson — *ABB Corporate Research (S)*

Current implementations of digital controllers assume that sensing, control and actuation are performed in a periodic fashion. In classic control schemes, where sensors and controllers are directly connected, periodicity does not provide particular drawbacks, but, in the case of wireless sensor networks, such a choice may be questionable. One of the driving constraints in the design of wireless sensor networks is represented by its energy efficiency, and it has been shown that the main cause of energy consumption is due to the radio activities of the sensor nodes. By using periodic implementations, the sensor nodes are enforced to keep on transmitting measurements to the controller even if it is not really needed, thus wasting energy. To cope with these problems, self-triggered control was recently introduced. This technique aims at reducing the conservativeness of periodic implementations providing an adaption of the inter-sampling intervals based on the current output of the system. Existing work on self-triggered control considers linear systems controlled by state feedback controllers under the assumption of small time-delays. In this paper the problem of designing a self-triggered control scheme that applies to first-order processes with large dead-times controlled by PI controllers is addressed. Moreover, the proposed self-triggered scheme is robust with respect to set-point changes and external disturbances, which are typical in process industry. The results are validated by simulations.

On event-based PI control of first-order processes

Ubaldo Tiberi — *KTH Royal Institute of Technology (S)*
Jose Araujo — *KTH Royal Institute of Technology (S)*
Karl Henrik Johansson — *KTH Royal Institute of Technology (S)*

In this paper the design of an event-based proportional-integral (PI) control scheme for stable first-order processes is considered. A novel triggering mechanism which decides the transmission instants based on

an estimate of the PI control signal is proposed. This mechanism addresses some sideeffects that have been discovered in previous event-triggered PI proposals, which trigger on the process output. In the proposed scheme, the classic PI controller is further replaced with PIDPLUS, a promising version of PI controller for networked control systems. Although PIDPLUS has been introduced to deal with packet losses and time delays, and, to the best of our knowledge, a stability analysis of the closedloop system where such a controller is used has never been performed, here the performance of such a controller in an event-based fashion are analyzed, and a stability analysis is further provided. The proposed event-based scheme ensures set-point tracking and disturbance rejection as in classic timeperiodic implementations of PI controller, while greatly reducing the number of sensor transmissions. The theoretical results are validated by simulations, where the benefits in using PIDPLUS in combination with the proposed PI event-based triggering rule are shown.

ThPa: Future Perspectives of PID control (Panel Session) 16.00-18.00, Sala Consiliare

Chair: Karl Johan Åström *Lund University (S)*

Karl Johan Astrom	*Lund University (S)*
Takashi Naito	*Yokogawa Electric Corporation (J)*
Alf Isaksson	*ABB and Linkoping University (S)*
Willy Wojsznis	*Emerson Process Management (USA)*
Adriano Chinello	*Gefran SpA (I)*
Jason Wright	*Rockwell Automation (USA)*
Rafael González	*Respol (E)*
Emre Kuzu	*Tupras (TR)*

ThPS: Applications and Design of PID Controllers I (Poster Session)
9.30-15.30, Poster Area

Chair: Miloš Schlegel — *University of West Bohemia (CZ)*
Co-Chair: Ricardo Julian Mantz — *Universidad Nacional de La Plata (AR)*

Design of a weigh feeder control system for energy saving

Takao Sato — *University of Hyogo (J)*
Shohei Kitano — *University of Hyogo (J)*
Toru Yamamoto — *Hiroshima University (J)*
Nozomu Araki — *University of Hyogo (J)*
Yasuo Konishi — *University of Hyogo (J)*

In the present paper, we discuss a design method for controlling a weigh feeder that has been widely used in industry. Since a control system is designed using a performanceadaptive method, the control parameters are adaptively updated based on user-specified control performance. In conventional performance-adaptive methods, control systems are designed such that the variance of the control error is less than or equal to a specified value and the variance of the differences in the control input is minimized without changing the acceptable variance value of the control error. On the other hand, since the design objective of the present study is to reduce energy consumption, the variance of the differences in the control input is first set, and then the variance of the control error is minimized without changing the acceptable variance value of the differences in the control input. Consequently, the variation of the control input can be substantially reduced. In the proposed method, a proportional-integral controller is designed based on generalized minimum variance control (GMVC) with steady-state predictive output (GMVCS). One of the design parameters in GMVCS is automatically decided such that a desired control performance can be attained, and the PI parameters of a PI control law are calculated based on a GMVCS law.

Adaptive PI control of an organic rankine cycle power plant

Fabrizio Padula — *University of Brescia (I)*
Roberto Sandrini — *University of Brescia (I)*
Giuseppe Cominardi — *Turboden s.r.l., Pratt & Whitney Power Systems. (I)*

In this paper a PI based adaptive control system is developed to control an organic Rankine cycle power plant. In particular, the control of the turbine speed during the transient between the normal operation mode of the system (connected to the grid) and the islandmode (connected to a stand-alone load) is of main concern. A control algorithm suitable for the implementation on a programmable logic controller is developed. The designed controller is adaptive with respect to different plant thermodynamic boundary conditions and takes into account the limitations imposed to the control variable. An object oriented simulator of the system is developed and the controller is tuned via simulation.

Advanced PID control algorithms built into the rex control system

Pavel Balda — *University of West Bohemia (CZ)*
Milos Schlegel — *University of West Bohemia (CZ)*

REX is an industrial control system which has been developed by the authors of this paper and by several their colleagues during the last decade. Control algorithms of REX are contained in a large function block library (block set). Controller blocks, including various PID controllers, cover a significant part of the library. This paper briefly explains main ideas of REX and it focuses on description of two advanced PID controller function blocks with built-in auto-tuning facilities. Both of these controllers use active identification experiment for the process identification, first of them uses a pulse experiment, second of them uses a relay experiment. After finishing of the identification experiment, the designed controller parameters are immediately computed in both cases. These controllers and some additional function blocks are presented in several examples demonstrating various control structures.

Improving PID recovery from limit conditions

Terry Blevins — *Emerson Process Management (USA)*
Willy Wojsznis — *Emerson Process Management (USA)*
Mark Nixon — *Emerson Process Management (USA)*
Dan Coyne — *BP America Inc. (USA)*

This paper addresses the performance of the PID under startup or during normal operation when the PID output becomes limited. Common techniques that have been utilized to reduce the time required to get to setpoint during process startup are reviewed. The response of the PID to conditions that limit PID operation during normal operating conditions is discussed for different implementation approaches. In particular under limiting conditions, anti-reset windup is automatically activated when a positive feedback network is used to create the reset contribution. For such implementations, the recovery from a process saturation condition may be improved by modifying the PID operation. An application example is used to show the impact of this modification on response speed and overshoot.

Active vibration control of two-mass flexible system using parametric Jordan form assignment

Martin Goubej — *University of West Bohemia (CZ)*
Miloš Schlegel — *University of West Bohemia (CZ)*
Jana Königsmarková — *University of West Bohemia (CZ)*

This paper deals with stage motion control system for scene manipulation during theater performance. Particular task of rope drum control is presented and solved. The system exhibits an oscillatory dynamics due to the elasticity of the rope with a hanging load. The goal was to find a simple control strategy based on a common cascade PID structure which is available in most of the industrial AC drives. Formerly developed method of parametric Jordan form assignment was used to solve the problem and obtain simple tuning rules.

Design of optimal low-order feedforward controllers

Martin Hast — *Lund University (S)*
Tore Hägglund — *Lund University (S)*

Design rules for optimal feedforward controllers with lead-lag structure in the presence of measurable disturbances are presented. The design rules are based on stable firstorder models with time delays,

FOTD, and are optimal in the sense of minimizing the integratedsquared error. The rules are derived for an open-loop setting, considering a step disturbance. This paper also discusses a general feedforward structure, which enables decoupling in the design of feedback and feedforward controllers, and justifies the open-loop setting.

A new predictive PI controller with additonal filtering

Aleksandar Ribić — *Institute Mihajlo Pupin (SRB)*
Miroslav Mataušek — *Faculty of Electrical Engineering Belgrade (SRB)*

A new predictive PI controller is proposed and applied to the benchmark MIMO PID 2012. Estimate of disturbance, obtained from the Disturbance Observer (DO), is introduced in the loop to obtain the offset free control. First-Order Plus Dead-time (FOPDT) model of stable, integrating and unstable plants is used to design DO, by applying inverse modeling technique. Tuning rules are proposed, and analyzed by simulation of stable, integrating and unstable processes. The high performance of the proposed predictive PI controller with additional filtering is demonstrated by simulation and on the benchmark MIMO PID 2012 plant, with the open-loop dynamics approximated by FOPDT models for the pressure and the water level.

Design of PID controller with filter for distributed parameter systems

José Domingo Álvarez Hervás — *Universidad de Almería (E)*
Julio Elias Normey Rico — *Federal University of Santa Catarina (BR)*
Manuel Berenguel Soria — *Universidad de Almería (E)*

This paper presents a method for tuning simple controllers for distributed parameter systems in the process industry. These systems are usually described by partial differential equations (PDE), which are then simplified into lumped parameter systems represented by ordinary differential equations (ODE), providing low order transfer functions used for PID control design. The drawback of this approach is that the control system only performs well at low bandwidths and without disturbances, as relevant system dynamics, such as resonances lying at medium-high frequencies, are not taken into account, limiting the performance of the closedloop system. This work proposes a method for SISO systems which uses a transfer function that models the resonances (obtained directly from the PDE) to tune a PID controller that incorporates a filter that is designed to fulfill control requirements.

Closed form expressions of discrete linear system responses with an application to PID controllers

Sven Sigurdsson — *University of Iceland (IS)*
Anna Soffia Hauksdottir — *University of Iceland (IS)*

General closed–form expressions of linear discrete–time system responses of arbitrary order are presented without proof. The system poles can be real and/or complex, and may be repeated. While these expressions are readily computed from the system in standard forms, they are based on a backward difference formulation, shown to offer some important simplifications and a closer analogy with the continuous case. Expressions are also derived for Lyapunov (Sylvester) equations, whose solution is the corresponding (cross) Grammian matrix, thus allowing evaluation of it without direct reference to the poles of the system. Finally, an example is presented of how these expressions may be utilized to obtain an expression for zero-optimized open-loop PID coefficients.

Another novel modification of predictive PI controller for processes with long dead times

Pasi Airikka *Metso Corporation (FIN)*

PID controllers are indisputably the most common controller type encountered in process control applications. They are used for regulating processes with diverse dynamics in industrial applications. Especially, processes with long dead times should require special attention as they are difficult to handle with conventional PID controllers. A lof of different dead time compensating control methods have been introduced in theory. This paper presents another modification of a predicitive PI controller contributing to its inventor and, also hereby, Smith predictor. The proposed method has resemblance with a PID controller and, therefore, is rather applicable for industrial implementations for dead time dominating processes. The introduced method has an additional tuning parameter which is, however, intuitively rather appealing.

A PI controller with dynamic set-point weighting for nonlinear processes

Ricardo Julian Mantz *Universidad Nacional de La Plata (AR)*

The paper deals with the control of nonlinear processes with 2DOF-PI controllers. A new and practical tuning method, based on recent ideas of immersion and invariance, is proposed for the dynamic adjustment of the set-point weight. The main attractive feature of the proposal is the possibility of assigning a reduced-order linear dynamics for the tracking response beyond the nonlinear characteristics of the process and the amplitude of the set-point changes. From a practical point of view the adjustment is performed by a simple sliding mode regime that accepts a straightforward implementation.

Underdamped second-order systems overshoot control

Paulo Moura Oliveira *University of Tras-os-Montes e Alto Douro (P)*
Damir Vrančić *J. Stefan Institute (SLO)*

The paper addresses the problem of decreasing the overshoot for underdamped second-order systems. A new technique to control the overshoot is proposed, which is based on Posicast control and proportional integral and derivative (PID) control, which performs switching between two controllers. The aim is to use open-loop feedforward control to increase tracking performance and PID control to deal with disturbance rejection. It has been shown that the proposed control scheme can have some advantages over the classical approaches without switching capabilities.

Analytical and graphical design of PID compensators on the Nyquist plane

Roberto Zanasi *University of Modena and Reggio Emilia (I)*
Stefania Cuoghi *University of Modena and Reggio Emilia (I)*

This paper focuses on the design of PID compensator to exactly satisfy the gain margin, the phase margin and the gain or phase crossover frequency specifications. The design problem is numerically solved using the so called PID inversion formulae method. A graphical interpretation of the solution on the Nyquist plane is presented. This could be suitable on education environment to deeply understand the design of PID compensators. Simulations results show the effectiveness of the presented method.

Friday (March 30)

<table>
<tr><td>8.30–9.30</td><td colspan="3">PID Advances in Industrial Control (Plenary Session)</td></tr>
<tr><td>9.30–10.00</td><td colspan="2">Coffee Break</td><td rowspan="4">Applications and Design of PID Controllers II (Poster Session)</td></tr>
<tr><td>10.00–12.00</td><td>Autotuning of PID Controllers</td><td>PID Tuning Rules</td></tr>
<tr><td>12.00–13.30</td><td colspan="2">Lunch</td></tr>
<tr><td>13.30–15.30</td><td>Tuning of PID Controllers</td><td>Fractional Order PID Control (Invited Session)</td></tr>
<tr><td>15.30–16.00</td><td colspan="3">Closing Ceremony</td></tr>
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FrPl: PID Advances in Industrial Control (Plenary Session) 8.30-9.30, Sala Consiliare

Chair: Antonio Visioli *University of Brescia (I)*

Terry Blevins *Emerson Process Management (USA)*

Optimal PI-settings are derived for first-order with delay processes for specified levels of robustness (Ms -value) and compared with the simple SIMC-rule. Optimality (performance) is defined in terms of the integrated absolute error (IAE) of the output for combined step changes in setpoints and input disturbances. With SIMC, the robustness level is adjusted by changing the tuning parameter τ_c, and the SIMC-rule was found to give surprisingly good setting with almost Pareto-optimal performance. The exception is a pure time delay processes where the SIMC-rule gives a pure integral controller with somewhat sluggish response. A simple modification to improve on this, is to increase the time constant in the rule by one third of the time delay.

Biography

Terry Blevins has been actively involved in the application and design of process control systems throughout his career. For over fifteen years, he worked as a systems engineer and group manager in the design and startup of advanced control solutions for the pulp and paper industry. Terry was instrumental in the establishment of Emerson Process Management's Advanced Control Program. Terry was the team lead for the development of DeltaV advanced control products, including auto-tuner and adaptive PID, Fuzzy Logic, Neural Network and MPC controllers. He is the Fieldbus Foundation team lead for the development and maintenance of the Function Block Specification and editor of the SIS Architecture and Model Specifications. Terry is involved in the movement of Fieldbus Foundation function block work into international standards. Terry is the US expert to the IEC SC65E WG7 function block committee that is responsible of the IEC61804 function block standards. He is a voting member and chairman of ISA SP104- EDDL (Electronic Device Description Language) and is the technical advisor for IEC 65E USTAG. Also, he is a member of USNC TAG (IEC/SC65 and IEC/TC65). Terry authored "An Overview of the ISA/IEC Fieldbus", Section 11, Standards Overview, Fifth Edition of Process/Industrial Instruments and Controls Handbook and coauthored four sections in the Fourth Edition of Instrumentation Engineer's Handbook, Process Control and Optimization. He coauthored the ISA bestseller book, "Advanced Control Unleashed" and the book "Control Loop Foundation – Batch and Continuous Processes" and accompanying web site http://www.controlloopfoundation.com/. Terry has 45 patents and has written over 70 papers on process control system design and applications. He regularly addresses process control and simulation topics in the blog http://modelingandcontrol.com/author/Terry-Blevins/ . Terry received a BEE from the University of Louisville in 1971 and a Master of Science degree in Electrical Engineering from Purdue University in 1973. In 2004, Terry was induced into Control Magazine's Process Automation Hall of Fame. Presently, Terry is a principal technologist in the future architecture team of Emerson's DeltaV Product Engineering.

FrA1: Autotuning of PID Controllers
10.00-12.00, Sala Consiliare

Chair: Massimiliano Veronesi — *Yokogawa (I)*
Co-Chair: Bohumil Šulc — *Czech Technical University in Prague (CZ)*

Performance assessment and retuning of PID controllers for load disturbance rejection

Massimiliano Veronesi — *Yokogawa (I)*
Antonio Visioli — *University of Brescia (I)*

In this paper we propose an algorithm for the load disturbance rejection performance assessment of a PI(D) controller and for the retuning of the parameters in case the obtained response is not satisfactory. The technique can be applied simply by evaluating the load disturbance closed-loop response. The automatic tuning for a set-point filter is also proposed in order to address the set-point following task. Simulation results show the effectiveness of the methodology.

Model-free PID controller autotuning directly applicable to real circuits

Stanislav Vrána — *Czech Technical University in Prague (CZ)*
Bohumil Šulc — *Czech Technical University in Prague (CZ)*

Many PID controller tuning methods have been presented since Ziegler and Nichols published their method in 1942, but none of those methods were used widely. The Ziegler and Nichols method has several advantages over newer methods: it is easy to conduct, the relations for controller parameter computation are simple, the method relies on experiment, and it does not require any model. Newer tuning methods are usually model-based, but the model-free methods are preferred in common industrial practice. This paper presents a model-free tuning method that respects the "restrictions" given by the easy usage of the Ziegler and Nichols method. The method is model-free, and new controller parameter computation is based on evaluation of control quality indicators. The evaluation is done without disconnection of the controller and with no other control restrictions during control.

Pseudo-PID controller: design, tuning and applications

Antonio Silveira — *Federal University of Santa Catarina (BR)*
Antonio Coelho — *Federal University of Santa Catarina (BR)*
Aline Franca — *Federal University of Santa Catarina (BR)*
Valter Knihs — *Federal University of Santa Catarina (BR)*

In this paper, a pseudo PID (PPID) controller, including only one gain to be tuned, is proposed. The idea is to connect the I+PD control design with the Fertik and Ziegler-Nichols tuning rules in order to obtain not only a simple and efficient control algorithm but also to decrease the operator intervention time with respect to the calibration task and to obtain desired closed-loop dynamic. Three approaches for stable automatic tuning via, self-tuning, internal model control and small gain theorem, are investigated for adjusting the tuning parameter of the controller. Effectiveness and performance aspects of the proposed PPID controller are assessed in numerical and experimental plants.

Tracking simulation based on PI controllers and autotuning

Mats Friman *Metso Corporation (FIN)*
Pasi Airikka *Metso Corporation (FIN)*

A mechanism for automatic update of tracking simulator parameters is suggested. A tracking simulator is a simulator, which runs in real time, and which corrects its own behavior (models) by comparing real process measurements to simulator outputs. Typically, a process simulator, no matter if static or dynamic, cannot adapt its behavior to reality, but the tracking simulator has this ability due to its integrated update mechanism. A tracking simulator is commonly used for state estimation of non-linear process models (simulation models). The suggested invention utilizes standard PI controllers, which enables fast update of parameters. A major advantage with the PI controllers is that autotuning can be applied and, hence, no tuning parameters need to be plucked out of the air. With the proposed innovation, it will be easy to extend an ordinary process simulator to a tracking simulator, which can be used for many purposes, including predictive and fault tolerant control, soft sensors, prediction of future plant behavior, parameter estimation, and plant optimization.

Antiwindup-aware PI autotuning

Alessandro Vittorio Papadopoulos *Politecnico di Milano (I)*
Alberto Leva *Politecnico di Milano (I)*

This manuscript addresses the problem of "tuning the antiwindup mechanism" of PI(D) controllers, an issue seldom addressed in the literature but yielding improvement and reducing undesired large-transient behaviours if tackled correctly. A previously proposed framework is extended and related to both alternative antiwindup implementations and tuning methods, resulting in more methodological insight on the matter, and guidelines to set up the extension of a given method to include antiwindup. Simulation examples are reported to illustrate the achievable advantages.

Performance assessment and redesign of PI controllers with pulse excitations

Henrique Barroso *Federal University of Campina Grande (BR)*
Péricles Barros *Federal University of Campina Grande (BR)*

In this paper a methodology is presented to assess the performance of PI controllers from closed-loop response data for pulse setpoint signal. Here a previously published technique is extended to evaluate and redesign single-input single-output (SISO) control loops for single and double pulses. The paper describes a system identification procedure for continuous-time transfer function models and demonstrates how it can be used for control performance assessment and controller redesign.

FrA2: PID Tuning Rules
10.00-12.00, Aula N8

Chair: Alfonso Ba“os — *University of Murcia (E)*
Co-Chair: V“ctor M. Alfaro — *Universidad de Costa Rica (CR)*

Synthesis of PID tuning for a new parallel cascade control structure

Dola Gobinda Padhan — *IIT Guwahati (IND)*
Somanath Majhi — *IIT Guwahati (IND)*

Most of the published papers on parallel cascade control strategies present improvement of dynamic performance of stable processes. In this paper, a new parallel cascade control scheme is proposed for controlling stable and unstable processes with time delay. The two main features of the proposed scheme are: the primary process output completely tracks the primary setpoint and the servo response decouples the regulatory response in the nominal system. The proposed structure has only two controllers. The inner loop controller is designed based on IMC approach. The outer loop controller is a PID controller in series with lead/lag filter which is designed based on the desired complementary sensitivity function. Significant improvement in the load disturbance rejection performances are obtained when compared to some recent methods in the literature. Simulation results show the superiority and usefulness of the proposed control method over the existing ones.

Optimal-robust-tuning for 1DOF PI/PID control unifying FOPDT/SOPDT models

Victor Alfaro — *Universidad de Costa Rica (CR)*
Ramon Vilanova — *Universitat Autonoma de Barcelona (E)*

The aim of the paper is to present tuning equations for one-degree-of-freedom (1DoF) proportional integral (PI) and proportional integral derivative (PID) controllers. These are based on a performance/robustness trade-off analysis with first- and second-order plus deadtime models. On the basis of this analysis a tuning method is developed for 1DoF PI and PID controllers for servo and regulatory control that allows designing closed-loop control systems with a specified MS robustness that at the same time have the best possible IAE performance. The control system robustness is adjusted varying only the controller proportional gain.

Tuning method of PI controller with desired damping coefficient for a first-order lag plus deadtime system

Yuji Yamakawa — *Univ. of Tokyo (J)*
Yohei Okada — *SINTOKOGIO LTD. (J)*
Takanori Yamazaki — *Oyama National College of Technology (J)*
Shigeru Kurosu — *Research Inst. “Crotech” (J)*

This paper presents an entirely new tuning method of PI controller with a desired damping coefficient. We consider a plant model described by a first-order lag plus deadtime system in the process control. The ultimate sensitivity method presented by Ziegler and Nichols has been still widely used, but it has

a disadvantage that gives an oscillatory response. In recent years a less oscillatory response has been judged to be more appropriate for process controls. In tuning PI controller it is often convenient to determine the damping coefficient to obtain the desired control performance. The deadtime element can be approximated by the Padé equation to determine the damping coefficient for the equivalent second-order lag system. In this paper the integral time is normally chosen equal to the time constant of a plant to degenerate the order of the closed-loop transfer function so that pole-zero is cancelled. As a result, the relations among the gain constant, the time constant, the deadtime of the plant and the proportional gain of the controller are clarified when the desired damping coefficient is provided.

Tuning rules for a reset PI compensator with variable reset

Alfonso Baños — *University of Murcia (E)*
Miguel Angel Davó — *University of Murcia (E)*

The PI+CI compensator is a simple reset compensator, its base system is a PI, which has been shown to be effective in a number of practical applications. One fundamental parameter to be tuned is the reset ratio; for lag dominant systems or systems with integrators it is known to give good results overcoming PI compensation. In this work, a systematic method for the tuning of a variable reset ratio (variable at the reset instants) is developed for first and second order plants.

Kappa-tau type PI tuning rules for specified robust levels

Juan J. Gude — *University of Deusto (E)*
Evaristo Kahoraho — *University of Deusto (E)*

New tuning rules for 2-DoF PI controllers in the spirit of the kappa-tau ones are addressed in this paper. In particular, tuning rules have been devised in order to minimize the integrated absolute error with a constraint on the maximum sensitivity MS. Different tuning rules have been obtained for a batch of plants and for several robustness levels in terms of MS. The setpoint weight is also exploited to improve the setpoint following performance because the PI controller is tuned by optimizing the load disturbance rejection performance. In particular, explicit tuning rules are given in order to select the optimal setpoint weight to minimize the integrated absolute error. Simulation results demonstrate the effectiveness of these methodologies. Some comments relating to industrial practice are offered in this context.

Performance degradation driven PID controller design

Orlando Arrieta — *Universidad de Costa Rica (CR)*
Ramon Vilanova — *Universitat Autònoma de Barcelona (E)*
Víctor M. Alfaro — *Universidad de Costa Rica (CR)*

This paper is concerned with the design of the closed-loop control system, in order to take into account the system performance to load-disturbance and to set-point changes and its robustness to variation of the controlled process characteristics. The aim is to achieve a good balance between the multiple trade-offs. The proposed approach is complementary to the work presented by Arrieta and Vilanova (2011, 2012). Here, it is provided a PID design that allowing some degradation in the system's combined performance, achieves an increase in the robustness.

FrB1: Tuning of PID Controllers
13.30-15.30, Sala Consiliare

Chair: Claudio Scali — *University of Pisa (I)*
Co-Chair: Rogelio Mazaeda — *UVA (E)*

Effect of cascade tuning on control loop performance assessment

Claudio Scali — *University of Pisa (I)*
Elena Marchetti — *University of Pisa (I)*
Andrea Esposito — *ENI S.p.A. Divisione Refining & Marketing (I)*

The effect of cascade tuning on control loop performance is analyzed in the framework of a monitoring system implemented in a refinery plant. Improper (too conservative) tuning of the inner loop may bring to ambiguous or apparently wrong verdicts on the evaluation of single loop performance. Starting from the evidence that operators actions can be different from suggestions given by the monitoring system, the effect of cascade controllers tuning is examined through the illustration of possible scenarios, generated in simulation with different tuning policies. Explanation of the observed behavior and general guidelines to assist operators in the procedure of controller retuning are given.

Energy saving in industrial processes: a case study of strategies and tuning procedures for PI and PID controllers

Francisco Jose Gomes — *Federal University of Juiz de Fora (BR)*
Israel Felipe Lopes — *Federal University of Juiz de Fora (BR)*
Flavio Padilha Queiroz — *Federal University of Juiz de Fora (BR)*
Antonio Augusto Coelho — *Federal University of Santa Catarina (BR)*

Considering that the energy consumption of a given system can be directly related to its dynamics, this work presents a study accomplished at the Laboratory of Energy Efficiency (LEENER) and Industrial Process Laboratory of the Federal University of Juiz de Fora (UFJF). The work makes comparison studies among some different tunings for the flow control on pumping systems and tuning procedures for PID strategies for controlling industrial processes. The objective is to evaluate the energy efficiency of such strategies, by means of the analysis of energy consumption of the system.

Discrete-time PID controller tuning using frequency loop-shaping.

Ashfaque Shafique — *Arizona State University (USA)*
Konstantinos Tsakalis — *Arizona State University (USA)*

A loop-shaping approach for tuning Proportional-Integral-Derivative (PID) controllers is presented. A Glover-McFarlane controller is used to determine a target loop-shape that is approximated by a PID structure via the use of an LMI optimization method. If the approximation error from the minimization satisfies a standard small gain condition, then the tuned PID controller also shares the attractive robustness properties of the controllers. The entire design process is carried out in discrete-time assuming a discrete plant is available. Typical test cases are used to show the implementation of this method and the quality of the resulting closed loops.

IFTtune: a PID automatic tuning software tool

Rogelio Mazaeda *UVA (E)*
César De Prada *UVA (E)*

The regulatory layer of every process industry is made up of many decentralized loops using, almost exclusively, PID controllers. The task of keeping each of these devices correctly tuned is key to the efficient and safe operation of the factory but very demanding on the time of technical and maintenance personnel should it be carried out manually. The tool here described is designed to perform the automatic tuning of PID regulators facilitating its application in an industrial setting. The regulator parameters are updated starting from their current values so that a performance index is locally optimized using the Iterative Feedback Tuning algorithm. The tool is easily configurable and uses the widely adopted OPC industrial communication standard.

Online adaptive robust tuning of PID parameters

Ehsan Gholamzadeh Nabati *TU Dortmund (D)*
Sebastian Engell *TU Dortmund (D)*

In this paper, an online adaptation scheme for tuning of PID parameters is presented. This scheme is based upon our previous works on using a data-driven method to obtain a sufficient condition for robust stability and integrating robustness into the Unfalsified Control framework. Here, a modified bumpless transfer approach to facilitate the adaptation of the PID controller parameters is presented. The proposed scheme is demonstrated using a PID benchmark problem.

Evolutionary auto-tuning algorithm for PID controllers

Gilberto Reynoso-Meza *Universitat Politèctica de València (E)*
Javier Sanchis Saez *Universitat Politècnica de València (E)*
Juan M. Herrero *Universitat Politècnica de València (E)*
César Ramos *Universitat Politècnica de València (E)*

In this work, an auto-tuning procedure for PID controllers is presented. This autotuning procedure identifies a FOPDT model for a given process and uses an evolutionary algorithm to solve a constrained non-convex optimization problem to adjust the parameters of a PID controller with derivative filter. The auto-tuning procedure is validated with a set of process with different characteristics. Presented results validate the auto-tuning algorithm as a practical and viable application for auto-tuning procedures.

FrB2: Fractional Order PID Control (Invited Session) 13.30-15.30, Aula N8

Chair: Blas M. Vinagre — *University of Extremadura (E)*
Co-Chair: Martin Cech — *University of West Bohemia (CZ)*

Nonlinear fractional PI control of a class of fractional-order systems

Alessandro Pisano — *University of Cagliari (I)*
Milan Rapaic — *University of Novi Sad (SRB)*
Zoran Jelicic — *University of Novi Sad (SRB)*
Elio Usai — *University of Cagliari (I)*

This paper deals with the design of nonlinear PI control techniques for regulating a class of fractional-order dynamics governed by a commensurate-order model, possibly nonlinear, perturbed by an external disturbance. The suggested control algorithm is the combination between a fractional-order PI controller and a nonlinear robust version of it, namely a secondorder sliding mode control algorithm called "super-twisting" controller in the literature. A key feature of the approach is the use of ad-hoc sliding manifolds whose construction involves fractional order derivatives. A constructive Lyapunov based synthesis is illustrated, which leads to simple tuning rules for the controller parameters guaranteeing the asymptotic rejection of the external disturbance under appropriate smoothness restrictions. Computer simulations illustrate the effectiveness of the proposed technique.

A class of PID controllers tuned in fractional representation

Roman Prokop — *Tomas Bata University in Zlin (CZ)*
Jiri Korbel — *Tomas Bata University in Zlin (CZ)*
Radek Matusu — *Tomas Bata University in Zlin (CZ)*

The contribution is focused on design and tuning of simple controllers for continuous-time SISO systems without and with time delays by algebraic methods. The control synthesis is based on general solutions of linear Diophantine equations in the ring of proper and Hurwitz stable rational functions (RPS). Both, feedback (1DOF) a feedback and feed forward (2DOF) structures of the control system are considered. A scalar positive parameter is introduced for tuning and influencing control responses. In the paper, this parameter is used for aperiodic tuning of PI controllers. The methodology is utilized for autotuning principles and for robust applications. Interval perturbations in controlled systems and robustness of proposed algorithms are outlined through the value set concept, zero exclusion condition and Kharitonov theorem. For both applications user-friendly program packages were developed in the Matlab+Simulink environment with the support of Polynomial Toolbox.

Fractional order PI tuning for integrating plants with time delay

Paolo Lino — *Politecnico di Bari (I)*
Guido Maione — *Politecnico di Bari (I)*

In the last decade, non-integer order controllers have received great attention, due to their capacity of achieving robustness of the controlled loops with respect to gain and parameter variations of the

plant. However, despite the general interest, technical literature offers few widely accepted and easy tuning techniques for these new controllers. To overcome the lack of simple tuning rules, we use open-loop shaping ideas for tuning non-integer order PI controllers of integrating plants with time delay. We illustrate the potentiality and limitation of the proposed technique through extensive simulation. Simplicity and satisfaction of requirements are remarkable characteristics of the method.

Comparing fractional order PI controllers with variable gain and gain-order for the networked control of a servomotor

Ines Tejado — *University of Extremadura (E)*
S. Hassan Hosseinnia — *University of Extremadura (E)*
Blas M. Vinagre — *University of Extremadura (E)*

This paper addresses the use of fractional order control (FOC) in the context of control through networks to minimize or compensate the effect of the time-varying networkinduced delay. In particular, two fractional order strategies are presented based on the adaptation of, on one hand, the gains of a fractional order PI controller, and, on the other hand, both its gains and its order in accordance with the variable delay detected in a networked control system (NCS). The essence of these approaches is to make controller gains and both gains and order delay-dependent by minimizing a defined cost function in order to avoid a decreased control performance. Experimental results, related to the control of the angular velocity of a servomotor through the Internet, show the effectiveness of these fractional order adaptive strategies in comparison with the non-scheduled controller. Likewise, a useful application of variable order PI controllers is presented.

Computing PID tuning regions based on fractional-order model set

Martin Cech — *University of West Bohemia (CZ)*
Milos Schlegel — *University of West Bohemia (CZ)*

The paper describes a new PID tuning approach suitable for both researcher and industrial practice. It justifies the authors' previous work where only intervals for particular controllers parameters were developed. Compared to other ones, the robustness regions method provides an admissible area of all controller parameters satisfying the required closed loop performance for exactly defined class of fractional processes. In contrast to common time domain tuning methods the process is characterized by three moments of its impulse response. The resulting areas serve as a common playground for future development of feature based tuning rules as shown in the illustrative example. The described procedure was partly implemented into the interactive Java applet freely accessible at www.pidlab.com.

FrPS: Applications and Design of PID Controllers II (Poster Session)
9.30-15.30, Poster Area

Chair: Alireza Karimi — *EPFL (CH)*
Co-Chair: Bengt Lennartson — *Chalmers University of Technology (S)*

Data-Driven Design of a PI Fuzzy Controller for a Wind Turbine Simulated Model

Silvio Simani — *University of Ferrara (I)*

This paper proposes a fuzzy modelling and identification approach oriented to the design of a PI fuzzy controller for regulating both the pitch angle and the reference torque of a wind turbine model. This strategy has been suggested for enhancing the regulator design that could represent an alternative to the standard switching controller, already implemented in the wind turbine test system. The controller project requires the knowledge of the dynamic model of the wind turbine, which is achieved by means of a fuzzy modelling and identification scheme. On the other hand, the proposed PI fuzzy controller structure is straightforward and easy to implement with respect to different strategies proposed in literature. Moreover, by means of these design procedures, the proposed strategy is also able to provide a robust and reliable controller. The results obtained with the designed PI fuzzy controller are compared to those of a switching controller already implemented for the wind turbine benchmark.

New methodology to design sliding-PID controllers: application to missile flight control system

Belkacem Kada — *King Abdulaziz University (SA)*

In this paper, a new methodology to design robust sliding-PID tracking motion controllers for a certain class of nonlinear systems is presented. The methodology is based upon the combination of the conventional PID control, sliding-mode control in Filippov's sense, and relative degree concepts. The tracking of desired motion trajectories is performed in the presence of nonlinearities, modeling uncertainties, and external disturbances. The proposed methodology is successfully applied to the pitchaxis autopilot design for a tactical missile. High-level performances, robustness, and fast convergence of the closed-loop system are guaranteed.

Control analysis and tuning of an industrial temperature control system

Ivan Zajic — *Control Theory and Applications Centre (GB)*
Tomasz Larkowski — *Control Theory and Applications Centre (GB)*
Keith Burnham — *Control Theory and Applications Centre (GB)*
Dean Hill — *Abbott Diabetes Care Ltd. (GB)*

The paper focuses on control analysis and tuning of an already installed temperature control system in a manufacturing plant. The dynamics of the investigated heating ventilation and air conditioning system are inherently nonlinear throughout the operational region. Therefore, it is challenging to tune the adopted

proportional-integral controller. For this reason, a nonlinear temperature model, whose structure is predetermined based on simplified first principles assumptions, is derived. The corresponding parameters are estimated based on measured data using identification techniques. The obtained temperature model is used for off-line control analysis and subsequent control tuning.

Genetic algorithm based PID tuning for optimal power control of a three-shaft brayton cycle based power conversion unit

Kenny Uren *North-West University, Potchefstroom campus (ZA)*
George Van Schoor *North-West University, Potchefstroom campus (ZA)*

This paper considers the development of a PID control strategy to optimally control the power output of a High Temperature Gas-cooled Reactor (HTGR) power plant. A specific type of HTGR called the Pebble Bed Modular Reactor (PBMR) that utilises a closed recuperative Brayton cycle with helium as working fluid is considered. The power control of this kind of plant is significantly different from conventional steam cycle nuclear power plants. A distinguishing feature that complicates the control is the use of three separate shafts for different compressor/turbine or turbine/generator pairs. In addition the power output cannot be directly controlled by means of an upstream valve that regulates the flow through the power turbine, as is the case with conventional steam cycles. This paper addresses these challenges by means of a control strategy consisting of four PID control loops. The controller gains are optimised by means of a Genetic Algorithm (GA) that uses real-valued genes and the ITAE performance measure as a cost function. The control strategy is implemented and evaluated on a linear Simulink® model of the PBMR Power Conversion Unit (PCU). Results are presented illustrating the performance of the GA optimised PID control strategy.

PIDdesign - software for PID control education

Juraj Oravec *Slovak University of Technology in Bratislava (SK)*
Monika Bakošová *Slovak University of Technology in Bratislava (SK)*

The aim of this paper is to present the software PIDDESIGN. The software has been developed using MATLAB – Simulink programming environment and uses its graphical user interface to make software more interactive and user friendly. The software represents useful tool for simple step-response-based identification of a controlled process, fast PID controller tuning using various methods and effective evaluation of control performance using simulation of control. The software enables to focus the attention on control performance analysis to increase the quality of control. The properties of the software determine its application especially for educational purposes.

Multi criteria Hinf optimal PID controllers from an undergraduate perspective

Bengt Lennartson *Chalmers University of Technology (S)*

A simple design method for robust PID controllers is presented. It is based on a multi criteria H_∞ optimal control formulation, which is shown to be easily solved by a few lines of MATLAB code. This optimal solution for PID controllers including low pass filtering, is complemented by a simple paper and pen solution that can be used to obtain nearly optimal solutions. The presented approach is shown to give significantly better results compared to ordinary text book solutions based on frequency domain loop shaping. The paper also includes a discussion on how to best formulate PID controllers for design, and how additional filtering may easily improve high frequency robustness.

Uncertainty quantification for fractional order PI control system: polynomial chaos approach

Trung Duong Pham Luu — *PSDC (ROK)*
Moonyong Lee — *PSDC (ROK)*

Stability and performance of a system can be inferred from the evolution of statistical characteristic (i.e. mean, variance...) of system states. The polynomial chaos of Wiener provides a computationally effective framework for uncertainty quantification of stochastic dynamics in terms of statistical characteristic. In this work, polynomial chaos is used for uncertainty quantification of fractional order PI control system under the uncertainties both in parameters and additive stochastic disturbance.

Data-driven fractional PID control: application to DC motors in flexible joints

Jorge Villagra — *Polytechnic University of Madrid (E)*
Blas M Vinagre — *University of Extremadura (E)*
Ines Tejado — *University of Extremadura (E)*

Recent advances in data-driven (or model-free) control have permitted to enhance the closed loop behavior of linear and especially nonlinear systems using very simple control structures. As a result, unknown or badly known dynamics are compensated and disturbances are rejected without any learning or on-line identification procedure. However, the ultra-local phenomenological models on which this control technique rely have not yet exploited the fractional nature of many processes and the nonlocal nature of the fractional integrodifferential operators. In this paper, fractional derivatives are used in the so called model free control structure in order to explore the advantages they provide in terms of robustness and dynamic response. Fractional and integer order data driven PIDs will be compared for a DC motor in a robot flexible joint control application in a simulation environment.

Automatic design of robust PID controllers using QFT

Ramon Comasolivas — *Technical University of Catalonia (E)*
Teresa Escobet — *Technical University of Catalonia (E)*
Joseba Quevedo — *Technical University of Catalonia (E)*

This paper proposes an optimization algorithm for the automatic design of robust PID controllers using Quantitative Feedback Theory (QFT) specifications. The proposed algorithm is based on a criterion to minimize the energy of the control effort. To illustrate the methodology, the pitch angle of a laboratory helicopter is used as a model application with structured uncertainty. The results show that the design of robust controller can be formulated using an objective function and a number of restrictions that are developed as specifications.

Actuator fault tolerant PID controllers

César Castro — *Universidad Nacional Autónoma de México (MEX)*
Cristina Verde — *Universidad Nacional Autónoma de México (MEX)*
Alejandro Mora — *Universidad Nacional Autónoma de México (MEX)*

This paper deals with issues of actuator fault tolerant PID controllers. It is studied, how residual generation based on a linear model is affected by the robust properties of a PID used in feedback. To get the sensitivity of the residual with respect to faults and to keep the robustness of the controller, a scheme

is proposed with a non linear residual generator and a family of PIDs interconnected in such a way that the stability is held even with actuator faults. The conditions reported by Bhattacharyya for a family of stabilizing PID controllers are used to select the fault tolerant PID parameters considering actuator faults. Using the benchmark of the three tank system with two pumps, simulations and experimental results show the advantages of the fault tolerant PID scheme.

Joint confidence region for the tuning parameters of the PID controller

Nilton Silva — *Federal University of Campina Grande (BR)*
Heleno Bispo — *Federal University of Campina Grande (BR)*
Romildo Brito — *Federal University of Campina Grande (BR)*
João Manzi — *Federal University of Campina Grande (BR)*

The aim of this paper is to estimate the joint confidence region for the tuning parameters of the PID controller. Considerations on the statistical independence and the linear relationship between the tuning parameters for a more realistic scenario are taken into account. In order to capture the data necessary for the simulation, an appropriate structure was implemented, consisting of a process-modelbased controller. By using the data resulting from the simulations, it was also possible to find the probability density function for each tuning parameter, as well the region of joint confidence of such parameters, which indicates a contraction of the region when compared with the standard level of significance. What is also shown is how to restore the joint confidence region by means of the Principal Components Technique.

Easy tuning of PID controllers for specified performance

Štefan Bucz — *Slovak University of Technology in Bratislava (SK)*
Alena Kozáková — *Slovak University of Technology in Bratislava (SK)*
Vojtech Veselý — *Slovak University of Technology in Bratislava (SK)*

The presented method allows achieving maximum overshoot and specified settling time of the closed-loop step response. It provides a simple way to control linear stable SISO systems even if the mathematical model is unknown. Tuning rule parameters are based on one suitably chosen point of the plant frequency response obtained by sine-wave signal with specified excitation frequency, and the required phase margin. The main result provided is construction of empirical charts used to convert time-domain performance specifications (maximum overshoot and settling time) into frequency domain performance measure (phase margin). The method is applicable for systematic shaping of the closed-loop response of the plant. The new approach has been verified on a set of benchmark examples and on a real plant as well.

An approach for calculating all stable PID parameters for time delay systems with uncertain parameters

Frank Schrödel — *RWTH Aachen University (D)*
Jan Maschuw — *RWTH Aachen University (D)*
Dirk Abel — *RWTH Aachen University (D)*

There exists a large number of PID tuning rules for LTI systems. However, these rules often use time delay approximations and ignore parameter uncertainties. This work updates the classical parameter space approach to an one step PID tuning approach to guarantee robust stability for LTI time delay systems with explicit consideration of uncertainties in the plant parameters and the time delay. The basic idea is to calculate how the root boundaries changes due variation of system parameters. Bands of root boundaries are determined by this analysis. The challenging task of robust stability of time delay

systems is converted to an easier minimum/maximum search to estimate the borders of the root boundary bands. The presented method satisfies robust stability with only small conservatism.

Model-free synthesis of fixed structure stabilizing controllers using the rate of change of phase

Navid Mohsenizadeh — *Texas A&M University (USA)*
Swaroop Darbha — *Texas A&M University (USA)*
Lee H. Keel — *Tennessee State University (USA)*
Shankar P. Bhattacharyya — *Texas A&M University (USA)*

This technical note outlines an approach to the problem of synthesizing fixedstructure low-order controllers for systems whose mathematical models are unknown, but their frequency responses are available. Stability of the closed-loop system is guaranteed if the frequency response of the plant and the controller satisfy certain conditions at specific frequencies. It is shown that the relation between the rate of change of phase of the plant and the controller, at specific frequencies, characterizes the closed-loop system stability. We use this characterization in a systematic way to design fixed-structure low-order controllers such as PI and PID-controllers.

General Information

Language
The official language of the Conference is English. Simultaneous translation will not be provided.
Badges
All the registered participants will receive a personal badge upon registration and are requested to wear it when attending the sessions or any social event.
Wi-Fi Connection
Wi-Fi is available at the conference venue. However users are required to register with a valid ID for this service. Please visit this webpage for instructions.
National Organizing Committee staff
The National Organizing Committee is available to assist the participants during the conference. The staff is recognizable by a red stripe in the bagde.
Smoking
Smoking in the conference area is not allowed.
Mobile Phones
Participants are kindly requested to switch-off their mobile phones or to adopt the silent mode during all presentations.
Program Changes
The organizers cannot assume liability for any changes in the program due to external or unforeseen circumstances. The organizers reserve the right to cancel, postpone, relocate or change any of the sessions or to add new sessions.
Attendance Certificates
Certificates of attendance are handed out on request to all regularly registered participants at the end of the meeting.
Disclaimer
The Organizer Committee does not accept liability for any damage and/or loss that may be incurred by a conference participant during the activities of the conference or the social activities connected with the conference. The participants take parts in all events connected with the conference at their own risk. Participants are advised to charge any loss or damage they may incur during the conference or the travel to and from the conference location to their insurance.
Force Majeure
The organizers reserve the right to cancel without notice or compensation PID'12 Conference in the event of force majeure cases (for example, but not limited to, acts of nature such as fire, earthquake, hurricane, volcano eruption, flood or terrorist attacks). In such cases, the organizers are freed of all responsibility and no liability for any claim for damages and/or losses will be accepted. Limitation of liability of organization: In the event of it being impossible to carry out the PID'12 Conference for force majeure cases, so long as this arises from a cause not attributable to the organizers, the organization shall only be obliged to reimburse the payments received subject to deduction of any costs it has incurred in preparing the event. This liability only extends to the payments made directly to conference organization and not to payments made by the attendees to the hotel or airlines. The applicable law is the Italian law. Any

dispute, controversy or claim arising out of or in relation to this contract shall be resolved under the exclusive jurisdiction of the Court of Brescia.

Insurance

The Organizing Committee of the Conference shall not accept any responsibility for the individual medical, travel, or personal insurance for the participants in the Conference. All the participants are strongly advised to obtain a personal insurance before attending the Conference. The Organizing Committee will not be responsible for the loss or damage of the participants' personal belongings.

Banks

Banks are open from Monday to Friday from 08.30 to 13.30 and from 15.00 to 16.00 hrs. Banks are closed on Saturday and Sunday. many banks have automatic currency exchange machines that also take credit cards. Most hotels, restaurants and shops accept major credit cards.

Post Offices

The opening time of the Post offices are: Monday to Friday, from hrs 08.30 to 15.30. Saturaday from 08.30 to 12.00

Electricity

Voltage is 230AV, 50 Hz. Plugs (types: CEI 23-16/VII and CEE 7/7 (rarely)) have two or three round pins. Foreign plugs could require an adapter.

Userful Numbers

Ambulance: dial 118
Police: dial 113
Fire Brigade: dial 115

Taxis

Licensed taxis are white, have a name an identification number and are equipped with a taxi-meter. Taxis can be hailed on the streets, although they very rarely stop. It is better to hire them at taxi ranks. Telephone booking is possible at the following numbers: +39 03035111.

Public transportation

Brescia has a comprehensive bus network run by Brescia Mobilità. Services operate daily from hrs 06.00 to 24.00. Tickets cost 1.20 Euros (2 Euros on board) and lasts 75 minutes, allowing the traveller to use unlimited buses. Tickets can be bought from newsagents, tobacconists (distinguished by a capital T) and automatic selling machine at major bus stops. For lines and timetable see Brescia Mobilità website.

Climate

At the end of March, the mean temperature ranges from 6°C to 16°C.

Tipping

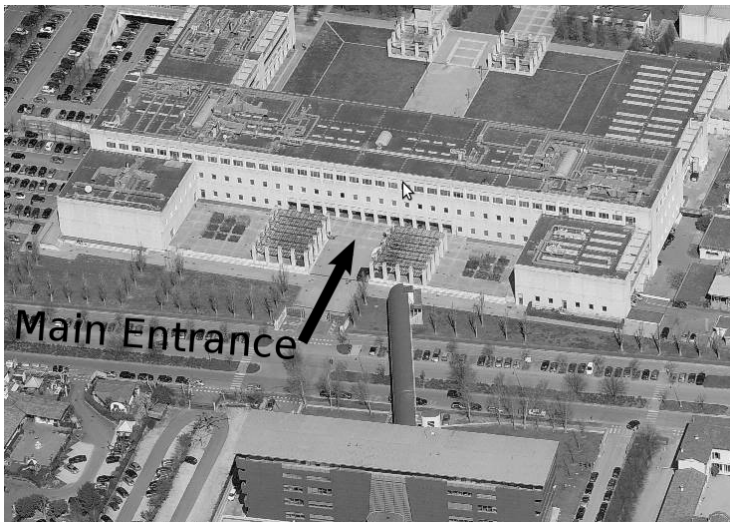
Tipping service is usually included in the bill in bars and restaurants, but tips are welcome.

Social Events

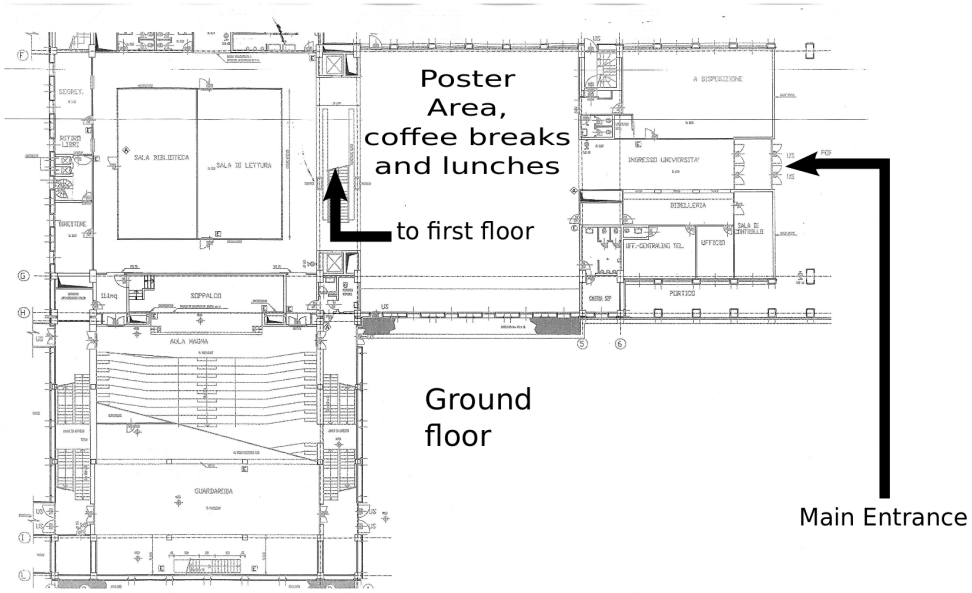
The welcome reception will be held on March 28 at Ristorante Cà Noa, Brescia (in front of the Faculty of Engineering, venue of the conference).

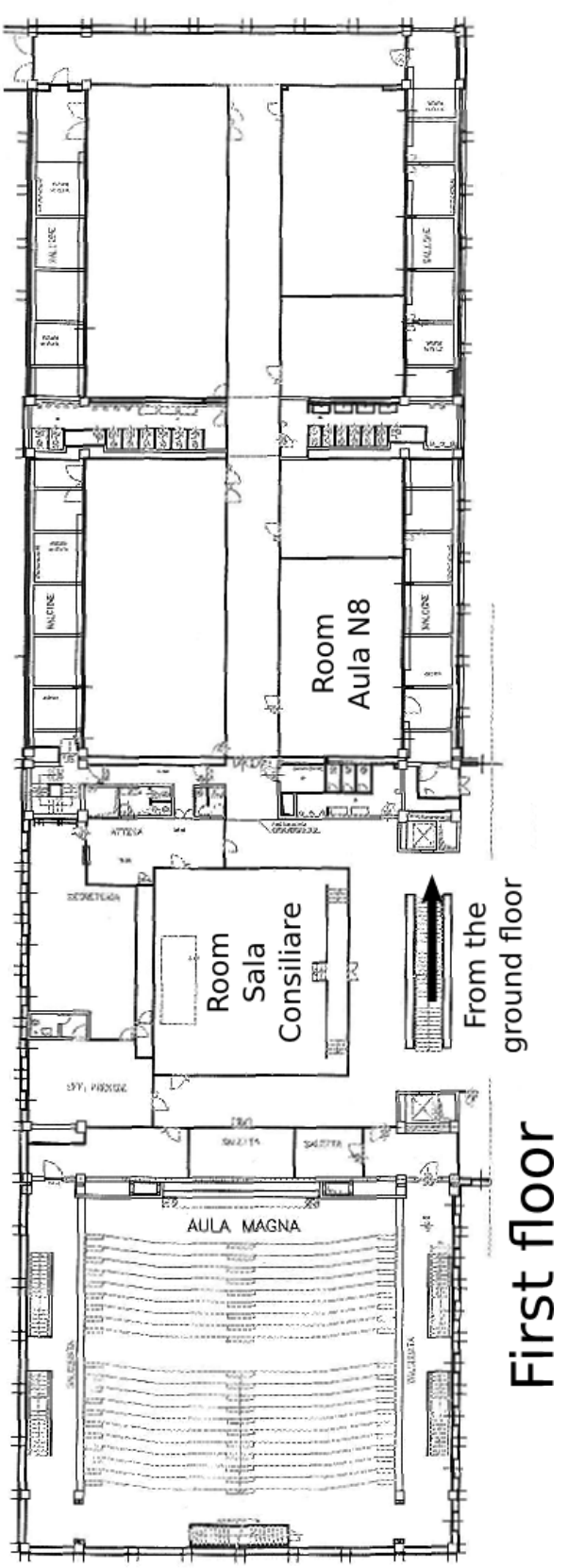
The banquet dinner will be held on March 29 at the Villa Baiana (www.villabaiana.it), in the heart of the Franciacorta wine region. A visit of the wine cellars is included.

Maps



External view of the Faculty of Engineering




Room
Aula N8
Room
Sala
Consiliare
From the
ground floor
AULA MAGNA
First floor