WM01-1 520

*Sliding Surface Design for Discrete VSS using LQR Technique with a Preset Real Eigenvalue*

Tang, Choon Yik; Univ. of Michigan
Misawa, Eduardo; Oklahoma State Univ.

This paper presents an LQR-based sliding surface design procedure that takes, in addition to the desired weighting matrix, a preset real eigenvalue consequential in discrete VSS as inputs. A weighting matrix that simultaneously stays ``closest'' to the desired one and yields the preset eigenvalue is sought. Sliding surface is then determined from the optimal gain matrix and the preset eigenvalue. The existence and non-uniqueness of feasible weighting matrices, the uniqueness of solution and convexity of the constrained optimization problem, as well as the use of least-squares to simplify and solve the problem are studied. The paper ends with two MATLAB examples that illustrate the design procedure.

WM01-2 525

*Decentralized Sliding Mode Control Design for Hybrid Systems*

Akar, Mehmet; The Ohio State Univ.
Ozguner, Umit; The Ohio State Univ.

This paper proposes a decentralized sliding mode control law for a class of large scale switching systems. It is assumed that some parts of the switching structures are fixed, and the design of the decentralized sliding mode control laws for the switching and fixed parts are carried out independently. The inclusion principle is developed so that one can expand a switching system, possibly performing sliding modes, into a higher dimensional switching system, design decentralized sliding mode controllers in the expanded space, then contract the solution for implementation on the original system. Some design issues, like connective reachability of the sliding manifold and the stability of the sliding mode equations in the expanded and original state spaces are examined. Finally, an example is given to illustrate the effectiveness of the design methodology.

WM01-3 530

*Chattering-Free Sliding Mode Control with Unmodeled Dynamics*

Krupp, Don; NASA Marshall Space Flight Center
Shtessel, Yuri B.; Univ. of Alabama at Huntsville

Sliding mode control systems are valued for their robust accommodation of uncertainties and their ability to reject disturbances. In this paper, a design methodology is proposed to eliminate the chattering phenomenon affecting sliding mode controlled plants with input unmodeled actuator dynamics of second order or greater. The proposed controller design is based on the relative degrees of the plant and the unmodeled actuator dynamics and the ranges of the uncertainties of the plant and actuator. The controller utilizes the pass filter characteristics of the physical actuating device to provide a smoothing effect on the discontinuous control signal rather than introducing any artificial dynamics into the controller design thus eliminating chattering in the system's output response.

WM01-4 535

*Youla-Parameterization of Output Feedback Sliding Mode Controller: Internal Stability and Disturbance Rejection*

Nonaka, Kenichiro; Musashi Inst. of Tech.

In this study, a parameterized output feedback dynamic sliding mode controller is proposed and internal stability, BIBO stability, and external disturbance rejection problem of generalized plant is studied. The proposed controller is described by a a solution of bezout equation and is parameterized by a Youla's free parameter. It is shown that by this controller, the sliding mode is achieved in finite time, and thereafter, the ideal sliding mode controller stabilizes the generalized plant in the sense that internal stability is assured. Also, the model matching problem is formulated for a generalized plant, and the difference between linear dynamic controller and sliding mode controller is highlighted. The two simulation results show the strength of this method.

WM01-5 540

*Friction Compensation via Smooth Adaptive Dynamic Surface Control*

Maulana, Aria Putra; Keio Univ.

This paper is dealing with a development of friction compensation scheme for positional set-point regulation at DC motor servomechanism via smooth adaptive dynamic surface control design. No exact knowledge of the friction model is required for the design of the controller. The global asymptotic stability is achieved using Lyapunov's direct method. Numerical simulation is presented to confirm the capability of the proposed scheme.

WM01-6 542

*Input-Output Analysis of Limit Cycling Relay Feedback Control Systems*

Boiko, Igor; SNC-Lavalin

This paper proposes a frequency-domain method for input-output analysis of a class of relay feedback control systems. The approach is based on the notion of the locus of a perturbed relay system. The proposed locus specifies the response of a linear plant to its non-symmetric pulse waveform input in a closed-loop system and, consequently, comprises transfer properties of the relay system. Formulae for loci calculation are derived. The techniques of computing of the parameters of limit cycles and the gain of the relay employing the notion of the locus are given.

WM02-1 547

*Adaptive Internal Model Control: the Discrete-Time Case*

Silva, Guillermo J.; Texas A&M Univ.
Datta, Aniruddha; Texas A&M Univ.

This paper considers the design and analysis of a discrete-time H2 optimal robust adaptive controller based on the internal model control structure. The Certainty Equivalence principle of adaptive control is used to combine a discrete-time robust adaptive law with a discrete-time H2 internal model controller to obtain a discrete-time adaptive H2 internal model control scheme with provable guarantees of stability and robustness. The approach used parallels the earlier results obtained for the continuous-time case. Nevertheless, there are some differences which, together with the widespread use of digital computers for controls applications, justifies a separate exposition.

WM02-2 556

*Output Feedback Adaptive Robust Control of Uncertain Linear Systems with Large Disturbances*

Xu, Li; Purdue Univ.
Yao, Bin; Purdue Univ.

In this paper, the discontinuous projection based adaptive robust control (ARC) is extended to a class of uncertain linear systems with large disturbances. An observer is first designed to provide exponentially convergent estimates of the unmeasured states. This observer has an extended filter structure so that on-line parameter adaptation can be utilized to reduce the effect of the possible large nominal disturbance that has a known shape but unknown amplitude. Estimation errors are dealt with via robust feedback at each step of the design procedure. Compared to other existing robust adaptive schemes, the proposed method explicitly takes into account the effect of disturbances and uses both parameter adaptation and robust feedback to attenuate its effect for an improved performance. Furthermore, the upper bound on the absolute value of the tracking error over entire time-history is given and related to certain controller design parameters in a known form, which is more transparent than that in RAC design.

WM02-3 561
*Direct Pole Placement Adaptive Control for Sinusoidal Signal Tracking*
Zhang, Youping; United Technologies Research Ctr.

In this paper, we propose a direct pole placement adaptive control scheme for unknown but open loop stable linear plant with time delays. This controller utilizes the internal model principle to eliminate steady state tracking error for signals with known distinct frequencies. The controller order depends only on the number of frequencies in the reference input, but not on the order of the plant. It is shown that with sufficiently small loop gain, the controller can guarantee stable closed loop, and asymptotic tracking.

WM02-4 566
*Iterative Unfalsified Adaptive Control: Analysis of the Disturbance-Free Case*
Kosut, Robert L.; SC Solutions, Inc.

The performance of three iterative adaptive schemes is analyzed and compared: (1) indirect control design via classical system identification, (2) indirect control design via plant uncertainty model unfalsification, and (3) direct controller unfalsification. Each approach will be analyzed under the same simplifying assumptions: infinite data, the plant is linear-time-invariant and disturbance-free, and the iterative controller is also linear-time-invariant.

WM02-5 571
*Model Reference Adaptive Control for a Class of Nonlinear Systems with Unknown Degrees and Uncertain Relative Degrees*
Miyasato, Yoshihiko; The Inst. of Statistical Mathematics

This paper presents a novel approach to the design of model reference adaptive control for a class of nonlinear systems with unknown degrees and uncertain relative degrees. Contrary to the previous researches of model reference adaptive control where the degrees and relative degrees of controlled systems are assumed to be known, the degrees in the present paper are completely unknown, and the relative degrees are partly unknown; that is, the relative degrees are known to be r, r+1, or r+2 with known r. It is shown that the proposed model reference adaptive controllers stabilize nonlinear systems of unknown degrees without exact knowledge of relative degrees, and make the tracking errors converge to arbitrarily small residual regions. This can be done by constructing approximate model matching control systems where continuous and sufficiently smooth sigma-modification robust adaptive laws are utilized.

WM02-6 576
*Improving Transient Behavior of Model-Reference Adaptive Control*
Costa, Ramon R.; COPPE/UFRJ

This paper develops a new approach for the Model--Reference Adaptive Control scheme and analyzes its stability and transient behavior. The main idea of the new algorithm is the introduction of a lead-filter (an approximate inverse of the reference model) in the adaptation law. With respect to stability and transient tracking properties, the results achieved by the new algorithm are considerably superior when compared to the standard algorithm. The transient behavior is analyzed using the singular perturbation method.

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WM03-1 581
*On the Use of Magnetic Bearings for Global Control of Fan Noise*
Watkins, John; United States Naval Academy
Piper, George E.; United States Naval Academy
O'Brien, Richard; United States Naval Academy
Baumann, David C.; Oral Roberts Univ.

In this paper, a novel approach is presented to reduce fan related noise in an acoustic duct. By installing magnetic bearings on the noise producing machinery, it is possible to collocate the anti-noise source with the disturbance noise source. This approach allows for global noise reduction through out the duct system.

WM03-2 586
*Pendulation Suppression of a Shipboard Crane using Fuzzy Controller*
Kimiaghalam, Bahram; North Carolina A&T State Univ.
Homaifar, Abdollah; North Carolina A&T State Univ.
Bikdash, Marwan U.; North Carolina A&T State Univ.

We derive the nonlinear equations of motion for a shipboard crane equipped with the Maryland Rigging. We then develop a state-space model of the crane from an implicit description without simplifying assumptions. A chaotic rolling moment with a dominant frequency of the same order as the resonance frequency of the shipboard crane is applied as an external disturbance. The effect of the disturbance is studied. A fuzzy controller is then designed and tested for this shipboard crane. In this fuzzy controller the change in the length of the rope is the control action, while the friction in the pulley is assumed negligible. The results for this controller show a big decrease in the pendulation magnitude as compared to the cases with no control.

WM03-3 591
*Why Robust Control is a Solution to the Narrow Band Problem in Active Noise Control*
Carmona, J. C.; Technopole de Chateau Gombert
Alvarado Martinez, Victor Manuel; LAG/ENSIEG/INPG

In this paper, an analytical comparaison between the F.A.N.C. approach and the polynomial R.S.T. approach is made. The major result is the use in the two cases of a control law linear in the estimate of the disturbance noise. The opportunity of employing the robust control approach in the narrow band problem avoiding the bulkiness of the classical adaptive solution is analysed. An industrial application is presented.

WM03-4 593
*Modeling and Optimal Control Design of Shipboard Crane*
Wen, Bing; North Carolina A&T State Univ.
Homaifar, Abdollah; North Carolina A&T State Univ.
Bikdash, Marwan U.; North Carolina A&T State Univ.
Kimiaghalam, Bahram; North Carolina A&T State Univ.

A linearized dynamical model of shipboard crane with the Maryland Rigging is derived by using Lagrange's equations. Based on the linearized model, numerical resonant frequencies of Maryland Rigging are obtained and verified for complete nonlinear model. One disturbance, the ship roll motion angle, and three control authorities, changing the length of pulley cable, pulley-brake mechanism control option and load control torque are included in the linearized model for analysis. Controllability and observability are confirmed for each control variable. An active control law to cancel the effect of ship roll motion on load pendulation is achieved by changing the cable length of the pulley and proved to be valid for small ship roll motion. Also, a controller based on Linear Quadratic Regulator (LQR) is designed to reduce pendulation.

WM03-5 598
*Application of Discrete-Time Gain-Scheduled Q-Parameterization Controllers to Magnetic Bearing Systems with Imbalance*
Mohamed, Abdelfatah; Assiut Univ.
Hassan, Ikbal M. M.; Assiut Univ.
Hashem, Adel M. K.; Assiut Univ.

In this paper the problem of imbalance in magnetic bearings is solved using discrete-time gain-scheduled Q-parameterization controllers. Imbalance in rotating machines causes sinusoidal vibrations of variable frequencies. Since the frequency of vibrations equals the rotational speed, the free parameter Q of the Q-parameterization controllers is scheduled as a function of the rotational speed to achieve rejection of the imbalance sinsuoidal

disturbance forces (which cause the vibrations) at all operating speeds. First we present a mathematical model for the magnetic bearing in state space from which includes the effect of imbalance . Second, we explain the discrete-time Q-parameterization controller design for the magnetic bearing to achieve robust stability and imbalance compensation. The free parameter Q is assumed to be a second order proper stable transfer function whose denominator parameters are fixed and the numerator parameters are scheduled as second order polynomial functions of the rotational speed such that rejection of the imbalance sinusoidal disturbance is achieved. Finally several simulation results are presented. The results showed that elimination of the imbalance vibrations are achieved at all operating speeds, moreover robust stability is also achieved.

WM03-6 603

*Servo Design for a High Stiffness Linear Repulsive Magnetic-Levitation Bearing*

Huang, Chao-Ming; National Taiwan Univ.
Yen, Jia-Yush; National Taiwan Univ.

This paper presents the servo design of a high stiffness linear repulsive magnetic-levitation (Maglev) bearing. The maglev bearing is a highly nonlinear system with very serious parameter uncertainties. Most existing literatures have discussed the system stability while very few results have talked about the rigidity of the bearing. This paper proposes an adaptive sliding mode controller via input-output feedback linearization (IOFL) process to overcome these difficulties. The system uncertainties are analyzed and a stability proof is presented. A systematic design procedure is then presented. Comparison among the existing experimental results with show that the proposed control has a better performance.

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WM04-1 608

*Robust Fault Diagnosis of State and Sensor Faults in Nonlinear Multivariable Systems*

Trunov, Alexander B.; Univ. of Cincinnati
Polycarpou, Marios M.; Univ. of Cincinnati

The paper presents a robust fault diagnosis scheme for detecting and approximating state and sensor faults occurring in a class of nonlinear multi-input multi-output systems. The changes in the system dynamics due to a fault are modeled as nonlinear functions of the control input and measured output variables. Both state and sensor faults can be modeled as slowly developing (incipient) or abrupt, with each component of the state/sensor fault vector being represented by a separate time profile. The robust fault diagnosis scheme utilizes on-line approximators and adaptive nonlinear filtering techniques to obtain estimates of the fault functions. Robustness, fault sensitivity and stability conditions of the learning scheme are rigorously derived.

WM04-2 613

*Detection and Identification of Faulty Sensors with Maximized Sensitivity*

Qin, S. Joe; Univ. of Texas at Austin
Li, Weihua; Univ. of Texas at Austin

In this paper we propose a new method for the detection, identification and reconstruction of faulty sensors using a generalized normal process model. The model residual is used to detect sensor faults, and a structured residual approach with maximized sensitivity (SRAMS) is proposed to identify the faulty sensor. An exponentially weighted moving average (EWMA) filter is applied to reducing the effects of noise and dynamic transients. Three different indices are proposed and compared for the identification of faulty sensors. Faulty sensor is reconstructed based on the normal process model and faulty data. The effectiveness of the proposed scheme is tested using the data from an industrial boiler process, where four types of faults are simulated.

WM04-3 4496

*Fault Detection for Jump Discrete Systems*

Tzes, Anthony; Polytechnic Univ.
Le, Ke; Lucent Tech. Bell Laboratories

The development of a fault detection scheme for linear jump systems is addressed in this article. The system's parameter vector is identified through a sliding-window orthotopic set membership identification scheme. A recursive algorithm predicts the interval of the system's output based on the identified parameter bounds. The fault is detected when the actual system output is not within the predicted `worst case' interval output, or when the actual parameter vector is not within the identified interval. Simulation and experimental studies are offered to illustrate the scheme's performance.

WM04-4 618

*Functional Safety Analysis of Reliable Control Systems using Decision by Majority*

Suyama, Koichi; Tokyo Univ. of Mercantile Marine

Fault detection and reliable control theory are for design of safety-related systems. They should be realized in systems comprised of electrical and/or electronic and/or programmable electronic components, which are called electrical/electronic/programmable electronic systems (E/E/PE systems). The IEC (International Electrotechnical Commission) is preparing the international standard for functional safety of such E/E/PE safety-related systems, IEC 61508, which is planned to be adopted by the ISO (International Organization for Standardization). It uses safety integrity levels to specify the target safety level of functions to be implemented by E/E/PE safety-related systems. The author has presented a framework of tolerance against sensor failures using decision by majority. This paper analyzes its functional safety according to the policy of the IEC 61508. A great deal of effort will be made on safety analysis especially based on the international standard in the field of control theory. This paper is the first step to such studies.

WM04-5 622

*On the Design of Fault Diagnosis Filters and Fault Tolerant Control*

Kabore, Pousga; UMIST
Wang, H.; UMIST

The problem of the design of fault diagnosis design and their use for fault tolerant control is addressed in this paper whereby a new formulation is given. In this formulation, the fault signal is regarded as an input to the system. A set of residual generators is designed, each being sensitive to a different fault. The contribution of the paper is then to design a feedback controller to control the residuals to zero. As a result, the feedback compensates the effect of the faults on the residuals, thus providing the estimates of the faults. These estimates can be use for fault tolerant control. A simulation dealing with pH control in papermaking is presented. In this example, the estimation of the fault is shown using the proposed approach.

WM04-6 627

*Dynamic Fault Detection Approaches*

Stroph, Ralf; Univ. of York
Clarke, T.; Univ. of York

In this paper, several novel dynamic acceptance test approaches, applicable to any linear, causal, time-invariant control system, are developed. The acceptance tests perform a reasonableness check on controller outputs, based upon critical control theory. The dynamic approach checks the control system on-line and in run-time and reacts to controller demand changes as the control system operates. Theory is presented to enable one to place dynamic magnitude and rate bounds on controller output signals in the time domain. Practical implementation of the acceptance tests into realistic control systems is discussed leading to verification of a highly successful fault detection technique.

WM05-1 632

*Dynamic Matrix Control of a Specialty Chemical Plant with Different Plantwide Control Structures*

Zhan, Qiang; Lehigh Univ.
Grassi, Vincent G.; Air Products & Chemicals, Inc.

Model Predictive Control Technology has been successfully applied within the industry for more than 20 years. Most of the applications appear in the refining and petrochemicals industry, with few in specialty chemical plant. In this paper DMC+ commercial multivariable control software is evaluated for a specialty chemical process using offline simulation. The relative benefit that can be obtained from DMC+ above and beyond advanced regulatory plantwide control is carefully studied. In this study, DMC+ is built as a supervisory controller on the decentralized SISO plantwide control structure. DMC+ uses the setpoints of PI controllers as the manipulated variables. In this paper, different plantwide control structures are used and the performance of DMC+ on top of all these different plantwide control structures are compared. It will be shown that a well designed regulatory plantwide control structure is necessary to stabilize and linearize the process around some operating point. Good plantwide control design will give a better performance for DMC+.

WM05-2 637

*A Model Predictive Fault-Tolerant Temperature Control Scheme for Hot Isostatic Pressing Furnaces*

Gopinathan, Murali; Scientific Systems Co., Inc.
Mehra, Raman K.; Scientific Systems Co., Inc.
Runkle, Joseph C.; Ultraclad Corp.

In this work, a fault-tolerant Model Predictive Control (MPC) scheme for precise control of temperature in HIP furnaces was developed, implemented and tested on a production 6-zone HIP furnace at Bodycote IMT, Inc., in Andover, MA. A nonlinear state space representation of the dynamics of the temperature in a HIP furnace was developed and used to design MPC. The MPC-based fault-tolerant control system was demonstrated to outperform the existing PID controller in the following aspects: (i) achievement of heating rate of at least twice more than the existing PID, which resulted in the reduction of the total cycle time and hence substantial increase in the production; (ii) automatic detection of loss of power to furnace zone (due to ground faults), and controller reconfiguration to achieve the desired process objectives, which with the PID system was impossible and required operator intervention.

WM05-3 642

*A Case Study on Performance Analysis and Trouble Shooting of an Industrial Model Predictive Control System*

Kadali, Ramesh; Univ. of Alberta
Huang, Biao; Univ. of Alberta
Tamayo, Edgar; Syncrude Canada Ltd.

This paper is concerned with multivariate performance analysis and trouble shooting of an industrial distillation column model predictive control system. Control performance is analyzed through model validation of the distillation column, feed-forward and feedback control performance assessment of the existing MPC controller, and multivariate analysis of variance of routine process operating data. Problems of the existing MPC controller and major disturbance sources are identified through this case study.

WM05-4 647

*Predictive Control: Propositions for the Design Methodology*

Drogies, S.; Darmstadt Univ. of Tech.
De Geest, D.; CNRS

The work presented in this paper deals with predictive control tuning. The study is carried out by simulating second order linear or non-linear processes, corresponding to simulator models of industrial furnaces. The interest for predictive control is tied to its attractive concept and properties, as well as to its widespread use in industry. Unfortunately many parameters have to be tuned in order to achieve efficient control laws. The goal of the present work was to concentrate on the Model-based Predictive Controller (MPC) tuning methodology in order to derive a nearly automatic design strategy. Firstly, new design parameters are introduced in order to improve the results when the reference signal is known in advance. Secondly, propositions are made for a heuristic tuning method based on expert rules. A non-linear furnace model is used to illustrate the guidelines.

WM05-5 652

*A Design of a Strongly Stable Generalized Predictive Control using Coprime Factorization Approach*

Inoue, Akira; Okayama Univ.
Yanou, Akira; Okayama Univ.
Hirashima, Youichi; Okayama Univ.

This paper proposes a new generalized predictive control (GPC) having new design parameters. In selecting the design parameters, the controller becomes a strongly stable GPC, that is, not only the closed-loop system is stable, but also the controller itself is stable. The parameters are introduced by applying the coprime factorization approach and comparing Youla parametrization of stabilizing compensators to the controller by the standard GPC.

WM05-6 657

*Linear Matrix Inequalities and Polyhedral Invariant Sets in Constrained Robust Predictive Control*

Lee, Young I; Oxford Univ.
Kouvaritakis, Basil; Oxford Univ.

Robust predictive control has been tackled through the use of linear matrix inequalities and ellipsoidal invariant sets. Earlier work in this area restricted the prediction class to state feedback and did not make use of a control horizon; furthermore the computational load in this approach was excessive. Both these problems can be overcome through the use of an autonomous but augmented system for the purposes of prediction. Recent work considered the use of a control horizon and polyhedral sets, and here we extend this approach to the more efficient formulation based on the autonomous system predictions.

WM06-1 662

*Tutorial: Model Predictive Control Technology (I)*

Rawlings, James B.; Univ. of Wisconsin-Madison

This paper provides a brief tutorial on model predictive control (MPC) theory for linear and nonlinear models. The discussion of MPC with linear models covers the topics of steady-state target calculation, infinite horizon receding horizon regulation, resolving infeasibilities caused by constraints, and state estimation and disturbance models. The section on nonlinear models briefly discusses what is desirable from a theoretical perspective and what is possible from an implementation perspective and focuses on some current efforts to bridge this gap. The paper concludes with a brief outlook for future developments in the areas of nonlinear MPC, robustness, moving horizon state estimation and MPC of hybrid systems.

WM06-2 *

*MPL Implementation: a Project View (I)*

Hawkins, Robert B.; Aspen Technology, Inc.

Abstract not available.

WM06-3 *

*Multivariable Control of Parallel Product Dryers (I)*

Meier, W. Jeff; E.I. Du Pont de Nemours and Co.

Abstract not available.

WM06-4 *

*Control Strategy Design using Model Predictive Control (I)*

Downs, James J.; Eastman Chemical Co.
Vogel, Ernest F.; Eastman Chemical Co.

The purpose of this paper is to describe some of the successes and problems encountered when implementing infinite horizon model predictive control (IHMPC) on chemical processes. The IHMPC algorithm employs a Kalman filter as a plant observer to reconstruct plant states, a quadratic program formulation to determine steady state process targets, and an infinite horizon linear quadratic regulator to calculate process inputs. The IHMPC algorithm has been used as an effective tool to gain the process control benefits that come from its ability to handle constraints, process interactions, and multiple time frames. The use of the IHMPC algorithm on a variety of chemical processes has led to insight on how to effectively use IHMPC along with traditional control strategy notions to improve process control. The development of control strategies using IHMPC has resulted in the typical benefits of increased throughput and reduced process variability. Several issues remain to be addressed. These include: controller tuning, managing measurements with low but important information content, complex performance criteria, redundant process information, and controller robustness to measurement loss or deterioration. These areas of improvement will be described in the context of how they impede the more widespread implementation of IHMPC on chemical processes.

WM06-5 677
*Nonlinear Model Predictive Control (I)*
Martin, Greg; Pavilion Technology, Inc.

Nonlinear Model Predictive Control (NMPC) has been introduced in commercial applications. Since mid 1996 approximately 50 applications have been commissioned in polymers, chemicals, food, pulp and paper, and oil refining. The nonlinear capability is facilitated by neural networks. Inferred property models are obtained by training neural network models on process and lab data. These models are implemented on-line to provide feedback for the NMPC controlled variables. They are also used to calculate gains that are passed to the NMPC control models at each control interval. Dynamic parameters in the NMPC control models are linear, but possibly time-varying. The gain parameters in the NMPC control models are updated at each control interval from the neural network sensitivities and are therefore nonlinear. They are also updated during the manipulated variable move - controlled variable trajectory calculations. NMPC is particularly beneficial in process applications where grade changes are made. In polymers, for example, often a dozen grades are manufactured by a given line, and the difference between grades can be large in terms of the process sensitivities of a controlled inferred property to the manipulated variables. In polypropylene it is not unusual to see gain change by a factor of fifteen between grades. A linear (fixed-gain) MPC application in this case must be drastically de-tuned. The result is good performance for the hi-gain grade, and sluggish performance for the low-gain grade. So sluggish, in fact, that the linear MPC application does not meet performance requirements for disturbance rejection and grade transition times. This industrial presentation will provide a brief overview of the commercial NMPC package and move quickly to a summary of a specific polymers application: a Spheripol design polypropylene loop reactor at OPP Petroquimica's plant in Triunfo, Brazil. This is a 3x3 NMPC application with neural network inferred properties for the controlled variables. Trend plots that demonstrate grade change performance will be presented for linear MPC (the nonlinear capability of the NMPC package can be turned off), NMPC without optimization, and NMPC with nonlinear optimization (the nonlinear equivalent to what has been referred to as the "MPC linear program front-end"). NMPC decreases transition time by a factor of four over linear MPC. NMPC with optimization further decreases transition time about 35% over NMPC alone. There are several paths which can be used to complete a transition; the NMPC optimizer selects the "right" path based on economics, not purely on the controlled variable predictions. This NMPC application has been in closed-loop since mid 1996. Polymer grade transition time has been reduced by two thirds. Production rate has been increased dramatically. This unit currently holds the world record for Spheripol unit production.

WM07-1 679
*Stability Analysis of Nonlinear Machining Force Controllers (I)*
Landers, Robert G.; Univ. of Michigan
Lu, Yen-Wen; Univ. of California at Los Angeles

Regulating machining forces is a common process control technique used to increase productivity and quality. Model parameters vary significantly during a normal operation, thus, adaptive techniques have predominately been used. However, model-based techniques that carefully account for changes in the force process have again been examined due to the reduced complexity afforded by such techniques. In this paper, the effect of model parameter variations on the closed-loop stability for two model-based force controllers is examined. It was found that the stability boundary in the process parameter space can be exactly determined for force control systems designed for static force processes. For force control systems designed for first-order force processes, it was found that the stability boundary is sensitive to the estimate of the discrete-time pole. The analysis was verified via simulations and experimental studies.

WM07-2 684
*Turning Force Control Systems Based on the Estimated Cutting Force Signals (I)*
Huh, Kunsoo; Hanyang Univ.
Kim, Jaeok; Hanyang Univ.

While a cutting tool is machining a workpiece at various cutting depth, the feedrate is usually selected based on the maximum depth of cut. Even if this selection can avoid power saturation or tool breakage, it is very conservative compared to the capacity of the machine tools and can reduce the productivity significantly. Many adaptive control techniques have been reported that can adjust the feedrate to maintain the constant cutting force. However, these controllers are not very widely used in manufacturing industry because of the limitations in measuring the cutting force signals. In this paper, turning force control systems based on the estimated cutting force signals are proposed. A synthesized cutting force monitor is introduced to estimate the cutting force as accurately as a dynamometer does. Three control strategies of PI, adaptive and fuzzy logic controllers are applied to investigate the feasibility of utilizing the estimated cutting force for turning force control. The experimental results demonstrate that the proposed systems can be easily realized in CNC lathe with requiring little additional hardware.

WM07-3 689
*A Linear Estimation Algorithm for ARMAX Models with Time Dependent Coefficients (I)*
Mrad, R. Ben; Univ. of Toronto
Farag, E.; Univ. of Toronto
Levitt, J. A.; Ford Motor Co.

An approach that models a nonlinear process based on multi-input/single-output measurements is developed. The approach uses stochastic Time-varying AutoRegressive Moving Average models that incorporate a number of eXogeneous measurable inputs (TARMAX). The TARMAX model coefficients are explicit functions of time and are expressed as a linear combination of a set of pre-selected functions. The modeling approach is shown to be suitable to a milling process and a strictly linear method for evaluating the TARMAX model coefficients is presented. The model estimation approach does not require initial guess parameter values and is suitable for micro-computer implementation. The performance of the estimation algorithm is verified through numerical simulation examples.

WM07-4 694
*Detecting Nonlinearities in Time Series of Machining Processes (I)*

Beule, Dieter; Institut Fur Theoretische Physik
Herzel, Hanspeter; Institut Fur Theoretische Physik
Uhlmann, Eckart; Fruanhofer-Inst. F. Produktion. Und Konstruk.
Krueger, Joerg; Fruanhofer-Inst. F. Produktion. Und Konstruk.
Becker, Frank; Fruanhofer-Inst. F. Produktion. Und Konstruk.

The current situation in manufacturing industry is characterized by a demand for increasing product quality, smaller batch sizes and just-in-time production. Strong competition requires higher productivity and profitability. This situation especially puts machine tools industry under pressure. The increasing development of cutting speed, dry turning or hart turning are new trends in production. However it is very difficult to achieve high process safety with these conditions. The diagnosis of mechanical machine elements or tool monitoring with these machining processes cannot be satisfactorily achieved with simple methods. The increasing demands made on the performance of modern machine tools imply new functionality to guarantee the quality and reliability of production process. Another decisive factor is the machine availability in automated manufacturing systems. To achieve this goal, it is necessary to consider nonlinearities in process. Classical methods for modeling concentrate on linear descriptions. In this way, signal analysis only separates between signal parts, which can be modeled in a linear way, and noise. Other proceedures use nonlinear models, i.e. artificial neural networks. However, they do not analyse if the observed behaviour is really nonlinear or if it is linear with a high complexity. In order to account for nonlinearities in the modeling and control of manufacturing systems one has to analyze to what extent nonlinearities are essential. For this purpose we study time series of turning and milling processes as well as friction characteristics of drive systems with linear and nonlinear techniques. Our approach includes the following first steps: sliding power-spectral analysis to test stationarity, trend removal (if necessary), check whether or not the distribution is Gaussian. These preliminaries allow the constriction of appropriate stochastic processes (surrogates) with the same distribution and power-spectrum as the time series under consideration. Next we apply tools from nonlinear dynamics to test the hypothesis that the time series has been generated by a linear stochastic process. For this purpose the correlation integrals according to Grassberger and Proccachia 1983 are calculated for the original data and surrogates. Another related strategy is the comparison of linear and nonlinear prediction techniques (DVS plot as an abbreviation for Deterministic Versus Stochastic). Predictions are based on an embedding of time series in a pseudo-phase-space with the aid of delay-coordinates. Using one half of the data local linear maps are constructed to perform short-term predictions. The predictor is constructed via least-square approximation from k neighbors in pseudo-phase-space. The standard deviation of the prediction is calculated from the other half of the data the test set. The dependence of the prediction error on the number of neighbors k contains the crucial information. If the optimal k is close to the total number of data points, global linear models are appropriate, i.e. nonlinearities are not essential. If, in contrast, small k gives optimal prediction local models are superior as an indicator of nonlinearities. The above tools are applied to time series of processes, which are measured by force sensors as well as acoustic emission sensors. A extensive examination actually relies on force signals, detected by a three component sensor during milling of steel. A comprehensive experimental program based on current, force and acoustic emission measurements is formulated to predict the state of the cutting tool or state of the process. Finally, we discuss the implications of time series analysis for the characterization of wear and for the short-term prediction of tool breakage. Future activities will not only concentrate on the recognition of faults in process. We will also try to detect problems of electromechanical drive components (i. e. bearings, ball screw, slides) by means of the analysis of nonlinear systems. In early stages of component faults, complex behaviour can be observed in the state variables of the control circles, especially in the current signal and the derivates of the speed signal. In our examinations, time series analysis has in some points already shown advantages compared with classical spectral analysis. In an early stage of wear of slides and other types of bearings, the effects on measurement signals are only short-term and irregular in time, so that spectral analysis methods such as Fast Fourier Transform can not be applied successfully. An important indicator for wear is the friction that can be observed in various linear and nonlinear forms. Especially the nonlinear friction behaviour of the drive system has not yet been taken into account for the detection of wear. A task of a later stage of the project is to identify those methods which will be useable for computer based online supervision of machining processes. Increasing importance is in the integration of sophisticated and powerful algorithms into the computerized numerical control, since CNC platforms have a rapid growth in computational power. The first steps for an integration of methods for analysis of nonlinear dynamic systems will concentrate on patterns, which can be achieved by phase-space-diagrams. A main topic in this field will be the generation of more-dimensional threashold levels to cluster efficiently the areas of 'normal' process behaviour.

WM07-5 699

*Linear Robust Motion Control of Flexible Joint Robots Part A: Modeling (I)*

Ciuca, Frank; Univ. of Windsor
Lahdhiri, Tarek; Univ. of Windsor
Elmaraghy, Hoda A.; Univ. of Windsor

This paper presents a realistic linear and comprehensive model for flexible joint robot manipulators to be used in designing robust robot motion controllers. Unlike most of existing models, the proposed model includes the effects of stick-slip friction, and of the rotors' coriolis and centrifugal acceleration due to the velocities of the precedent links and rotors. In addition, this model uses a nonlinear spring force deflection curve and takes into account the unmodeled dynamics and measurement noise. Extensive simulations were performed on an experimental flexible joint robot and the results demonstrate that the proposed linear model outperforms the classical linear models in tracking its corresponding detailed nonlinear model.

WM07-6 704

*Robust Linear Motion Control of Flexible Joint Robots Part B: Control (I)*

Lahdhiri, Tarek; Univ. of Windsor
Ciuca, Frank; Univ. of Windsor
Elmaraghy, Hoda A.; Univ. of Windsor

This paper presents the development of a robust linear motion tracking controller for the linear robot model, derived in Part A of this paper for an experimental flexible joint robot. The proposed controller is designed using linear robust control methodologies: linear quadratic Gaussian (LQG) / loop transfer recovery (LTR) techniques. Extensive simulations are performed, and the results demonstrate that the proposed controller provides excellent tracking performance and very high disturbance rejection in the presence of parameter uncertainties, unmodeled dynamics, and measurement noise.

WM08-1 709

*Design and Implementation of HIL Simulators for Powertrain Control System Software Development (I)*

Raman, Shankar; Ford Motor Co.
Sivashankar, Narayanan; Ford Motor Co.
Milam, W.; Ford Motor Co.
Stuart, Walt; Visteon Automotive Systems
Nabi, S.; Visteon Automotive Systems

There is considerable interest in the automotive industry in computer aided engineering tools that support rapid development of quality products. In this paper, we describe some of the design and implementation issues for such a tool, namely, a Hardware-in-the-Loop (HIL) simulator, in the context of powertrain control system software development. This HIL system is used to verify the production powertrain controller module (PCM) performance. Hence,

the powertrain and driveline dynamics are simulated on the HIL hardware and the production PCM is the "hardware" in the loop. HIL system requirements from the users' and the system developer's perspectives are described. The paper focuses on important HIL issues related to the real-time powertrain models and the hardware signal interfaces.

WM08-2 714
*Driver Model Uncertainty (I)*
Chen, Liang-Kuang; Univ. of Michigan
Ulsoy, A. Galip; Univ. of Michigan

This article presents a preliminary investigation of the modeling of driver uncertainty. A linear second order driver model with parametric and unstructured uncertainty is proposed. We obtain and validate the uncertainty models using the data from real drivers driving a fixed-base driving simulator.

WM08-3 719
*On Real-Time Simulation of Induction Motors (I)*
Sureshbabu, Natarajan; Ford Motor Co.
Seshagiri, S.; Ford Motor Co.
Masrur, Abul; Ford Motor Co.
Powell, Barry K.; Ford Motor Co.

In this paper we address concerns relating to building real-time executable software models to simulate the dynamics of an induction motor driving a vehicle. Using an example, we investigate how the selection of a reference frame influences the ability to simulate the induction motor dynamics in real-time. We also investigate the possible advantages of a state transition matrix based approach over the standard simulation techniques based on Euler integration.

WM08-4 724
*An Experimental Investigation of a CW/CA System for Automobiles using Hardware-in-the-Loop Simulations (I)*
Yi, Kyongsu; Hanyang Univ.
Woo, Minsu; Hanyang Univ.
Kim, Sung Ha; Kia Motor Co.
Lee, Seong-Chul; Kia Motor Co.

Collision Warning/Collision Avoidance (CW/CA) Systems have been an active research and development area as the interest and demands for active safety of road vehicles increase. This paper presents an investigation of CW/CA Systems for automobiles. A CW/CA 'Hardware-in-the-Loop' Simulation (HiLS) system has been designed and used to test a CW/CA algorithm, radar sensors, and warning displays under realistic operating conditions in the laboratory. A CW/CA algorithm consists of a distance warning decision algorithm and a combined throttle/brake control law for collision avoidance. The CW/CA HiLS system consists of a personal computer, a preceding vehicle simulator, a radar sensor and a warning display. The personal computer has been used to simulate preceding and following vehicles. The computer calculates velocities of the preceding and following vehicles, relative distance and relative velocity of the vehicles using vehicle simulation models. The relative distance and velocity are applied to the vehicle simulator that is controlled by a DC motor. The relative distance of the vehicle simulator is measured by the radar sensor and is fed back into the computer.

WM08-5 729
*Active Steering Control Based on the Estimated Tire Forces (I)*
Huh, Kunsoo; Hanyang Univ.
Seo, Chanwon; Hanyang Univ.
Kim, Joonyoung; Hanyang Univ.
Hong, Daegun; Hanyang Univ.

Steering of the vehicles on a slippery highway is a difficult task for most passenger car drivers. The vehicles tend to slide outward with less lateral forces than on normal roads. When the drivers notice that their vehicles on a slippery highway start to depart from the cornering lane, most of them get easily panic and make a sudden steering and/or braking, which in turn may induce spin-out and instability on their vehicles. In this paper, an active steering control method is proposed such that the vehicles in slippery roads are steered as if they are driven by experienced drivers. Those drivers have better perceptive capability of judging the slippery status and they respond faster with smooth compensatory action. In the proposed method, the estimated lateral forces acting on the steering tires are compared with the reference values and the difference is compensated by the active steering method. A fuzzy logic controller is designed and its performance is evaluated on a Hardware-In-the-Loop Simulation (HILS) system. This method can be realized with steer-by-wire concept and is promising as an active safety technology.

WM08-6 734
*Embedded Control System Implementation and Modeling Issues (I)*
Erkkinen, Thomas; Applied Dynamics, Inc.

Electronic Control Unit (ECU) manufacturers are reaching a mid-life crisis of sorts in that while most development processes now include simulation, rapid prototyping, and Hardware-in-loop testing (HIL) the limitations of existing methods are preventing further growth. Perhaps the most bothersome limitation is the lack of an automated implementation tool which generates production code from the ECU model used during simulation and prototyping. Next on the wish list is a prototyping environment that accurately represents the actual target-constrained production system. This paper discusses these two problems and provides options for their solution.

WM09-1 739
*Alternative Robust Control Strategies for Disturbance Rejection in Fluid Power Systems (I)*
Pannett, Richard F.; Univ. of Bath
Chawdhry, Pravir K.; Univ. of Bath
Burrows, Clifford R.; Univ. of Bath

When a number of actuators or motors are operated from a single hydraulic supply their performance is subject to both pressure and load disturbances. The controller on each consumer unit must therefore be capable of ensuring robust performance in the face of these disturbances. It must also accommodate the inherent non-linearities associated with hydraulic equipment. This paper is an interim report on an on-going study of alternative strategies for the robust control of non-linear systems. It describes two alternative strategies, one based on a linear design route using the H-infinity loop shaping technique, and the other using self-organising fuzzy logic in which a fuzzy controller automatically adjusts its rules as system characteristics change. Comparisons are made between the two approaches. The representative experimental system is a loaded variable displacement axial cylinder motor supplied from a laboratory ring main via a servovalve. Controllers are implemented digitally on a PC. Rig test results are included. Key words: fluid power, fuzzy logic, H-infinity

WM09-2 744
*A Comparison of Some Control Strategies for a Hydraulic Manipulator (I)*
Tochizawa, M.; Univ. of Bath
Edge, K. A.; Univ. of Bath

This paper is concerned with a simulation and experimental study of the control of a two-axis servo-hydraulic manipulator. The objective was to control each axis independently with the aim of achieving good tracking performance for a wide range of payloads and for different configurations. For hydraulic systems, which comprise many components with non-linear characteristics, a controller which is robust against changes in dynamic characteristics and disturbances is required. In this study, a disturbance observer scheme and an adaptive control scheme were evaluated. To design these controllers, a simulation study was important because of the ease of rapid assessment of the effectiveness of the control and the

simplification of the adjustment of control gains. By using the Bathfp simulation package, which is designed for simulating hydraulic systems, a model of the manipulator was constructed and the controllers were designed and compared with a classical control scheme. Each control method was tested experimentally on the manipulator. For one particular manipulator configuration the classic controller with fixed gains could not achieve the desired accuracy target of +/- 2[mm] for the largest payload of 90 kg. However, the disturbance observer and the adaptive controller not only met this target but the accuracy was much better than the classic controller over a wide range of configurations and loads. It was also demonstrated that the disturbance observer was robust with respect to the type of nominal plant model selected. Comparing the predictions with the experimental data, there was some quantitative difference but good qualitative agreement was achieved. For practical use, the simulation is sufficiently accurate. In the adaptive control scheme, good results were obtained in both the simulation and the experimental work. However, the implementation was not as easy as the disturbance observer. In addition stability problems were sometimes encountered as previously described by other investigators. For the case of the highest load, stability was lost when the adaptive gain was set high. It appears that when the payload is large, the non-linearity of the system is more pronounced, and this causes a large modelling error. A large tracking error at the starting point was also measured, with the magnitude depending on the initial value of the estimated parameters; the setting of these values was difficult. The number of parameters which need to be set is much greater than the disturbance observer, even if a low order reference model is used. If high accuracy is not required around the starting point, setting all initial values to zero is possible, but for trajectory control, this is not acceptable.

WM09-3 749

*Robust Stability Analysis of Large Hydraulic Control Systems (I)*

Kremer, Gregory G.; Ohio Univ.

Many large-scale hydraulic systems such as automatic transmission hydraulic systems and fluid power systems are so complex that their initial design must be carried out using only steady-state models - nonlinear system dynamic characteristics are often only checked for the final design configuration by simulation and/or prototype testing. The characteristics that prohibit a rigorous analysis of nonlinear system dynamic characteristics in the initial design of large-scale systems are the size and complexity of the mathematical models, the number of system parameters, and the expense of each nonlinear analysis. This paper proposes a bifurcation-based analysis procedure that is efficient enough to permit the consideration of system dynamics earlier in the design process. The main obstacle to achieving a rigorous dynamic analysis of a large-scale system with a bifurcation-based procedure is the possibility of multiple response modes in the feasible parameter space. Each possible response mode has a different sensitivity with respect to the different system parameters, and the task of finding all possible response modes and determining which is the most likely to occur is daunting – but is feasible with an efficient analysis algorithm. The key advancement described in this paper is the development of an efficient global search procedure that combined with the closest bifurcation method produces a 'practically rigorous' result with respect to the identification of all possible response modes and a meaningful quantification of the relative probability of occurrence for each one. For demonstration, the global search procedure is used to rigorously analyze the stability robustness of a particular large-scale automatic transmission hydraulic system with a 9-dimensional state space and a 24-dimensional parameter space.

WM09-4 754

*Feedback Design for Robust Tracking and Robust Stiffness in Flight Control Actuators using a Modified QFT Technique (I)*

Thompson, David F.; Univ. of Cincinnati
Pruyn, John S.; Univ. of Cincinnati
Shukla, Amit; Univ. of Cincinnati

The problem of dynamic stiffness of hydraulic servomechanisms has often been recognized as a significant performance issue in a variety of applications, the most notable of which includes flight control actuation. A hydraulic servomechanism is said to be "stiff" if it exhibits acceptable rejection of force disturbances within the control bandwidth. In this paper, an approach to feedback design for robust tracking and robust disturbance rejection is developed via the Quantiative Feedback Theory (QFT) technique. As a result, it is shown that reasonable tracking and disturbance rejection specifications can be met by means of a fixed (i.e., non-adaptive), single loop controller. Robust tracking and robust disturbance rejection specifications are mapped into equivalent bounds on the (parametrically uncertain) sensitivity function; hence, the frequency ranges in which tracking or disturbance rejection specifications dominate become immedi-ately obvious. In this paper, a realistic nonlinear differential equation model of the hydraulic servomechanism is developed, the linear parametric frequency response properties of the open loop system are analyzed, and the aforementioned QFT design procedure is carried out.

WM09-5 759

*Adaptive Robust Motion Control of Single-Rod Hydraulic Actuators: Theory and Experiments (I)*

Yao, Bin; Purdue Univ.
Bu, Fanping; Purdue Univ.
Reedy, John; Purdue Univ.
Chiu, George T.-C.; Purdue Univ.

High performance robust motion control of single-rod hydraulic actuators is considered. In contrast to the double-rod hydraulic actuators studied previously, the two chambers of a single-rod hydraulic actuator have different areas. As a result, the dynamic equations describing the pressure changes in the two chambers cannot be combined into a single load pressure equation. This complicates the controller design since it not only increases the dimension of the system to be dealt with but also brings in the stability issue of the added internal dynamics. A discontinuous projection based adaptive robust controller is constructed. The controller is able to take into account not only the effect of parameter variations coming from the inertia load and various hydraulic parameters but also the effect of hard-to-model nonlinearities such as uncompensated friction forces and external disturbances. Extensive experimental results are obtained for the swing motion control of a hydraulic arm. In comparison to a state-of-the-art industrial motion controller, the proposed ARC algorithm achieves more than a magnitude reduction of tracking errors. Furthermore, during constant velocity and regulation periods, the ARC controller reduces the tracking errors almost down to the measurement resolution level.

WM09-6 764

*Nonlinear Observer Based Force Control of Electro-Hydraulic Actuators (I)*

Sun, Hong; Purdue Univ.
Chiu, George T.-C.; Purdue Univ.

This paper presents a nonlinear observer based force control of single-rod hydraulic actuators. An observer based force control of EH cylinders is proposed that does not require the cylinder position and velocity information. By treating the effect of cylinder position and velocity on the pressure dynamics as perturbation to the control model, We employ the perturbation observer concept to estimate the effect of piston motion and design a robust force control algorithm. The proposed method improved both the steady state and transient performance compared with traditional PID method. Simulation and experimental results are presented.

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WM10-1 769

*Master-Slave Passivity Design for Stabilization of Nonlinear Systems*

Jankovic, Mrdjan; Ford Research Labs
Larsen, Michael; Univ. of California at Santa Barbara

Kokotovic, Petar V.; Univ. of California at Santa Barbara

A new development of the master-slave design makes it applicable to single input nonlinear systems. In the new design, a virtual input-output pair is first selected for passivation. A control law for the actual input is then found which renders the virtual input-output pair passive. One of the goals of the master-slave approach is to avoid the relative degree obstacle to passivation. For certain classes of systems, linear matrix inequalities (LMI's) are used to find a passivating control law.

WM10-2 774
*Adaptive Passive Velocity Field Control*
Li, Perry Y.; Univ. of Minnesota

Passive velocity field control (PVFC) methodology is developed for mechanical systems that must be coordinated and / or must interact with the physical environment. PVFC encodes tasks by means of time invariant desired velocity fields unlike the traditional method of specifying tasks using timed trajectories. This make explicit the coordination requirement of the task. PVFC also guarantees that the closed loop system interacts with its physical environment passively so that stability and robustness will be enhanced, especially when interacting with uncertain physical environment. Applications include teleoperated manipulators, contouring tasks in machining and smart exercise machines. The present paper extends PVFC to situations where the inertia parameters of the mechanical system are unknown. A direct adaptive control scheme is proposed which preserves the passivity of the closed loop system and ensures that the asymptotic convergence of the velocity to the direction of desired velocity field.

WM10-3 780
*How to Have Passively Q-Switched Lasers Self-Pulsate*
Shahruz, Shahram M.; Berkeley Eng. Research Inst.

The rate equations of passively Q-switched lasers are considered. These equations represent the dynamics of the photon number in the laser cavity, the population inversion of the laser, and the ground-state population of the saturable absorber, when excited by an input (pumping rate). Having the rate equations, (i) it is shown that the laser is the bounded-input bounded-state (BIBS) and the bounded-input bounded-output (BIBO) stable; (ii) the amplitudes of step inputs are determined for which all equilibrium points of the laser are unstable. The boundedness of the laser output and the instability of its equilibrium points imply that the laser can have a periodic, a quasi-periodic, or a chaotic output. When the output is periodic, the laser is self-pulsating, which is the desirable behavior of the laser.

WM10-4 785
*Passivity-Based Induction Motor Speed Control: Unknown Load Torque Case*
Abdel Fattah, Hossam A.; Case Western Reserve Univ.
Loparo, Kenneth; Case Western Reserve Univ.

The problem of specifying a desired torque trajectory to achieve speed tracking in passivity-based control of induction motors is addressed. The paper presents a solution to the problem that does not require acceleration measurement nor knowledge of the load torque. Simulation results show the feasibility of the scheme when used as an improvement to the non-observer based scheme proposed by Espinosa et al [1].

WM10-5 790
*On Multi-Dissipative Dynamic Systems*
Thygesen, Uffe H.; Tech. Univ. of Denmark

We consider deterministic dynamic systems with state space representations which are dissipative in the sense of Willems with respect to several supply rates. This property is of interest in robustness analysis and in multi-objective control. We give conditions under which the convex cone of dissipated supply rates is closed. Furthermore we show convexity and continuity properties of the available storage and required supply as functions of the supply rate.

WM10-6 795
*Dissipativity and Stability of Nonlinear Jump Systems*
Aliyu, M. D. S.; King Fahd Univ. of Petroleum and Minerals

In this paper, we extend the concept of dissipativeness developed for deterministic systems, to stochastic systems with Markov jump disturbances. We give necessary and sufficient conditions for the system to be dissipative in terms of a set of cross- coupled Hamilton-Jacobi inequalities. Finally, we discuss the relationship between the dissipativeness of the system and its stochastic stability.

WM11-1 800
*Delay-Dependent Robust H_Infinity Control of Uncertain Linear Systems with Input Delay*
Li, Xi; Univ. of Alberta
Guay, Martin; Univ. of Alberta
Huang, Biao; Univ. of Alberta
Fisher, D. Grant; Univ. of Alberta

This paper examines the problems of robust stabilization and robust H_{infinity} control for linear systems with both delayed and non-delayed inputs and subject to norm-bounded parameter uncertainty. The case of a single, constant time-delay is considered. Attention is focused on the design of memoryless state feedback controllers that guarantee either closed-loop stability or closed-loop stability with an H_{infinity} performance for any delay not larger than a given bound and for all admissible uncertainties. The proposed methods are given in terms of linear matrix inequalities and the delay bound can be computed by using the standard LMI techniques.

WM11-2 805
*Steady State Offset in Predictive Control*
Ordys, Andrzej W.; Univ. of Strathclyde

The paper analyses a linear discrete-time system controlled by a state-space predictive controller. It is assumed that the parameters and the dynamic order of the system used for the design of the controller differ from the true parameters of the plant. For such a system, the steady state output predictions are calculated. Subsequently, it is shown that the steady-state tracking error is zero. Some generalisations of this result are also discussed.

WM11-3 810
*Suboptimal Dead Beat Controller for a Discrete-Time Multivariable Plant with Measurement Noise*
Kase, Wataru; Osaka Inst. of Tech.

In this paper, a suboptimal dead beat controller design for a plant with measurement noise is proposed. This method uses the freedom which arises by using non-minimal order observer. For the parameterization of the controller, an extended division algorithm is considered. Numerical examples are also shown to confirm the varidity of the proposed method.

WM11-4 815
*Stability Radius of Linear Delay Systems*
Son, Nguyen Khoa; Hanoi Inst. of Mathematics
Ngoc, Pham Huu Anh; Hue Univ.

In this paper we study robust stability of linear time delay systems under structured parameter uncertainty. A formula for complex stability radius is derived. We then consider linear positive delay systems and prove that for this class of systems the complex stability radius is equal to the real stability radius which can be computed via a simple formula. An illustrative example is given.

WM11-5 817

*Discrete Modeling of Continuous Interval using Higher-Order Integrators*

Hsu, Chen-Chien; St. John's & St. Mary's Inst. of Tech.
Wang, Wei-Yen; Soochow Univ.

A higher-order integrator approach is proposed to obtain an approximate discrete-time transfer function for uncertain continuous systems having interval uncertainties. Thanks to simple algebraic operations of this approach, the resulting discrete model is a rational function of the uncertain parameters. The problem of non-linearly coupled coefficients of exponential nature in the exact discrete-time transfer function is therefore circumvented. Furthermore, interval structure of the uncertain continuous-time system is preserved in the resulting discrete model by using this approach. Formulas to obtain the lower and upper bounds for the discrete interval system are derived, so that existing robust results in the discrete-time domain can be easily applied to the discretized system. Digital simulation and design for the continuous-time interval plant can then be performed based on the obtained discrete-time interval model.

WM11-6 822

*Simple Predictor for Processes with Time Delay*

Zhang, Weidong; Shanghai Jiaotong Univ.
Xu, Xiaoming; Shanghai Jiaotong Univ.

A new method is presented based on optimal control theory for the design of Smith predictor. The resulted controller has two notable merits. First, explicit formulas are obtained for calculating parameters of the controller. Second, the nominal performance of closed loop system, such as overshoot and rise time, can be evaluated quantitatively. It is found that the proposed Smith predictor can be equivalent to Dahlin controller and PID controller. Numerical example is provided to illustrate the new method.

WM12-1 827

*Identification with the Youla Parametrization in Identification for Control*

Ansay, Pierre; Univ. de Liege
Gevers, Michel; Univ. Catholique de Louvain
Wertz, Vincent; Univ. Catholique de Louvain

The typical context in identification for control is where it is desired to estimate a plant model, with the view of designing a new controller that achieves better performance on the true system while providing robustness guarantees. The plant model is estimated in closed-loop, i.e. with data collected on the closed-loop formed by the feedback connection of the unknown system and some stabilizing controller. Most closed-loop identification techniques have in common the ability to estimate approximate models of the open-loop system on the basis of closed-loop data. The identification in the Youla framework is one of these, known in the literature as the Hansen scheme. It is based on the parameterization of all plants stabilized by the controller. The true system is parameterized as a controller-based perturbation of some plant model, defined by a Youla parameter. The identification of this Youla parameter is an open-loop identification problem. The new identified model is then obtained as a Youla-parameter correction of the previous model. Typically, in iterative identification for control schemes, the open-loop models for both input-output and noise dynamics are reconstructed from the closed-loop estimated parameters, followed by the design of a new controller on the basis of these reconstructed open-loop models. In this paper an alternative methodology is used; we parameterize the controller such that its design is directly a function of the estimated parameters of the closed-loop model in lieu of those of the reconstructed open-loop model. A quick description of our methodology is as follows. We modify the Hansen scheme such that it allows to estimate separately the dual Youla parameters: the input-output perturbation of the plant model as well as the disturbance dynamics are estimated separately in an open loop framework. Finally, we relate these estimates to a controller perturbation. The controller perturbation is obtained by parameterizing the set of all controllers that stabilize the new plant model (Youla parameters). We shall see that it is the knowledge of the dual Youla parameters that allows us to design an LQG controller with the optimization performed directly on the Youla parameters.

WM12-2 832

*A Comparison of Canonical Variate Analysis and Partial Least Squares for the Identification of Dynamic Processes*

Simoglou, Alexandros ; Univ. of Newcastle
Martin, Elaine; Univ. of Newcastle
Morris, A. Julian; Univ. of Newcastle

This study contributes to the comparison of Partial Least Squares (PLS) and Canonical Variate Analysis (CVA) for the identification of dynamic systems. Two model forms, Autoregressive with Exogenous Inputs (ARX) and state space representations are developed with PLS and CVA being used to calculate the model parameters. The different models are compared using two case studies: a benchmark simulation of a binary distillation column and an industrial fluidised bed reactor.

WM12-3 838

*Identification of MIMO Bilinear State Space Models using Separable Least Squares*

Verdult, V.; Delft Univ. of Tech.
Verhaegen, Michel H.; Delft Univ. of Tech.
Chou, C. T.; Delft Univ. of Tech.

We present an algorithm to identify multi-input,multi-output (MIMO) discrete-time bilinear state space models from input-output measurements. We estimate the system matrices by optimizing an output error criterion. This criterion depends linearly on some of the system matrices and nonlinearly on the others. Using the principle of separable least squares, we can first solve for the matrices that enter nonlinearly and then obtain the others by solving a linear least squares problem. It is pointed out that subspace-based techniques can be used to estimate the order of the system and to compute initial estimates of the matrices that enter the criterion in a nonlinear way. The algorithm has been tested on a MIMO simulation example.

WM12-4

*Withdrawn*

WM12-5 843

*Thermal Power Plant Dynamics Identification*

Kulessky, Roland; Israel Electric Corp. Ltd.
Hudelman, G.; Israel Electric Corp. Ltd.
Hain, Yakov; Israel Electric Corp. Ltd.

Aspects of the process identifiability and accuracy of the frequency response identification are discussed for two stage's identification approach. A frequency region is defined in which accuracy of frequency response identification from noised data reaches maximum. Besides, the requirement for a deterministic test signal is formulated from the identifiability point of view. Retrofit of two 75MW boilers and 140MW power unit modeling at IEC Power Station are fulfilled by implementation of this identification procedure, yielding satisfactory results.

WM12-6 848

*On the Identification of High-Order Lightly-Damped Multivariable Systems*

Fisher, Darin; Univ. of California at Berkeley
Jue, Deborah; Univ. of California at Berkeley
Packard, Andrew K.; Univ. of California at Berkeley
Poolla, Kameshwar; Univ. of California at Berkeley

This paper describes a practical off-line approach to system identification of very high-order, lightly-damped, multi-variable systems. In particular, we address the practical and computational aspects of this problem. We also discuss the various choices that the modeler must make interactively. Our eventual objective is to enable

``automated'' modeling for such systems by minimizing the burden on the modeler. We begin with sampled measurements of the system's frequency response to obtain an initial model. The frequency domain data could be supplied from finite-element simulations, or from traditional sine-sweep experiments. This model is further refined based on time-domain data as it becomes available. The method is designed to identify very high-order systems by solving several low-order identification problems using the iterative least squares algorithm of Santhanam-Koerner, coupled with the multi-band strategy of Bayard. The individual solutions are combined to yield a transfer-function matrix model of the overall system. A succinct state-space realization of this estimate may be obtained using standard model reduction methods. This approach has made it possible to readily estimate systems with hundreds of modes, thousands of frequency data points, and hundreds of input/output channels using standard PC hardware.

WM13-1 854
*A Learning and Estimation Problem Arising from In Situ Control and Diagnostics of Manufacturing Processes*
Galarza, Cecilia; Univ. of Michigan
Khargonekar, Pramod P.; Univ. of Michigan

We analyze the problem of estimating product variables from process measurements in manufacturing systems. In particular, a novel approach for studying the performance of such estimators in terms of their expected performance is introduced. Using ideas from statistical learning theory, we obtain sufficient conditions on the manufacturing process, the estimation algorithm, and the design procedure to guarantee asymptotic convergence of the estimation algorithm to some optimal estimator when the available data goes to infinity.

WM13-2 860
*Intelligent Signal Validation System for a Cupola Furnace, Part 2: Testing and Analysis*
Subramanian, Senthil; Tennessee Tech. Univ.
Abdelrahman, Mohamed; Tennessee Tech. Univ.

In the first paper of this series [1], the motivation behind the signal validation system for the cupola furnace was presented. A methodology for developing an ANN rule based filter (ANN-RBFTE) and inferential sensors for the molten-iron temperature was described. In this paper we present the testing results of the filter and inferential sensors using cupola experimental data. A methodology for building a signal validation system for the cupola by fusing the data from the ANN-RBFTE and the inferential sensors is also described. The signal validation system is tested using experimental data from a cupola furnace. The testing results verify the excellent performance provided by the validation system. This research provides solid foundation for the implementation of signal validation system to other measurands in the cupola and to other industrial plants.

WM13-3 864
*Learning of Nonlinear FIR Models under Uniform Distribution*
Najarian, Kayvan; Univ. of British Columbia
Dumont, Guy A.; Univ. of British Columbia
Davies, Michael S.; Univ. of British Columbia
Heckman, Nancy E.; Univ. of British Columbia

The PAC learning theory creates a framework to assess the learning properties of a modeling procedure. This paper presents a bound on the size of the training data set required to train a nonlinear FIR model, where the input data are assumed to be generated according to the uniform distribution. The bound is further specified for a family of feedforward neural networks which utilizes a sigmoid activation function. The learning properties of a neural identification task have been assessed using the foresaid family of neural networks. Also, using structural risk minimization algorithm, a learning procedure for the modeling tasks in which the exact number of the hidden neurons is unknown has been introduced.

WM13-4 870
*Input-Output Data Based Tracking Control*
Babinski, Alex; Univ. of Illinois at Urbana-Champaign
Tsao, Tsu-Chin; Univ. of Illinois at Urbana-Champaign

Traditional methods of tracking controller design involve inverting the system dynamics using the model of the system. Model errors will result in performance degradation and may lead to instability. Since the system parameters vary due to the factors such as age, temperature, etc., there is an interest in tracking control schemes that can efficiently address changes in the system behavior. This research proposes a tracking control scheme, in which the inverse dynamics of an LTI system are determined using the system's input-output data. In many practical applications the system is desired to track a set of trajectories that can be characterized by a subspace of L_2. The proposed algorithm utilizes expansion of the system output in terms of a signal obtained in an identification experiment by generating a set of vectors spanning the desired subspace. The performance of the scheme is compared with the performance of the conventional model-based feedforward and repetitive controllers.

WM13-5 875
*Intelligent Signal Validation System for a Cupola Furnace, Part 1: Methodology*
Abdelrahman, Mohamed; Tennessee Tech. Univ.
Subramanian, Senthil; Tennessee Tech. Univ.

In this research we present a methodology for developing a signal validation technique that can be introduced to improve the operation of the cupola iron-melting furnace, an important foundry process used to melt iron. To improve the operation of the furnace, digital controllers are employed. The operation of such controllers, however, depends on accurate measurement of controlled variables. It is necessary to provide reliable signals to the controller for its proper operation. In this research we develop a signal validation system for one of the process variables of the cupola furnace, namely iron temperature. An artificial neural network (ANN) rule-based filter and trend estimator (RBFTE) is developed to estimate the measurement signals and to eliminate spikes and other external disturbances from the measurement signals. Analytical redundancy is provided through the use of inferential sensors developed through the identification of input-output dynamic models for the iron temperature using ANN. Another type of inferential sensor that relies on the identification of nonlinear relations between the iron temperature and another temperature measurement across the furnace body is also developed. In part II of the paper, testing results for the RBFTE filter and inferential sensors and a sensor fusion algorithm are provided.

WM13-6 880
*Sliding-Window Neural State Estimation in a Power Plant Heater Line*
Alessandri, A.; CNR-IAN National Research Council
Parisini, Thomas; Politecnico di Milano
Zoppoli, Riccardo; DIST-Univ. of Genova

Power plant monitoring is addressed by means of a sliding--window neural state estimator. The complexity and the nonlinearity of the considered power plant application prevents us from using standard techniques as Kalman filtering. The statistics of noises are assumed unknown and the estimator is designed by minimizing a given least squares cost function (in general, non--quadratic) under very general assumptions on the state equation and the system measurement channel. The estimator has been designed off line in such a way as to be able to process any possible measurement on line. Extensive simulation of a state estimation problem in a model of a section of a real power plant are reported showing the effectiveness of the applied method as compared to the extended Kalman filter.

WM14-1 885
*Genetic Algorithm for Single Machine Scheduling with General Early-Tardy Penalty Weights*

Yu, Haibin; Chinese Academy of Sciences
Xu, Xinhe; Northeastern Univ. Shenyang
Xue, Jinsong; Chinese Academy of Sciences
Wang, Haobo; Chinese Academy of Sciences

It is in accordance with Just-In-Time (JIT) philosophy to penalize early/tardy jobs. An optimal method genetic-based is presented to solve single machine scheduling problem with general early-tardy penalty weights in the paper. A new heuristic crossover operator is proposed for searching optimal sequences. On different scale of scheduling problems, lots of comparative experiments were carried out and the results manifested the method effectiveness.

WM14-2 890
*Efficient Global Optimization using SPSA*
Maryak, John L.; Johns Hopkins Univ.
Chin, Daniel C.; Johns Hopkins Univ.

A desire with iterative optimization techniques is that the algorithm reach the global optimum rather than get stranded at a local optimum value. One method used to try to assure global convergence is the injection of extra noise terms into the recursion, which may allow the algorithm to escape local optimum points. The amplitude of the injected noise is decreased over time (a process called "annealing"), so that the algorithm can finally converge when it reaches the global optimum point. In this context, we examine a certain "gradient free" stochastic approximation algorithm called "SPSA," that has performed well in complex optimization problems. We develop a proof of conditions under which SPSA will converge globally. We argue that, in some cases, the naturally occurring error in the SPSA gradient approximation effectively introduces injected noise that promotes convergence of the algorithm to a global optimum (obviating the necessity for injecting extra noise). The discussion is supported by a numerical study.

WM14-3 895
*A Genetic Algorithm with a Machine Order-Based Representation Scheme for a Class of Job Shop Scheduling Problem*
Song, Yingsheng; Univ. of Ulster at Jordanstown
Hughes, J. G.; Univ. of Ulster at Jordanstown

In this paper, we propose a genetic algorithm (GA) with a machine order-based representation scheme (MORS) and apply it to a class of job shop scheduling problems (JSSPs), the n/m/J/Cmax problems, where n >= 3* m. The proposed approach uses a special genotype-to-phenotype decoding method which guarantees to generate feasible schedules for any chromosomes and aims at using genetic algorithm to solve some kind of large JSSPs with reasonable solution and reasonable computation time. The approach has been tested with three sets of benchmark JSSPs. Experimental results show that the GA with MORS (MORS-GA) can solve the benchmark JSSPs of the type mentioned above to optimal or near-optimal with simple GA-operators and fewer objective evaluations. Compared with other GA methods, MORS-GA is shown to be a competitive and promising approach for solving this kind of JSSPs.

WM14-4 900
*Design of L_1-Optimal Controllers by Multiobjective Linear Programming*
Carvalho, Jose R. H.; Univ. of Campinas
Ferreira, Paulo a Valente; Univ. of Campinas

The design of discrete-time controllers as a multiobjective l1-optimal control problem is addressed in this paper. The multiobjective linear programming problem that results from the use of approximation methods based on the theory of l1 optimization is solved by a goal programming technique, which reveals to be an efficient design technique. Performance specifications are easily described as goals for the objectives and their trade-offs can be explicitly represented. In addition, the goal programming formulation efficiently explores the properties of l1-optimal control methods based on linear programming. The paper includes numerical examples that illustrate the proposed approach.

WM14-5 905
*Optimization of Bilinear Systems using Higher-Order Method*
Agrawal, Sunil K.; Univ. of Delaware
Xu, Xiaochun; Univ. of Delaware
Faiz, Nadeem; Univ. of Delaware

This paper derives some optimization results for bilinear systems using higher-order method by characterizing them over matrix Lie groups. In the derivation of the results, a bilinear system is first transformed to a left-invariant system on matrix Lie groups. The product of exponential representation is then used to express this system in a canonical form. The conditions for optimality are then obtained by the principles of variational calculus. It is demonstrated that closed-form analytical solutions exist for classes of bilinear systems whose Lie algebra is nilpotent.

WM14-6 910
*A Robust Controller for Scalar Autonomous Optimal Control Problems*
Lam, S. H.; Princeton Univ.

Is it possible to exert control on a physical system without detailed knowledge of its open-loop dynamics? Recently, this author showed that a special dynamic control law can accomplish this feat for a certain class of nonlinear systems, provided accurate and reliable data of the output variables, including their time derivatives, are made available to the controller. This paper generalizes this theoretical idea to a class of scalar autonomous optimal control problems.

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WM15-1 915
*Static Output Feedback Controllers for Systems with Parametric Uncertainty and Controller Gain Variations*
Corrado, Joseph R.; Georgia Inst. of Tech.
Haddad, Wassim M.; Georgia Inst. of Tech.

A feedback control design problem involving structured plant parameter uncertainties and controller gain variations is considered. Specifically, the robust guaranteed cost controller synthesis framework is extended to address the design of robust resilient static output feedback controllers for systems with structured parametric uncertainty and controller gain uncertainty.

WM15-2 920
*Practical H_Infinity Weighting Functions and their Application to Real-Time Control of a Pilot Plant*
Hu, Jiankun; The Univ. of Melbourne
Bohn, Christian; Ruhr-Univ. Bochum
Wu, H. R.; Monash Univ.

In this paper, the selection of H-infinity weighting functions for general practical applications is investigated. Uncertainty weighting functions for typical low-order plants with parametric uncertainties are derived. It is shown that H-infinity weighting function for a general SISO plant can be obtained by the combination of these elementary low-order plants. Weighting functions of reflecting other system specifications in H-infinity design are also investigated. Explicit weighting function expressions are given to address position and rate limits of an actuator, tracking error performance, overshoot, etc. Finally, the proposed methods are demonstrated by the roll-angle control design of a laboratory-scale model of a vertical take-off aircraft via simulation and real-time control.

WM15-3 925
*On a Quasi-Convex Method for Designing Robust Predictive Controllers*
Mahon, Harry M.; Univ. of Florida
Baab, Charles; Univ. of Florida

Crisalle, Oscar D.; Univ. of Florida

A systematic method of designing robust predictive controllers for systems with parametric ellipsoidal uncertainty is proposed. Ellipsoidal uncertainty descriptions arise in many engineering applications and are relevant to predictive control operations where model parameters are often found by fitting experimental data. A significant feature is that the robust predictive controller retains the servo performance of a nominal predictive controller designed using conventional methods. The synthesis procedure involves solving a quasi-convex optimization problem that has analytic expressions for the gradients. The optimization problem is based on rigorous theoretical foundations for robust stability, and convergence to the global solution is guaranteed. An illustrative design example is given.

WM15-4 931

*Robust Speed Control of Induction Motors using Adaptive Observer*

Aloliwi, Bader; Michigan State Univ.
Khalil, Hassan K.; Michigan State Univ.
Strangas, Elias; Michigan State Univ.

A nonlinear robust adaptive output feedback speed controller is designed for induction motors. The control uses only measurements of the rotor position and stator current and temperature. It contains two observers, a ninth-order adaptive observer to estimate the rotor flux and rotor resistance, and a third-order high-gain observer to estimate the rotor speed and acceleration from its position. The control is robust to uncertainties in the motor parameters and a bounded time-varying load torque. It guarantees that the speed tracking error can be made small by choice of certain design parameters. Experimental results are shown.

WM15-5 936

*A Simple Robust Control for Induction Motors*

Guerrero-Ramirez, Gerardo; National Univ. of Mexico
Tang, Yu; National Univ. of Mexico

This paper presents a simple robust control for induction motors. The control is robust to uncertainties in the rotor and stator winding resistances, and a bounded load torque perturbation. In the proposed scheme, assuming that a nominal control law, designed with the knowledge of the plant parameters, ensures the exponential stability of the closed-loop system in the absence of parameter uncertainty, we use the Lyapunov redesign technique to design an additional feedback signal that is added to the control signal to guarantee the uniform ultimate stability in the presence of uncertainties. Simulation results are included to illustrate the performance of the control scheme.

WM15-6 941

*Robust Regularization of Uncertain Singular Systems*

Wang, Dianhui; Dalian Maritime Univ.

This paper considers a problem of robust regularization of uncertain singular systems by decentralized output feedback. It derives a perturbation upper bound that ensures the existence of single local output feedback such that the closed-loop system remains both regularity and impulse-free for all allowable perturbations.

WM16-1 943

*Output Endpoint Weighted Generalized Predictive Control: a Polynomial Approach*

Ebert, Wolfram; Humboldt-Univ. of Berlin
Morari, Manfred; ETH Swiss Fed. Inst. of Tech.

A new Generalized Predictive Control algorithm is presented, which makes use of the concept of output end-point weightings. The aim of the algorithm is a reduced computational burden with respect to the state end-point weighted Generalized Predictive Control (EWGPC) and a relaxation of the infinite output weighting of Constrained Receding Horizon Predictive Control (CRHPC). The new output end-point weighted Generalized Predictive Control (OWGPC) algorithm is developed using the polynomial approach. After a proof of nominal stability the relation of Kalman filtering and predictive control is derived. A final simulation of a benchmark example emphasizes the reduced computational burden and the enhanced stochastic tracking capability.

WM16-2 948

*On System Identification and Robust Control on Hardy Sobolov Space*

Venkatesh, Saligrama R.; United Technologies Research Ctr.

The objective of the paper is to present a systematic methodology that integrates input-output data with robust control, by interfacing it with system identification, for systems belonging to Hardy-Sobolov space. The inner-product structure of the space makes it attractive for both identification and robust control design of infinite dimensional systems. The class of infinite-dimensional systems considered do not allow for an arbitrarily close finite-dimensional parameterization during the identification stage, which results in unmodeled dynamics bounded by the Sobolov norm in addition to parametric uncertainty. Robust control design has to thus explicitly take this structure into consideration. We present recursive algorithms for system identification to estimate unmodeled dynamics and parametric uncertainty. The robustness analysis and synthesis results are developed for these type of uncertainties.

WM16-3 953

*Passivity and Stability of Nonlinear Systems with Markarian Jump Parameters*

Aliyu, M. D. S.; King Fahd Univ. of Petroleum and Minerals

In this paper, we extend the concept of passivity developed for deterministic systems, to stochastic systems with Markov jump disturbances. We give necessary and sufficient conditions for the system to be passive, and discuss the relationship batween positive-real systems and passive systems. The stability properties of the system and the implications of passivity on the stochastic stability of the system are also discussed.

WM16-4 958

*Policies for Simultaneous Estimation and Optimization*

Lobo, Miguel Sousa; Stanford Univ.
Boyd, Stephen P; Stanford Univ.

Policies for the joint identification and control of uncertain systems are presented. The discussion focuses on the case of a multiple input, single output linear system, with no dynamics and quadratic cost, and system parameters assumed to have a known Gaussian distribution. Extensions for multiple output, and for finite impulse response systems are straightforward. The policies proposed are heuristics, and an approximation of the optimal dynamic programming solution, that exploit convex optimization techniques. Numerical experiments are encouraging.

WM16-5 965

*Stabilization of Stochastic Quantized Control Systems*

Lee, Kyung-Sup; LG Electronics, Inc
Haddad, Abraham H.; Northwestern Univ.

This paper considers a feedback control system where a plant is actuated by a quantized control. The measurements are assumed to be disturbed by an additive wideband Gaussian noise. The nonlinear control is obtained by the quantization of the measurements and it may cause the system to be variable structure in the presence of the noise. Variable structure systems disturbed by the noise exhibit sliding modes on the switching manifold. When the system is unstable, linear optimal controls using Linear-Quadratic-Gaussian (LQG) formulation are investigated to stabilize the system in a region around the origin while the quantized control guides the system to the region. The performance and behavior of

the stabilized systems are examined via a quadratic performance index in the steady state.

WM16-6 970
*On Designing H_Infinity Controller for a Class of Nonlinear Markarian Jump Systems with Parametric Uncertainties*
Boukas, El-Kebir; Ecole Polytechnique de Montreal
Shi, Peng; Univ. of South Australia
Nguang, Sing Kiong; Univ. of Auckland
Agarwal, Ramesh K.; Wichita State Univ.

This paper studies the problem of stochastic stability and disturbance attenuation for a class of uncertain nonlinear continuous-time systems with Markovian jumping parameters. The uncertainties are assumed to be nonlinear and state, control and external disturbance dependent. A sufficient condition is presented to solve the above problem. An H-infinity controller is designed which is in terms of the solutions of a set of coupled Riccati inequalities. A numerical example is included to demonstrate the potential of the proposed technique.

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WM17-1 975
*Chemical Process Control Education and Practice (I)*
Bequette, B. Wayne; Rensselaer Polytechnic Inst.
Ogunnaike, Babatunde A.; Dupont Central Res. & Engineering

Chemical process control textbooks and courses are significantly different from their electrical or mechanical-oriented brethren. It is our experience that colleagues in EE and ME assume that we teach the same theory in our courses, and merely have different application examples. The primary goals of this paper are (i) to emphasize the distinctly challenging characteristics of chemical processes, (ii) present a typical process control curriculum, and (iii) discuss how chemical process control courses can be revised to better meet the needs of a typical BS-level chemical engineer. In addition to a review of material covered in a standard process control course, we discuss innovative approaches in process control education, including: the use of case studies; distributed control systems in laboratories; identification and control simulation packages; and studio-based approaches combining lecture, simulation and experiments in the same room. We also provide perspectives on needed developments in process control education.

WM17-2 980
*Discussion of Chemical Process Control Education and Practice (I)*
Fabien, Brian C.; Univ. of Washington

This article presents a discussion of paper Chemical Process Control Education and Practice. Here we emphasize the major differences between chemical process control and the control of mechanical systems. This is accomplished by considering a simple chemical processÊ and illustrating areas where the dynamic system model differs significantly form mechanical systems. Some features encountered in chemical process models include, nonlinearities, extremely long time constants, (extremely short time constants), time delays, parameter uncertainty and the inability to measure the system states. These properties make control system design for chemical systems quite challenging.

WM17-3 983
*Undergraduate Control Education: an ME Perspective (I)*
Agrawal, Sunil K.; Univ. of Delaware

This paper describes the contents, emphasis, and challenges of a typical first controls course taught in an undergraduate program in mechanical engineering. Usually, this course is taught in the senior year and builds upon student's knowledge of differential equations, dynamics, heat transfer, electrical circuits, and machine design. This is the first course that draws upon concepts from all subareas of mechanical engineering. The course is often supplemented by engineering examples and laboratory experiments to illustrate the mathematical concepts applied to physical systems.

WM17-4 987
*Discussion of Undergraduate Control Education: an ME Perspective (I)*
Zhu, J. Jim; Louisiana State Univ.

In response to the article "Undergraduate control education: an ME perspective," by S. K. Agrawal [1] (This proceedings), this article presents the author's view on several key issues in control engineering education, some are pertinent to electrical engineering (EE), some are more general. These issues include: (1) In comparison to mechanical engineering (ME) and other engineering disciplines, what does EE have to offer in control engineering education? (2) Does an undergraduate control curriculum have to start from LTI system theory? In an attempt to answer these questions, and in the hope to promote, or provoke further discussions, the author proposes some radical thoughts about fundamental changes in the infrastructure and pedagogical structure for control engineering education with ramifications to control engineering practices. These suggestions include: (i) seriously considering the advantages and drawbacks of centralized and independent Control and Systems Engineering program, and (ii) changing the entry point to control engineering curriculum from LTI to nonlinear system theory.

WM17-5 992
*Control Education Crossing Department Boundaries (I)*
Spong, Mark W.; Univ. of Illinois at Urbana-Champaign

In this paper we discuss our recent experiences in the development of a network of cross-disciplinary laboratories for control systems education at the University of Illinois at Urbana-Champaign. Control systems are inherently multi-disciplinary and controls courses are typically offered by multiple Departments within a university. This has resulted in duplication of controls laboratories in many cases. At the University of Illinois we have eliminated such duplication by elevating control laboratory instruction from the Department level to the College level with the development of a network of laboratories that are shared by all Departments in the College of Engineering. We describe our laboratory network and how it services the various Departments. We also discuss the advantages, both financial and pedagogical, that such a development offers and argue that our laboratory concept can be duplicated elsewhere and can lead to a fundamental shift in the way control laboratory experience is provided to undergraduates.

WM17-6 997
*Training Simulators Enhance Process Control Education (I)*
Cooper, D. J.; Univ. of Connecticut
Fina, Danielle; Univ. of Connecticut

Training simulators enhance learning by integrating the theoretical abstraction of textbooks with the tactile nature of the lab. The primary objective of training simulators is education. They motivate, help with visualization, and provide hands-on practice and experience. This paper explores the use of training simulators for process control education. Discussed are the methods used and experiences gained in developing Control Station, a training simulator used in the curriculum of more than 100 colleges and companies worldwide. We note that training simulators are distinguished in this work from tools such as Matlab, which have a primary function of design, analysis and simulation. Practice in applying textbook control theory can greatly benefit the learning process. Such practice is motivating, promotes critical thinking, facilitates understanding in the use and limitations of the theory, and helps prepare students for the challenges of the professional world. Too often, the application of textbook theory is limited to solving questions listed at the end of the chapter. A typical question is to have the student expand or extend a mathematical development presented in the book. Another is to provide bits of data and then challenge the student to select and employ a combination of formulas to obtain a desired result. Unfortunately, even when cleverly crafted, these one-dimensional challenges fall short of providing students the depth or breadth of

practice required for learning and comprehension. Thus, the chemical engineering department at UConn, like most around the world, supplements the textbook with laboratory exercises. Hands-on laboratory exercises are extremely important to learning because they help students make the intellectual transition from theory to practice. The abstractions presented in textbooks are literally brought to life through the tactile nature of lab experience. The reality of the laboratory is that each study can take many hours and even days to perform. Also, equipment failures and other problems teach the important but not always appropriate lesson that the real world can be uncertain. Thus, it can be difficult to have the students explore more than a few central concepts in the lab. An alluring method for providing students with the significant hands-on practice critical to learning process control is with a training simulator that provides virtual experience much the way airplane and power plant simulators do in those fields. The proper tool can provide students with a broad range of focused engineering applications of theory in an efficient, safe and economical fashion. Such a simulator can work as an instructional companion as it provides interactive case study challenges which track along with classroom lectures. Process control is a subject area well suited to exploit the benefits of a training simulator. Modern control installations are computer based, so a video display is the natural window through which the subject is practiced. With color graphic animation and interactive challenges, a training simulator can offer experiences which literally rival those of the real world. These experiences can be obtained risk free and at minimal cost, enabling students to feel comfortable exploring nonstandard solutions at their desk. If properly designed as a pedagogical tool with case studies organized to present incremental challenges, learning can be enormously enhanced for process control. We stress that we do not believe a training simulator is better than or a replacement for real lab experiences. If fact, we believe that hands-on studies with actual equipment are fundamental to the learning process. We are of the opinion, however, that a proper training simulator can provide students with a broad range of meaningful experiences in a safe and efficient fashion. These experiences can be obtained risk free and at minimal cost, enabling students to feel comfortable exploring nonstandard solutions at their desk. If properly designed, a training simulator can bridge the gap between textbook and laboratory, enabling significantly enhanced learning for process control theory and practice. The lessons presented in this paper have been drawn from the Control Station process control training simulator to illustrate the value such software provides the curriculum. For more information about Control Station, visit www.ControlStation.com

WM18-1 1002

*Smart Bridge Dampers (SBD) (I)*

Patten, W. Neff; Univ. of Oklahoma
Sun, J.; Univ. of Oklahoma
Zeng, Annie; Univ. of Oklahoma

A program of research has been conducted by the Center for Structural Control (CSC) at the University of Oklahoma to extend the service life of highway bridges, by retrofitting them with computer-controlled hydraulic stiffeners. The system consists of a moment producing assembly that bolts on to an existing bridge. The heart of the SBD system is a special hydraulic actuator that is outfitted with a motor controlled valve. The valve position is regulated to provide appropriate amounts of stiffness and damping to the bridge in order to minimize the stress caused by heavy trucks. Lyapunov's Second Method was used to synthesize a control law. A simulation, using a simple pin-pin bridge, demonstrates the advantages of the new technology. The results indicate that the SBD system can reduce maximum stress by as much as 65%; thus, adding many years of additional service life to the bridge.

WM18-2 1007

*Active Vibration Control of Multiple Buildings Connected with Active Control Bridges in Response to Large Earthquakes (I)*

Seto, Kazuto; Nihon Univ.
Matsumoto, Yukito; Nihon Univ.

This paper proposes an active vibration control method for multiple high-rise buildings arranged in parallel. According to the proposed method, some flexible buildings connected with control devices called "active control bridge", are controlled through active interaction among them. This method has a merit of obtaining sufficient control force under low frequency. By this method, it is possible to control vibration of the super tall buildings against strong winds and large earthquakes. In this paper, four model buildings are connected with four actuators. The objective of this research work is to control the first bending and the first torsional mode of each building by this method. The control effect is evaluated by exciting the base of the structures with earthquake waves and measuring the response of the structures. Both simulation and experimental results show that fairly good control performance has been gained by this method.

WM18-3 1012

*Hybrid Adaptive Robust Structural Vibration Control (I)*

Shoureshi, Rahmat; Colorado School of Mines
Chaghajerdi, Amir H.; Colorado School of Mines
Bell, Mark J.; Colorado School of Mines

The focus of this paper is active vibration control with applications to cable-stayed bridges. Hybrid vibration control, involving the combined use of feedforward and feedback techniques, is proposed for a cable-stayed bridge. A 1/150-scale model of an actual cable-stayed bridge is designed, fabricated and compared to an existing structure using modal analysis. An analytical method for placing sensors and actuators on the structure is developed using operational deflection shapes (ODS) data within the frequency range of interest. Using DSP-based digital hardware, controllers are designed, developed and implemented on the structure. Analytical and experimental results are presented and compared.

WM18-4 1017

*Semi-Active Structural Control with Variable Friction Dampers (I)*

Nishitani, Akira; Waseda Univ.
Nitta, Yoshihiro; Waseda Univ.
Ishibashi, Yoji; Waseda Univ.
Itoh, Atsushi; Waseda Univ.

This paper discusses a methodology of semi-active structural control using a variable friction damper. The presented algorithm is that only the slipping level of the friction damper is controlled in response to the first modal coordinate. More specifically, the target constant ductility factor with respect to the first modal response is to be maintained by controlling the slipping level within each hysteresis loop. The effectiveness of the proposed semi-active control is demonstrated both by means of computer simulations and scale model experiments.

WM18-5 *

*Effects of Cable Sag on the Control of Cable-Stayed Bridges Subjected to Ground Motion (I)*

Magana, M. E.; Oregon State Univ.
Rodellar, Jose; Tech. Univ. of Catalonia
Casas, J. R.; Tech. Univ. of Catalonia
Sardans, C.; Tech. Univ. of Catalonia

Abstract not available.

WM18-6 1022

*Seismic Response Control using Smart Dampers (I)*

Yi, Fu; Washington Univ.
Dyke, Shirley J.; Washington Univ.
Caicedo, Juan M.; Washington Univ.
Carlson, J. David; Lord Corporation