

VSS' 06

The 9-th International Workshop on Variable Structure Systems

Alghero, Sardinia, Italy — June 5–7, 2006



Book of Abstracts

Index of Authors

Monday June 05, 2006

Mon A 09:10 ÷ 10:50 New applications of VSS

09:10-09:30

MonA.1 - *Sliding Mode Control of One-Dimensional Heat Exchange Processes*, pp. 1-4

Rao, Sachit Ohio State University
Utkin, Vadim I. Ohio State University

This paper deals with control of contact evaporation heat transfer processes that are common in refrigeration applications. First, an open loop control technique is developed for the system described by the infinite dimensional heat equation. Finally, a feedback control strategy is provided that only utilizes the knowledge of output temperature. Analysis is confined for heat transfer in a single dimension alone.

09:30-09:50

MonA.2 - *Sliding Mode Neurocontrol with Applications*, pp. 5-10

Poznyak, Alexander CINVESTAV-IPN
Chairez, Isaac CINVESTAV-IPN
Poznyak, Tatyana ESIQIE-IPN

In this study the tracking problem for a class of nonlinear uncertain systems is tackled. A new sliding mode neurocontroller is suggested to solve this problem. The designing of this controller includes the construction of online state estimates and the corresponding tracking control based on sliding mode approach using obtained state estimates. We apply a special sliding mode technique during the "offline training" to estimate the right-hand side of the given dynamics in finite-time and then to use these estimates for the best (in LQ-sense) nominal weights selection in the designed neuro observer. A switching (sign) type term is incorporated in to the observer structure to correct the current state estimates using only available and on-line measurable output data supplied with a new learning procedure with a relay term. The illustrative example dealing with a real water ozonation process is presented.

09:50-10:10

MonA.3 - *Higher Order Sliding Mode Control for Blood Glucose Regulation*, pp. 11-16

Kaveh, Parisa University of Alabama in Huntsville
Shtessel, Yuri B. University of Alabama in Huntsville

Diabetes is discussed as a serious condition in which the body's production and use of insulin is impaired, causing glucose concentration level to increase in the bloodstream. In this paper, higher order sliding mode control technique, in specific super-twisting algorithm, is used to robustly stabilize the glucose concentration level of a diabetic patient in presence of the parameter variations and meal disturbance. The super-twisting algorithm is employed to attenuate the effect of chattering and obtain continuous control. The structure of the proposed sliding mode controller is appropriate for making the insulin delivery pumps in closed loop control of diabetes. A computer simulation is performed to manifest the theoretical analysis. The efficiency of the proposed controller i.e. robustness and high accuracy, in presence of physical disturbances like food intake is verified via simulations.

10:10-10:30

MonA.4 - *Digital Sliding Modes and Quasi-Exact Tracking Discrete-Valued Signals*, pp. 17-22

Shkolnikov, Ilya Intergraph Corporation
Shtessel, Yuri B. University of Alabama in Huntsville
Adhami, Reza University of Alabama in Huntsville

This work initiates study of level quantization effect in the digital implementations of sampled-data systems featuring real sliding modes of first and second order. The effect of rounding midtreat quantizer at the input or in the loop of a feedback control system of relative degree one is analyzed. Novel concepts of regular digital codes, relative degree of digital signal autocorrelation, discrete-level and digital sliding modes are introduced.

10:30-10:50

MonA.5 - *Using Sliding Mode Control Theory for Radio Resource Management in Wireless Systems*, pp. 23-28

Cistelean, Mihaela Technical University of Cluj-Napoca
Popescu, Dimitrie University of Texas at San Antonio

In this paper we present a theoretical approach to power control for ad-hoc wireless networks using sliding mode control theory. We allow user mobility, as well as addition of new links to the wireless network or removal of inactive links from the network. We derive a dynamic system based on the signal-to-interference ratio (SIR) of links in the network whose control input is related to the transmitted power, and show how sliding mode control theory is used to derive the power equations that lead to an equilibrium point where the link SIRs are optimized.

Mon B 11:10 ÷ 13:10 Discrete-time control

11:10-11:30

MonB.1 - *On the Discrete-Time Sliding Mode Control*, pp. 29-34

Abidi, Khalid National University of Singapore
Xu, Jian-Xin National University of Singapore
Yu, Xinghuo Melbourne Institute of Technology

A new discrete-time integral sliding mode control (DISMC) scheme is proposed for sampled-data systems. The new control scheme is characterized by a discrete-time integral switching surface which inherits the desired properties of the continuous-time integral switching surface, such as full order sliding manifold with eigenvalue assignment, and elimination of the reaching phase. In particular, comparing with existing discrete-time sliding mode control, the new scheme is able to achieve more precise tracking performance. It will be shown in this work that, the new control scheme achieves $O(T^2)$ steadystate error for state regulation with the widely adopted delaybased disturbance estimation. Another desirable feature is, the proposed DISMC prevents the generation of overlarge control actions, which are usually inevitable due to the deadbeat poles of a reduced order sliding manifold designed for sampled-data systems. Both the theoretical analysis and illustrative example demonstrate the validity of the proposed scheme.

11:30-11:50

MonB.2 - *An Implementation of an Output Tracking Dynamic Discrete-Time Sliding Mode Controller on an Aircraft Simulator* pp. 35-40

One Lai, Nai University of Leicester

Edwards, Christopher
Spurgeon, Sarah K.

University of Leicester
University of Leicester

This paper describes the implementation of a new discrete time sliding mode scheme for control of the longitudinal motion of an aircraft. The discrete sliding mode control scheme requires only measured outputs – i.e. a subset of the states, and is dynamic in nature. The scheme imposes only minor restrictions on the system theoretic properties and in particular does not require the system to be minimum phase. The controller has been implemented on a Real Time All Vehicle Simulator (RTAVS) configured to represent a modern two engine fighter aircraft. The results which are presented are from some experiments which have been carried out in realtime where manual pilot input commands have been used to drive the system.

12:10-12:30

MonB.3 - *Multirate Output Feedback based Digital Redesign of Sliding Mode Control Algorithms*, pp. 41-44

Sivaramakrishnan, Janardhanan Indian Inst. of Technology
Bandyopadhyay, Bijan Indian Inst. of Technology
G/Egziabher Abera, Alemayehu Indian Inst. of Technology

Though continuous-time sliding mode control has a variety of desirable properties, its discrete-time counterpart does not guarantee the same performance. This is due to the fact that most of the discrete-time sliding mode control algorithms are based on reaching laws that are only approximations of continuous-time reaching laws and thus may not give a performance close to continuous-time sliding mode control. This paper presents a method of multirate output feedback based discrete-time control design which guarantees the closest possible performance for a pre-designed continuous-time sliding mode control algorithm.

12:30-12:50

MonB.4 - *Discrete-Time Variable Structure Control for Causal Nonminimum Phase System Using Stable System Center*, pp. 45-50

Iskrenović-Momčilović, Olivera

Electronic Industry Research and Development Inst., Nis
Milosavljević, Čedomir University of Nis
Shtessel, Yuri B. University of Alabama in Huntsville

The output tracking is considered for discretetimecausal SISO nth order linear time invariant system with unstable zero dynamics (nonminimum phase zeros) via discretetime variable structure control. The stable system center method that originally was developed for controlling the output in continuous time nonminimum phase causal system using sliding mode (variable structure) control is extended to the discrete-time systems. The developed discrete-time stable system center technique transforms an output tracking problem to a corresponding state variable tracking problem by asymptotically identifying the ideal internal dynamics for the unstable internal states of a discrete-time system. The causal disturbances and output tracking profiles are assumed to obey a linear exogenous system with known characteristic polynomial. The theoretical results are confirmed by robust to matched disturbances discrete variable structure control design for the track parabolic-type signal problem in the third order nonminimum phase systems.

12:50-13:10

MonB.5 - *Digitally Controlled Sliding Mode Based Servo-System with Active Disturbance Estimator*, pp.51-56

Veselic, Boban
Milosavljevic, Cedomir
Perunicic-Drazenovic, Branislava
Mitic, Darko

University of Nis
University of Nis
University of Sarajevo
University of Nis

This paper considers the design of robust servosystem for accurate tracking of complex referent signals in the presence of internal and external disturbances. Discrete-time sliding mode tracking controller is employed in servo-system design. In order to improve tracking accuracy, application of active disturbance estimator is suggested. The same sliding mode controller, designed for reference tracking of nominal system, is identically implemented in the control subsystem within the estimator. The overall servo-system exhibits high tracking accuracy under action of parameter uncertainties and external disturbances. Experimental results confirm the effectiveness of the proposed servo-system structure.

13:10-13:30

MonB.6 - *Digital Sliding Mode Control Design Based on I/O Models of Nonlinear Plants*, pp. 57-62

Mitic, Darko
Milosavljevic, Cedomir
Perunicic-Drazenovic, Branislava
Veselic, Boban

University of Nis
University of Nis
University of Sarajevo
University of Nis

The paper deals with the design of digital sliding mode controllers using only input and output sequences of plant. Two approaches are considered. The first one is based on the sliding mode based generalized minimum variance control implemented on the linearized plant model, whereas the second one utilizes the similar idea from the previous method modified for and applied on the discrete-time nonlinear model of the plant. The proposed algorithms are presented and tested by digital simulation on an example of inverted pendulum control.

Mon C 14:30 + 16:10 Optimization and VSS

14:30-14:50

MonC.1 - *Design of Integral Sliding Manifolds for Multi-model Uncertain Systems via LMI*, pp. 63-67

Castaños, Fernando
Fridman, Leonid

SUPELEC
National Autonomous Univ. of Mexico

In this note we provide a way of designing the nominal trajectory of an integral sliding mode controller for linear multi-model uncertain systems. The nominal system is chosen using a mini-max criterion for the norm of the discontinuous, feed-forward control. The continuous feedback control is then designed using linear matrix inequalities.

14:50-15:10

MonC.2 - *Output Integral Sliding Mode with Application to the LQ - Optimal Control*, pp. 68-73

Bejarano, Francisco Javier
Fridman, Leonid
Poznyak, Alexander

CINVESTAV-IPN
National Autonomous Univ. of Mexico
CINVESTAV-IPN

The problem of the realization of integral sliding mode controllers, based on output information only, is discussed. In the case when the number of inputs is more or equal than a number of outputs, the closed system, describing the integral sliding mode dynamics, is shown to lose observability. For any other case, a hierarchical sliding mode observer is proposed, allowing to reconstruct the system states practically just after the initial moment (theoretically). A low pass filter is suggested to be used for the observer realization. Taking the sampling step (during this filter realization) small enough, the convergence time and the observation error can be made arbitrary without the

power system, first, for an initial condition and then under a disturbance. The dynamics of a reduced model of a real power system is also studied under a disturbance. The combined strategy, asymptotic stability with sliding mode, shows to be adequate for power system stabilization.

17:10-17:30

MonD.3 - *Tracking Signal in a Centered Pulse ZAD Power Inverter*, pp. 104-109

Biel, Domingo
Cardoner, Rafel
Fossas, Enric

Technical University of Catalonia
Technical University of Catalonia
Technical University of Catalonia

This paper is devoted to the application of the centered pulse Zero Average Dynamics (ZAD) to tracking signals. Based on the use of a switching surface, which performs sliding mode with desired tracking in steady state, a centered pulse ZAD algorithm is designed to yield fixed-frequency Pulse Width Modulation (PWM). A power inverter has been simulated by means of PSIM software, which allows including realistic (i.e. resistive losses, dead time of switches, quantification and sampling and so on) effects in the simulation process. Additionally, the control algorithm has been programmed in C code, which could be used, with slight modifications, to programme a digital controller (microprocessor, DSP, etc.). The simulation results from generating triangular and sinusoidal waveforms show the fulfilment of the specifications. Namely, zero error tracking and robustness with respect to different loads: resistive load, nonlinear load, time-variable load and open circuit operation.

17:30-17:50

MonD.4 - *Integral Nested Sliding Mode Control: Application to the Induction Motor*, pp. 110-114

Rivera, Jorge
Loukianov, Alexander

CINVESTAV
CINVESTAV

In this work we design an integral nested sliding mode control for a certain class of nonlinear systems with unknown matched and unmatched perturbations. It is well known that sliding modes is robust against matched perturbations. In order to introduce robustness, we make use of a novel nested sliding mode procedure, that in combination with integral sliding mode technique will reduce the sliding function gains. Then, the controller here designed is applied to the induction motor, where the nominal parameters are known, the load torque is an unknown perturbation term with known upper bound, the stator and rotor resistances are varying, where its respective upper bounds are known

**Mon E 17:50 + 19:00
Interactive Poster Session**

MonE.1 - *A Geometric Approach for the Design of MIMO Sliding Mode Controllers. Application to a Wind Driven Double Output Induction Generator*, pp. 115-120

Valenciaga, Fernando
Puleston, Paul F.,
Spurgeon, Sarah K.

University of La Plata
University of La Plata
University of Leicester

This paper presents a systematic methodology to design controllers for a general class of nonlinear MIMO systems affine in the control in the presence of bounded uncertainties and disturbances. The proposed design method is developed through a theoretical framework based on the combination of a geometric approach and sliding

mode techniques. The resulting robust control law guarantees finite time convergence, while chattering reduction is attained by utilising the minimum discontinuous action required to ensure disturbance rejection. The proposed methodology is applied to the control of a grid connected wind energy generation system based on a double output induction generator.

MonE.2 - *A bumpless method for MIMO process controllers via sliding mode*, pp. 121-126

Garelli, Fabricio
Mantz, Ricardo
De Battista, Hernán

University of La Plata
University of La Plata
University of La Plata

Sliding mode attributes are evaluated for being applied to a bumpless transfer scheme in multiple-input multipleoutput (MIMO) process control. Switching from manual to automatic mode is particularly considered, in which case the proposed methodology can be interpreted as building a multivariable sliding mode state-observer of a fictitious offline controller. This approach virtually changes the position of the switch from the controller outputs to internal stages of the controller. Furthermore, it avoids the jumps at the plant inputs even when the switch is performed before the observer transient has extinguished, while at the same time it properly accommodates the remaining controller states.

MonE.3 - *A Discrete-Time Sliding Mode Observer for Estimation of Auto-Regressive Model Coefficients with an Application in Condition Monitoring*, pp. 127-132

Twiddle, John
Spurgeon, Sarah K.
Kitsos, Christos
Jones, Barrie

University of Leicester
University of Leicester
University of Leicester
University of Leicester

Development of a Sliding Mode Observer (SMO) scheme for on-line condition monitoring of dry vacuum pumps is considered. The exhaust pressure signal from such a pump can be practically acquired with a standard transducer, and described with an auto-regressive (AR) model. A novel discrete-time SMO scheme has been designed to estimate AR model coefficients based on a short data set sampled from the exhaust pressure signal, and a nominal set of model coefficients estimated from fault-free data. Vacuum pumps' exhausts are at risk of blockage due to solid deposits of process chemicals. The results demonstrate that the reduction in free volume of the silencer can be detected by monitoring the injection signal of the SMO. The magnitude of the injection signal is related to the difference in location between the poles of the nominal AR model and those of the estimated model.

MonE.4 - *Finite-time control of a class of MIMO nonlinear systems using high order integral sliding mode control*, pp. 133-138

Defoort, Michael
Floquet, Thierry
Kokosy, Annemarie
Perruquetti, Wilfrid

Ecole Centrale de Lille
Ecole Centrale de Lille
Ecole Centrale de Lille
Ecole Centrale de Lille

A novel higher-order sliding mode control algorithm is presented for a class of MIMO uncertain nonlinear systems. This problem can be viewed as the finite-time stabilization of an n th order input-output dynamical system with bounded uncertainties. The developed control strategy gives a control based on geometric homogeneity with an additional integral sliding mode term. The additional sliding mode controller part completely dismisses the influence of uncertainties from the initial time instant. The algorithm has been applied for a robust control of a hovercraft vessel model. The simulation

results show robustness to parameter variations and uncertainties in the dynamics

MonE.5 - *Stabilization of the cart-pendulum system via quasi-homogeneous switched control*, pp. 139-142

Riachy, Samer
Floquet, Thierry
Orlov, Yuri
Richard, Jean-Pierr

Ecole Centrale de Lille
Ecole Centrale de Lille
CICESE Research Center
Ecole Centrale de Lille

A novel higher-order sliding mode control algorithm is presented for a class of MIMO uncertain nonlinear systems. This problem can be viewed as the finite-time stabilization of an r th order input-output dynamical system with bounded uncertainties. The developed control strategy gives a control based on geometric homogeneity with an additional integral sliding mode term. The additional sliding mode controller part completely dismisses the influence of uncertainties from the initial time instant. The algorithm has been applied for a robust control of a hovercraft vessel model. The simulation results show robustness to parameter variations and uncertainties in the dynamics

MonE.6 - *Optimal sliding mode control for linear systems*, pp. 143-148

Xu, Rong
Ozguner, Umit

Ohio State University
Ohio State University

A sliding mode control with a dynamic sliding surface is proposed to solve the infinite-time optimal control problem for linear systems. The advantage of this kind of control is that it provides a robust optimal control to the optimal control problem.

MonE.7 - *Exact periodic solution for control system containing static nonlinear function*, pp. 149-154

Boiko, Igor

SNC-Lavalin

A solution of the periodic problem in a nonlinear system comprising a static symmetric nonlinearity and linear dynamics is presented. The solution is designed as an iterative algorithm of refinement of the approximate solution obtained via application of the describing function method. The algorithm is based upon the transformation of the original nonlinear system into an equivalent nonlinear system for which the filtering hypothesis is satisfied exactly, and for that reason the latter being suitable for application of the developed algorithm. It is also based upon the concept of the periodic signal mapping applied to the open-loop equivalent nonlinear system. The solution is sought for as a fixed point of the periodic signal mapping. The proposed approach is illustrated by examples of analysis of periodic motions in nonlinear systems. A good convergence and accuracy is demonstrated.

MonE.8 - *Position/attitude control of a jet-propelled surface-vessel prototype via the simplex-vector sliding-mode approach* pp. 155-160

Bartolini, Giorgio
Orani, Nicola
Pisano, Alessandro
Usai, Elio

University of Cagliari
University of Cagliari
University of Cagliari
University of Cagliari

This note concerns the design and implementation of a position/attitude sliding-mode controller for a surface vessel prototype. The prototype is equipped with a special, recently

patented [13], propulsion system based on hydrojets with variable output section. The sliding mode control design is based on the vector simplex method [11]. First we describe the structure and the working principle of the prototype. Then, we present an approximate dynamic model and describe the detailed derivation of the motion controller. Finally, the major implementation issues are discussed and some experimental results are shown.

MonE.9 - *Second Order Sliding Mode Observer for Estimation of Road Profile*, pp. 161-165

Rabhi, Abdelhamid
M'Sirdi, Nacer Kuider
Fridman, Leonid
Delanne, Yve

LSIS, CNRS UMR, Marseille
LSIS, CNRS UMR, Marseille
National Autonomous Univ. of Mexico
LCPC, Nantes

This paper deals with an approach to estimate the road profile, by use of second order sliding mode observer. This method is based on a robust observer designed with a nominal dynamic model of vehicle. The estimation accuracy of our observer has been validated experimentally using a trailer equipped with position sensors and accelerometers

Tuesday June 06, 2006

Tue A	8:30 + 10:50
VSS Theory	

8:30-8:50

TueA.1 - *Approximability of Sliding Modes and Regularization*, pp. 166-171

Levaggi, Laura
Villa, Silvia

University of Genova
University of Genova

Approximability of sliding motions for control systems governed by nonlinear finite-dimensional differential equations is considered. This regularity property is shown to be equivalent to Tikhonov well-posedness of a related minimisation problem in the context of relaxed controls. This allows us to give a general approximability result, which in the autonomous case has an easy to verify geometrical formulation. In the second part of the paper, we consider non-approximable sliding mode control systems. In the flavour of regularization of ill-posed problems, we propose a method of selection of wellbehaved approximating trajectories converging to a prescribed ideal sliding.

8:50-9:10

TueA.2 - *Analysis of Response of Second-Order Sliding Mode Control Systems to External Inputs*, pp. 172-177

Boiko, Igor
Castellanos, Ivan
Fridman, Leonid

SNC Lavalin
National Autonomous Univ. of Mexico
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Response of systems with the second-order sliding mode (SOSM) control algorithms to an external harmonic excitation is analyzed in the frequency domain. The analysis is done via application of the concept of the equivalent gain of nonlinear function. The equivalent gain is used as a model of propagation of averaged values of signals through nonlinear elements of the system. Two SOSM algorithms: twisting and super-twisting are analyzed. The results are presented in the format of conventional amplitude and phase frequency response.

9:10 - 9:30

TueA.3 - *Sliding Mode Control of Uncertain Nonlinear Systems with Arbitrary Relative Degree and Unknown Control Direction*, pp. 178-183

Hsu, Liu Federal University of Rio de Janeiro
Oliveira, Tiago R. Federal University of Rio de Janeiro
Peixoto, Alessandro J. Federal University of Rio de Janeiro

This paper considers the model reference tracking control for a class of uncertain nonlinear systems, based on sliding mode and output-feedback. No particular growth condition is imposed on the nonlinearity. Moreover, the design does not assume the prior knowledge of the control direction. For plants of arbitrary relative degree, global or semi-global asymptotic stability with respect to a compact set is guaranteed. Ultimate finite-time or exponential convergence of the tracking error to zero is achieved by using a hybrid lead filter based on 2-sliding mode exact differentiators. A monitoring function is used to determine the unknown control direction.

9:30 - 9:50

TueA.4 - *Chattering Free Simplex Sliding Mode Control for Systems with Mono-directional Actuators*, pp. 184-189

Bartolini, Giorgio University of Cagliari
Punta, Elisabetta ISSIA-CNR
Zolezzi, Tullio University of Genova

This paper considers regular simplices of vectors, the exploitation of which is analyzed in the simplex sliding mode control of multi-input uncertain nonlinear systems. The method is extended to eliminate the chattering phenomenon. To this end an estimation procedure based on second order sliding mode algorithms is coupled with a simplex sliding mode control of an augmented order system. The methodology is applied to affine systems with mono-directional actuators.

9:50 - 10:10

TueA.5 - *MIMO Second Order Sliding Mode Control*, pp. 190-195

Punta, Elisabetta ISSIA-CNR

The paper proposes an approach to second order sliding mode control for multi-input multi-output (MIMO) nonlinear uncertain systems. Second order sliding mode techniques for single-input single-output (SISO) systems show, with respect to standard sliding mode control, the same properties of robustness and precision, feature a higher order accuracy and can be exploited to eliminate the chattering effect. The application of second order sliding mode control to MIMO nonlinear systems is a challenging matter. The presented MIMO control method applies to a quite large class of nonlinear processes affected by uncertainties of general nature; the control design is simple; the conditions of existence on the controllers are weak. The proposed procedure represents a general approach to the second order sliding mode control of MIMO systems.

10:10 - 10:30

TueA.6 - *Nonsingular Terminal Sliding Mode Control of Uncertain Multivariable Systems*, pp. 196-201

Feng, Yong Harbin Institute of Technology
Yu, Xinghuo Melbourne Institute of Technology
Zheng, Jianfei Harbin Institute of Technology

This paper proposes a nonsingular terminal sliding mode control for uncertain multivariable systems with parameter uncertainties or disturbances. A hierarchical control structure is utilized for simplifying the controller design. Uncertain multivariable linear systems are converted into the block controllable form consisting of two subsystems, an input-output subsystem and a stable internal dynamic subsystem. In order to guarantee fast convergence and better tracking precision, a nonsingular terminal sliding mode manifold is proposed for the input-output subsystem. To eliminate the chattering phenomenon, a continuous nonsingular terminal sliding mode control law is designed using the second-order sliding mode approach. Under the proposed controllers, the states of the input-output subsystem can be driven to converge to zero asymptotically and the stability of the zero-dynamics of the system is guaranteed. The simulation results are presented to validate the design.

Tue B1 10:50 + 12:10 SM Observers

10:50-11:10

TueB1.1 - *High-Order Sliding-Mode Observer for Linear Systems with Unknown Inputs*, pp. 202-207

Fridman, Leonid National Autonomous Univ. of Mexico
Levant, Arie Tel-Aviv University
Davila, Jorge National Autonomous Univ. of Mexico

Extended sufficient conditions for the observation of linear time invariant systems with unknown inputs are formulated. A new observation scheme is proposed. An additional linear term ensuring global stability is included for this sake in the differentiation algorithm based on high-order sliding modes. The global robust finite-time-convergent estimation of observable states and unknown inputs is obtained, exact in the absence of measurement noises. Under the detectability conditions the whole state is asymptotically estimated. The accuracy of the estimation in the presence of bounded deterministic Lebesgue-measurable noises and discrete sampling is worked out.

11:10-11:30

TueB1.2 - *Observer for Linear Time Invariant Systems with Unknown Inputs based on the Hierarchical Super-Twisting Concept*, pp. 208-213

Bejarano, Francisco Javier CINVESTAV-IPN
Poznyak, Alexander CINVESTAV-IPN
Fridman, Leonid National Autonomous Univ. of Mexico

We use an algorithm, which allows to find the strong observable space, to design a hierarchical observer providing the exact reconstruction of the state components. In order to design the state estimation, we use the super twisting (second order sliding mode) algorithm. The continuity of the super twisting output injection allows to reconstruct in each step a vector formed by a matrix pre-multiplied by the state vector, all this in a finite time. The sequential application of this procedure finally leads to the obtaining of the state vector which can be represented by an auxiliary state vector plus the equivalent super twisting output injection. It is assumed only that the system has no zeros and the unknown inputs are bounded. A numerical example illustrates the efficiency of the suggested technique

11:30-11:50

TueB1.3 - *On Sliding Mode Observers for Systems with Unknown Inputs*, pp. 214-219

Floquet, Thierry
Edwards, Christopher
Spurgeon, Sarah K.

Ecole Centrale de Lille
University of Leicester
University of Leicester

This paper considers the problem of designing an observer for a linear system subject to unknown inputs. This problem has been extensively studied in the literature with respect to both linear and nonlinear (sliding mode) observers. Necessary and sufficient conditions to enable a linear unknown input observer to be designed have been established for many years. One way to express these conditions is that the transfer function matrix between the unknown input and the measured output must be minimum phase and relative degree one. Identical conditions must be met in order to design a 'classical' sliding mode observer for the same problem. This paper shows how the relative degree condition can be weakened if a classical sliding mode observer is combined with sliding mode exact differentiators to essentially generate additional independent output signals from the available measurements. A simple pedagogical example demonstrates the efficacy of the approach.

11:50-12:10

TueB1.4 - *Adaptive Sliding Mode Observers in Uncertain Chaotic Cryptosystems with a Relaxed Matching Condition*, pp. 220-225

Raoufi, Rehza
Zinober, Alan

The University of Sheffield
The University of Sheffield

We study the performance of adaptive sliding mode observers in chaotic synchronization and communication in the presence of uncertainties. The proposed robust adaptive observer-based synchronization is used for cryptography based on chaotic masking modulation (CM). Uncertainties are intentionally injected into the chaotic dynamical system to achieve higher security and we use robust sliding mode observer design methods for the uncertain nonlinear dynamics. In addition, a relaxed matching condition is introduced to realize the robust observer design. Finally, a Lorenz system is employed as an illustrative example to demonstrate the effectiveness and feasibility of the proposed cryptosystem..

Tue B2 12:10 + 13:10 SM Identification

11:50-12:10

TueB2.1 - *Stochastic Sliding Modes Identification*, pp. 226-231

Poznyak, Alexander
Escobar, Jesica
Shtessel, Yuri B.

CINVESTAV-IPN
CINVESTAV-IPN
University of Alabama in Huntsville

Time varying parameters identification of stochastic systems is addressed via sliding mode parameter observers. Sliding mode observer is governed by control that compensates a so-called Ito's term, which reflects a stochastic nature of a system. The matrix estimation algorithm based on equivalent control are proposed. A numerical example illustrates the effectiveness of the proposed approach.

12:10-12:30

TueB2.2 - *Observation and Identification of Mechanical Systems via Second Order Sliding Modes*, pp. 232-237

Davila, Jorge
Fridman, Leonid
Poznyak, Alexander

National Autonomous Univ. of Mexico
National Autonomous Univ. of Mexico
CINVESTAV-IPN

Time varying parameters identification of stochastic systems is addressed via sliding mode parameter observers. Sliding mode observer is governed by control that compensates a so-called Ito's term, which reflects a stochastic nature of a system. The matrix estimation algorithm based on equivalent control are proposed. A numerical example illustrates the effectiveness of the proposed approach.

12:30-12:50

TueB2.3 - *Sliding mode identification for surface profile estimation*, pp. 238-243

Kochetkov, Sergey
Shavrin, Pavel
Kiselyov, Sergey

Togliatty State University
Togliatty State University
Togliatty State University

The design algorithms of closed loop control system for surface profile measurement device are proposed. Control inputs are used to construct closed loop system, which oriented on identification of desired parameter that is identified by sliding mode observer then. As a result, the designed nonlinear system has high selective properties with respect to registered value. It is shown by computer simulation that proposed system has fast enough response, is quite invariant to additive and parametric disturbances.

Tue C 14:30 + 15:30 Time-delay systems

14:30-14:50

TueC.1 - *Sliding Mode Coordinated Decentralized Adaptive Following of Nonlinear Delayed Plants*, pp. 244-249

Mirkin, Boris
Mirkin, Eugene
Gutman, Per-Olof

Technion – Israel Institute of Technology
International University of Kyrgyz
Technion – Israel Institute of Technology

In this paper, we develop a coordinated decentralized state-feedback adaptive controllers for a class of large-scale delayed nonlinear interconnected systems. The design is based on a combination of two control techniques: the method of decentralized control with reference model coordination, and the variable structure design methodology. This scheme can not only guarantee closed-loop stability but also improves steady state and transient tracking performance when uncertainties and delays are present in the subsystems and interconnections.

14:50-15:10

TueC.2 - *Output Tracking via Sliding Modes in Causal Systems with Time Delay Modeled by Higher Order Padé Approximations*, pp. 250-255

Kosiba, Edward.
Liu, Gang
Shtessel, Yuri B.
Zinober, Alan

University of Alabama in Huntsville
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University of Alabama in Huntsville
The University of Sheffield

Output tracking in a SISO causal uncertain nonlinear system with an output subject to a time delay is considered using sliding mode control. A higher order Padé approximation to a delay function with a known time delay is used to construct a model of a transformed system without a time delayed output and is employed in a feedback sliding mode control. This model functions as a predictor of the plant states and the plant output, but is of nonminimum phase due to the application of the Padé approximation. The

method of the stable system center is used to stabilize the internal dynamics of this plant model, and a control is developed using a sliding surface to allow the plant to track a arbitrary reference profile given by an exogenous system with a known characteristic equation. Simulations of the system are performed for the plant model using a first, second and third order Padé approximations and a controller in plant feedback mode. Numerical examples for Padé approximations of increasing order are considered and compared.

15:10-15:30

TueC.3 - *Integral Sliding Mode Control for Systems with Time Delay*, pp. 256-261

Loukianov, Alexander	CINVESTAV
Espinosa-Guerra, Omar	CINVESTAV
Castillo-Toledo, Bernardino	CINVESTAV
Utkin, Victor	Institute of Control Science, Moscow

Output tracking in a SISO causal uncertain nonlinear system with an output subject to a time delay is considered using sliding mode control. A higher order Padé approximation to a delay function with a known time delay is used to construct a model of a transformed system without a time delayed output and is employed in a feedback sliding mode control. This model functions as a predictor of the plant states and the plant output, but is of nonminimum phase due to the application of the Padé approximation. The method of the stable system center is used to stabilize the internal dynamics of this plant model, and a control is developed using a sliding surface to allow the plant to track a arbitrary reference profile given by an exogenous system with a known characteristic equation. Simulations of the system are performed for the plant model using a first, second and third order Padé approximations and a controller in plant feedback mode. Numerical examples for Padé approximations of increasing order are considered and compared.

Tue D 15:50 ÷ 17:10
Automotive Applications

15:50-16:10

TueD.1 - *Sliding Mode Control For Automatic Driving Of A Platoon Of Vehicle*, pp. 262-267

Ferrara, Antonella	University of Pavia
Vecchio, Claudio	University of Pavia

During recent years, a number of studies has demonstrated the efficaciousness of the longitudinal control of platoon of vehicles in order to improve the exploitation of the capacity of road networks while maintaining safety distances between vehicles. Yet, the use of cruise control in urban areas can be critical because of the possible presence of pedestrians or other vulnerable road users (VRUs). The objective of increasing pedestrians' safety can be attained by providing the control system of the vehicles of the platoon with some collision avoidance capability. This issue is investigated in the present paper. The driver assistance system presented in this paper is realized by means of vehicle supervisors, which make the decision on which is the appropriate current control mode for each controlled vehicle. The control methodology adopted in the proposed control system is sliding mode control of the first and the second order.

16:10-16:30

TueD.2 - *Estimation and Analysis of the Tire Pressure Variations Effects on the Comportement of the Vehicle Center of Gravity*, pp. 268-273

Shraim, Hassan	LSIS, CNRS UMR, Marseille
Rabhi, Abdelhamid	LSIS, CNRS UMR, Marseille
Ouladsine, Mustapha	LSIS, CNRS UMR, Marseille
M'sirdi, Nacer K.	LSIS, CNRS UMR, Marseille
Fridman, Leonid	National Autonomous Univ. of Mexico

In the presented paper, the tire's pressure and its effects on the vehicle's center of gravity are estimated and analysed. For that reason, a relation relating the tire pressure to the vertical force and the tire vertical deflection is proposed and validated by real measures. Basing on this proposed model, the tire pressure estimation is realized by estimating the vertical force and the tire vertical deflection. The vertical force is estimated using data issued from accelerations sensor. The tire vertical deflection is the difference between its initial radius and its radius while rolling. This later is identified using a second orders sliding mode observer with super twisting algorithm (which observes the non measured states and identifies the effective radius). Simulations are made firstly in the absence of faults, in which results are compared by the real measures and secondly in the presence of faults, as an escape (sudden puncture) or a total failure in the tire pressure, in which results are compared to that of a validated model.

The analysis is made on the yaw angle and the yaw rate of the vehicle's centre of gravity, in which the later is compared to a certain threshold representing the maximum and the minimum acceptable values, these values vary with the velocity and the coefficient of friction permitting the driver to know when he leaves the safety region.

16:30-16:50

TueD.3 - *First and Second-Order Sliding Mode Observers to Estimate the Contact Forces* pp. 274-279

Rabhi, Abdelhamid	LSIS, CNRS UMR, Marseille
Ouladsine, Mustapha	LSIS, CNRS UMR, Marseille
M'sirdi, Nacer K.	LSIS, CNRS UMR, Marseille
Fridman, Leonid	National Autonomous Univ. of Mexico

In this work two efficient approaches to observe tire forces are developed. The cascaded observers, based on First or Second Order Sliding Modes, to estimate the contact forces are used. The contact forces are identified as unknown inputs.

16:50-17:10

TueD.4 - *Observation and Estimation of Dynamics Performance of Heavy Vehicle Via Second Order Sliding Modes* pp. 280-285

Bouteldja, Mohamed	Public Works Research Laboratory
El Hadri, Abdelhafid	Versailles Robotics Laboratory
Davila, Jorge	National Autonomous Univ. of Mexico
Cadiou, Jean-Charle	Versailles Robotics Laboratory
Fridman, Leonid	National Autonomous Univ. of Mexico

In this work two efficient approaches to observe tire forces are developed. The cascaded observers, based on First or Second Order Sliding Modes, to estimate the contact forces are used. The contact forces are identified as unknown inputs.

17:15 Panel Session

"What are sliding modes and sliding mode control? New challenges in emerging topics."

Wednesday June 07, 2006

Wed A 9:00 + 10:40 VSC of Switched and Hybrid Systems

9:00-9:20

WedA.1 - *Variable Structure Control with Sliding Sector for Hybrid Systems*, pp. 286-291

Pan, Yaodong Tokyo Denki University
Furuta, Katsuhisa Tokyo Denki University

This paper proposes a variable structure (VS) controller with sliding sector for hybrid systems where subsystems do not need to be stable and may be unknown. The controller is designed to switch among subsystems to stabilize the hybrid system by a variable structure switching law. The concept of the sliding sector is used in the paper to show that there exists an area, inside which a Lyapunov function decreases, for any system no matter whether it is stable or unstable. A Lyapunov function is designed by assuming that a stable convex combination of the subsystems exists. Then the VS controller is designed such that the Lyapunov function decreases in every period for the hybrid system to be switched once through all subsystems. The extremum seeking control algorithm is used to determine the switching rule such that the Lyapunov function track a pre-determined decrease signal. The proposed VS system is quadratically stable. Simulation results are given to show the convergence of the proposed VS control system.

9:20-9:40

WedA.2 - *Adaptive Robust Stabilizing Controllers for a Class of Uncertain Switched Linear Systems*, pp. 292-297

Oya, Hidetoshi Shonan Institute of Technology
Hajino, Kojiro The University of Electro-Communications, Tokyo

This paper discusses a design problem of an adaptive robust stabilizing controller for a class of uncertain switched linear systems. The uncertainties under consideration are supposed to satisfy the matching condition, and switchings among subsystems are determined by using the nominal system. The proposed adaptive robust stabilizing controller consists of the switching rule, the state feedback law with constant gain matrix and the state feedback law with the variable gain matrix tuned by adjustable parameters. In this paper, we show that the switching rule, the feedback gain matrices and the adjustment law of the adjustable parameter.

9:40-10:00

WedA.3 - *Adaptive Robust Stabilizing Controllers for a Class of Uncertain Switched Linear Systems*, pp. 298-303

Yunt, Kerim ETH, Zurich

The planning of optimal trajectories for nonholonomic systems and of structure-variant mechanical systems are active research areas. In this report the optimal trajectories of a structure-variant mechanical systems will be determined by making use of a combined direct shooting and successive unconstrained minimization method (SUMT), which performs the integrations of the dynamical system based on the timestepping scheme. A certificate of

optimality will be provided for the structure-variant trajectories obtained by the new optimization method.

10:00-10:20

WedA.4 - *Finite Time Model Orbit Stabilization of Friction Pendulum*, pp. 304-309

Orlov, Yury CICESE Research Center
Aguillar, Luis CITEDI-IPN
Acho, Leonardo CITEDI-IPN
Ortiz, Adan CICESE Research Center

A novel approach to orbital stabilization is presented and tested on a friction pendulum, operating under uncertain conditions. The quasihomogeneous control synthesis is modified to be introduced into the synthesis as an asymptotic harmonic generator of the periodic motion. The proposed modification possesses a limit cycle, producing a single harmonic as opposed to multi-harmonics of a standard harmonic oscillator. The parameters of the asymptotic harmonic generator are shown to specify damping, amplitude, and frequency of the limit cycle production. The resulting closed-loop system is capable of moving from one orbit to another by changing these parameters dynamically. Performance issues of the controller constructed are illustrated in an experimental study.

10:20-10:40

WedA.5 - *On the GPI-Sliding Mode control of switched fractional order systems*, pp. 310-315

Sira-Ramirez, Hebertt CINVESTAV-IPN
Feliu-Battle, Vicente Universidad de Castilla-La Mancha

The control of a special class of Single Input Single Output (SISO) switched fractional order systems (SFOS) is addressed from the viewpoints of the Generalized Proportional-Integral (GPI) feedback control approach and a sliding mode based $\Sigma - \Delta$ modulation implementation of an average model based designed feedback controller. A fractional order GPI controller is proposed which transforms the average model of the system into a pure, integer order, chain of integrations with desired closed loop dynamics achieved through a classical compensation network robustly acting in the presence of constant load perturbations. A sliding mode based $\Sigma - \Delta$ modulation implementation of the continuous, bounded, dynamic average output feedback control signal is adopted for the switched system. An illustrative simulation example dealing with an electric radiator system is presented.

Wed B 11:10 + 12:50 Linear Systems

11:10-11:30

WedB.1 - *On Non-reduced Order Model of Averaged Motions in Sliding Mode Control*, pp. 316-321

Boiko, Igor SNC-Lavalin

For the averaged motions in a sliding mode system with parasitic dynamics, a model of the order equal to the original order of the system is obtained via the use of the locus of a perturbed relay system (LPRS) method. This model proves that averaged motions in a sliding mode system differ from

those in the reduced-order model. In particular, such phenomena as nonideal disturbance rejection and non-ideal input tracking are observed in the non-reduced-order model. It is shown that the non-reduced-order model transforms into the reduced one when the parasitic dynamics are removed. An example is provided that illustrates the proposed approach.

11:30-11:50

WedB.2 - *Frequency-domain design of compensating filters for sliding mode control systems*, pp. 322-327

Boiko, Igor

SNC-Lavalin

It is known that a sliding mode (SM) control system perturbed by parasitic dynamics exhibits the "real" SM. The real SM features finite frequency switching (chattering) and the averaged motions being different from those in the reduced-order model. Yet, chattering and the averaged motion – being two components of the motion in the SM system – belong to two different frequency ranges (spectra). As a result, some kind of frequency characteristic shape compensation aimed at achieving the desired frequency of chattering and enhancing the dynamics of the averaged motions becomes possible. This research is the subject of the present paper.

11:50-12:10

WedB.3 - *Design of SPR Systems with Dynamic Compensators and Output Variable Structure Control*, pp. 328-333

Teixeira, Marcelo C. M.

Sao Paulo State University

Covacic, Márcio R.

Sao Paulo State University

Assunção Edvaldo

Sao Paulo State University

This paper presents necessary and sufficient conditions for the following problem: given a linear time invariant plant $G(s) = N(s)D(s)^{-1} = C(sI - A)^{-1}B$, with m inputs, p outputs, $p > m$, $\text{rank}(C) = p$, $\text{rank}(B) = \text{rank}(CB) = m$, and a tandem dynamic controller $G_c(s) = D_c(s)^{-1}N_c(s) = C_c(sI - A_c)^{-1}B_c + D_c$, with p inputs and m outputs and a constant output feedback matrix $K_o \in \mathbb{R}^{m \times p}$ such that the feedback system is Strictly Positive Real (SPR). It is shown that this problem has solution if and only if all transmission zeros of the plant have negative real parts. When there exists solution, the proposed method firstly obtains $G_c(s)$ in order to all transmission zeros of $G_c(s)G(s)$ present negative real parts and then K_o is found as the solution of some Linear Matrix Inequalities (LMIs). Then, taking into account this result, a new LMI based design for output Variable Structure Control (VSC) of uncertain dynamic plants is presented. The method can consider the following design specifications: matched disturbances or nonlinearities of the plant, output constraints, decay rate and matched and nonmatched plant uncertainties.

12:10-12:30

WedB.4 - *Robust stabilization of linear unstable plants with saturating actuators using a time varying sliding surface: preliminary results*, pp. 334-339

Corradini, Maria Letizia

University of Camerino

Orlando, Giuseppe

Università Politecnica delle Marche

Parlangeli Gianfranco

University of Lecce

This paper proposes the use of a time-varying sliding surface for the robust stabilization of linear uncertain SISO plants with saturating actuators. A constructive procedure for its design is also proposed, and stability of the closed loop system is proved in the null controllable region. The

proposed technique does not require plant stability, and can manage any bounded disturbance term satisfying the matching condition. Theoretical results have been validated by simulation using a third order plant.

12:30-12:50

WedB.5 - *Design of Sliding Mode Controllers for Linear Uncertain Systems Based on First Order Approximation Filters*, pp. 340-345

Cunha, José Paulo V.

State University of Rio de Janeiro

Costa, Ramon R.

Federal University of Rio de Janeiro

Hsu, Liu

Federal University of Rio de Janeiro

The focus of this paper is on the synthesis of first order filters which generate approximations for upper bounds of the norm of signals needed in the modulation function of some sliding mode control laws. The design of output-feedback sliding mode controllers for uncertain multivariable linear systems in regular form is considered. Optimization methods are applied to reduce the amplitude of the control signals. The model-reference control of a mechanical system with uncertain parameters and uncertain order illustrates the design method.

14:30 ÷ 15:30

Plenary session (jointly with ADHS'06)

"Chattering Problem for Sliding Mode Control"

Speaker: Prof. V. Utkin

Wed C

15:50 ÷ 17:50

Applications to mechanical systems

15:50-16:10

WedC.1 - *Performances Comparison of Linear and Sliding Mode Attitude Controller for Flexible Spacecraft with Reaction Wheels*, pp. 346-351

Abdulhamitbilal, Erkan

Technical University of Istanbul

Jafarov, Elbrous M.

Technical University of Istanbul

In this study, two control algorithms for the three axes stabilized communication satellite Intelsat V are given. The spacecraft is assumed to be controlled via reaction wheels. First, linear control method is used to design an attitude feedback control algorithm for a rigid satellite with attitude angle. Linearized form of the spacecraft dynamics are given in attitude angle representation. Second, sliding mode control method has used for the attitude controller with equivalent control term for flexible satellite. The performances and disadvantages are discussed on design example for both cases. Modeling and simulation are done by using MATLAB-Simulink programming. The results show that using of attitude linear controller may cause the mission cost to be high and decrease the performances maneuvers for a geosynchronous satellite mission and also do not include flexibility effects. However, attitude sliding mode controller for geosynchronous satellite with flexible solar arrays uses energy optimally and has a great performance

than that of linear controller. Moreover, attitude sliding mode controller is a robust to bounded external disturbances and includes unmodelled dynamics.

Pan, Yaodong
Furuta, Katsuhisa

Tokyo Denki University
Tokyo Denki University

This paper presents an adaptive controller for a new type prismatic manipulator. This adaptive controller is designed with the sliding mode, by which on-line parameters estimation mechanism is implemented and the control input is determined adaptively combining the estimation mechanism. The derivative of the signal is estimated by an adaptive VSdifferentiator..

16:10-16:30

WedC.2 - *Output Excitation via Second-Order Sliding-Modes to Generate Periodic Motion for Underactuated Systems*, pp. 352-357

Aguilar, Luis Instituto Politecnico Nacional, Mexico
Boiko, Igor SNC-Lavalin
Fridman, Leonid National Autonomous Univ. of Mexico
Iriarte, Rafael National Autonomous Univ. of Mexico

Generation of periodic motion for underactuated manipulator is done through the second-order sliding-mode (SOSM) algorithms, particularly via the twisting algorithm. This study is motivated by the recent results which show that the SOSM algorithm may generate a periodic motion if the relative degree of the plant is higher than two. To obtain the desired amplitude and velocity of oscillations we use the describing function and the locus of a perturbed relay system approach. Performance issue of the controllers is illustrated in a simulation study made for a three-link underactuated robot.

17:30-17:50

WedC.6 - *Robotic application of adaptive VSC with deformable sliding surfaces*, pp. 378-383

Dyda, Alexandr A. Maritime State University of Vladivostok
Markin, Vasily E.

Institute for Automation and Control, Vladivostok

Variable-structure systems (VSS) are known as a class of nonlinear systems with discontinuous control. One of the most attractive features of VSS is availability of sliding mode. System dynamics in sliding mode can be robust to parametric uncertainties. Adaptive control is also available in VSS. In the paper a new robust adaptive variable-structure control in robotics is proposed. Control algorithm provides both high performance and reduced energy expenditure in comparison with conventional VSS. It is based on usage of a pair of switching surfaces closely located in state space of the system. Another control algorithm uses adaptively deformable sliding surfaces. Simulations of robot drives control with derived adaptive VSS algorithms confirmed their high efficiency.

16:30-16:50

WedC.3 - *Feedback Linearization and High Order Sliding Mode Observer For A Quadrotor UAV*, pp. 358-365

Benallegue, A. Robotics Laboratory of Versailles
Mokhtari, A. University of Science and Technology of Oran
Fridman, Leonid National Autonomous Univ. of Mexico

In this paper, a feedback linearization-based controller with a high order sliding mode observer running parallel is applied to a quadrotor unmanned aerial vehicle. The high order sliding mode observer works as an observer and estimator of the effect of the external disturbances such as wind and noise. The whole observer-estimator-control law constitutes an original approach to the vehicle regulation with minimal number of sensors. Performance issues of the controller-observer are illustrated in a simulation study that takes into account parameter uncertainties and external disturbances.

16:50-17:10

WedC.4 - *Absolute orientation estimation based on high order sliding mode observer for a five link walking biped robot*, pp. 366-371

Lebastard, V. Uiversitè de Nantes
Aoustin, Y. Uiversitè de Nantes
Plestan, F. Uiversitè de Nantes
Fridman, Leonid National Autonomous Univ. of Mexico

An observer to determine the absolute orientation of a 5-link biped robot is designed, in order to avoid the use of a sensor, which is one of the originalities of this paper. As a matter of fact, the measurement of such variable is quite delicate. The observer is based on the high order sliding mode approach, for its features of robustness and finite-time convergence property.

17:10-17:30

WedC.5 - *Adaptive Sliding Mode Control of Belt Driven Prismatic Manipulator*, pp. 372-377

Tanaka, Maya Tokyo Denki University

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