ABSTRACTS
WORKSHOP ON ELECTRICAL AND MECHATRONICAL SYSTEMS
February 18 – 20, 2009

Wednesday:

J. Chiasson
Algebraic Techniques for Nonlinear Parameter and State Estimation of Electric Machines

Algebraic methods have long been used as tools for problems in linear systems theory. In this work, some algebraic tools are explored as methods for nonlinear parameter identification as well as for constructing observers of nonlinear systems. The methods are illustrated by identifying the parameters of an induction machine and showing how the speed of an induction machine can be estimated from the stator voltages, stator currents and their derivatives.
The proposed identification methodology starts with obtaining an input-output model which is linear in the parameters, but overparameterized. A standard least squares formulation is then used to set up the parameter identification of the overparameterized system. Next, using the assumption that the parameters are **rationally** related, appropriate substitutions are made to remove the overparamerization transforming the problem into a **nonlinear** least-squares problem. The least squares error is then found to be a polynomial function of the unknown parameters whose coefficients are functions of the collected/computed data (consisting exclusively of the inputs, outputs, and their derivatives). The value of parameters that minimize the least squares error is then shown to be solvable in a finite number of steps using elimination theory. A discussion is given to show that this approach is applicable to a significant class of practical problems and can be implemented online.

P. Rouchon
Euler-Lagrange Models with Complex Currents of Three-Phase Electrical Machines and Observability Issues

A Lagrangian formulation with complex currents is developed and yields a direct and simple method for modeling three-phases permanent-magnet and induction machines.
The Lagrangian is the sum of the mechanical kinetic energy and of the magnetic energy.
This magnetic energy is expressed in terms of rotor angle, complex stator and rotor currents. Such a Lagrangian setting is a precious guide for modeling space-harmonics and saturation effects. A complexification procedure is applied here in order to derive the Euler-Lagrange equations with complex stator and rotor currents. Such complexification process avoids the usual separation into real and imaginary parts and simplifies notably the calculations. Via simple modification of magnetic energies we derive non-trivial dynamical models describing permanent-magnet machines with both saturation and saliency, and induction machines with both saturation and space harmonics. Around any stationnary regime where the stator tensions are constant, such models yield to non observable first order linear systems, when we measure only the stator currents and the load torque is unknown but constant (the so-called sensorless case).
This work has been undertaken in collaboration with Duro Basic and François Malrait, Schneider Electric.

A. Fehn
Model-based Vehicle Dynamics Control

This contribution deals with a model-based vehicle dynamics control concept. Thereby, a modular control structure is designed by introducing the following layers: the lateral dynamics control, the control allocation, and the wheel control. The interfaces between these layers are realized by means of clear physical variables and allow efficient interaction with other control systems, as e.g. the anti-lock braking system. In this contribution a detailed discussion of the control design and of the experimental results will be given. Practically notable are on the one hand the excellent control performance, allowing to precisely maintain the desired body side-slip angle, and on the other hand the straightforward control tuning, both achieved by using only the standard ESP-hardware.

C. Canudas de Wit
Fun-to-Drive by Feedback

This lecture is devoted to new challenging control problems arising in the automotive industry as a consequence of the customer-driven performance specifications adopted by car builders which have dramatically increased the number of new proposed automated features where feedback interacts with the driver. The notion of "Fun-to-Drive by Feedback" relates, here, to the ability to design a control scheme resulting in good ride comfort behavior as well as acceptable safe operation.
The lecture shows how control techniques can be used to solve some of these problems, and discusses how these subjective notions can be formalized thanks to concepts such as passivity and model matching control.
We present a series of examples concerning systems that provide assisted automated devices (i.e. electrical power steering and assisted clutch synchronization), as well as systems with fully automated features (i.e. steer-by-wire system, stop-and-go), in which these aspects are assessed.
Material for this talk is from joint work with H. Bechart, X. Claeys, P. Dolcini, and J.-J Martinez, and results from long standing in collaboration with Renault, and the ARCOS Predit French program.

A. Karimi
Data-Driven Controller Tuning with Application to Mechatronic Systems

Using a set of input/output time-domain or frequency-domain data in open- or closed-loop operation, several approaches for controller tuning are proposed.
Time-domain approaches are based on the minimization of the correlation between a closed-loop performance error and the excitation signal. Frequency-domain approaches are based on the loop-shaping in the Nyquist diagram. In this approach robust performance specifications are approximated by a set of linear or convex constraints with respect to the parameters of linearly parameterized controllers.
Fixed-order controllers can be designed that satisfy H infinity performance for systems with frequency-domain and multimodel uncertainty. The approach can be used for gain-scheduled controller design and switched systems. In the same framework, decoupling and decoupled controllers can be tuned simultaneously for multivariable systems. An application to a high precision positioning system illustrates the effectiveness of the proposed approaches.

A. Oustaloup
A survey of the Non Integer Approach of Dynamics

This talk deals with fractal robustness. Of physical origin, this robustness represents the insensitivity of damping in nature, resulting from the combination of fractality and non integer differentiation. The study case is a natural robust phenomenon: the relaxation of water on a porous dyke whose damping ratio is independent of the mass of moving water. Damping robustness is illustrated by two isodamping half-straight lines in the operational plane, and by a frequency template in the Nyquist plane. Then, the principle of the CRONE suspension, the synthesis method and the performance are developed.

Thursday:

M. Krstic
Compensation of Long Input Delays for Nonlinear Control Systems and PDEs

Input delays create challenges in stabilization problems in many applications for unstable plants. I will present new designs for global stabilization of broad classes of nonlinear systems with long input delays. I will also introduce problems where the length of the input delay is highly uncertain, or even completely unknown, and present adaptive control designs for stabilization in the presence of this and other parametric uncertainties. In addition to input delays, I will discuss other infinite-dimensional input dynamics, such as those that combine convective and diffusive phenomena. Finally, I will show designs for PDEs with long input delays, such as unstable reaction-diffusion equations and anti-stable wave equations.

J.Botsis
Optical fiber strain sensors for structural monitoring and damage identification : measurements and simulations.

Optical fiber sensors have attracted considerable attention over the last decades due to their characteristic property to measure strains in the host structure. Compared to other traditional sensors, they are generally more compact, lightweight, and less invasive due to their small size. In addition, they are immune to electromagnetic interference, have excellent resistance to corrosion and high temperatures and long lifetimes. They are particularly adapted to polymer composite structures where they can be embedded between plies and result in accurate strain or temperature measurements at selected locations. Thus they provide a powerful tool in experimental mechanics and structural health monitoring.

In this presentation, first the essential aspects of optical fiber Bragg grating (FBG) sensors as a tool for strain measurements and examples of structural monitoring are outlined. Second, data and analysis of some important experiments with integrated FBG sensors are discussed. Third, the limitations of these fibers method and future needs are listed.

J. Rudolph
Modeling and Control of Tooling Spindles with Electromagnetic Bearings

Using active magnetic bearings in machine tool spindles makes it possible to produce non-circular holes. This is achieved by prescribing a synchronized path to the (single) cutting edge of the tool. Thus, a high precision synchronous tool path tracking problem must be solved.
There is an industrial demand for spindles which allow non-circular motion of about 50 micro-meters. The shape varies in the axial direction. The precision required is very demanding. Path tracking errors must be less than 1 micro-meter on circular paths and micro-meters on non-circular ones. Typical rotational velocities are at about 10000 rpm. We have solved this problem in cooperation with Axomat GmbH. Another class of applications concerns grinding of optical lenses.
Several types of magnetic bearings have been constructed and mathematical models for these di→ erent conÞgurations have been derived. They form the basis for the control design. Typically, the control is realized as a cascade, with a current controller in the inner and a position tracking controller in the outer loop. The design of the position controller follows the ßatness based control paradigm, for which a solution has been Þrst proposed by J. Lévine, J. Lottin, and J.-C. Ponsart in 1996.

A. Bloch
Nonholonomic, Dissipative, and Quantum Dynamics.

In this talk I will discuss various aspects of the modeling and control of nonholonomic systems. In particular I will discuss the Lagrange D'Alembert approach to these systems and their variational nature. I will describe how such systems do not always preserve volume in the phase space and how they can exhibit dissipative behavior in the absence of external friction. I will also discuss how one can represent the constraints as a limit of external friction and, in a particular case, how this friction may be represented as an external field, allowing us to quantize the system. The relationship of such systems to Hamiltonian systems via the inverse problem of the calculus of variations will also be described.

M. Hasler
Synchronization in Dynamical Networks

Collective dynamics in networks of interacting dynamical systems is of great current interest in many application areas. The most prominent form of collective dynamics is synchronized motion. In this overview talk, we will first review the various notions of synchronization.
Then, we will argue that synchronization in dynamical networks depends on a) the individual dynamical systems, b) the type and strength of interaction, and c) the structure of the interaction graph. We shall review necessary (Master stability function method) and sufficient (connection graph stability method) criteria for synchronization make the three ingredients for synchronization explicit.

Friday:

S. Arimoto
Modelling and Control of Multi-body Mechanicalssystems: Part I A Riemannian Geometry Approach

Control of robotic systems such as anthropomorphic robot arms and multi-fingered hands provides an important and challenging research area spanned between the studies of modern nonlinear control theory, neuro-motor control, and kinesiology. From a theoretical standpoint, the geometric structure of robotic systems gives way to gaining an indepth insight into design of coordinated control algorithms that generate dexterous robot motions and fulfill a given task.

This talk discusses a new perspective methodology of analysis and synthesis of control for multi-body systems including robotic arms and multi-fingered hands from the viewpoint of Riemannian geometry. First it is pointed out that, when a robot arm with n joints with free rotational motion is given as a physical entity in $\boldsymbol{E}3$, the set of all its postures can be regarded as a Riemannian manifold associated with the Riemannian metric that constitutes the robot's inertia matrix. A geodesic connecting any two postures is defined by a solution to the Euler-Lagrange equation of robot motion that originates only from inertial force. It is emphasized that the Riemannian distance between two postures is invariant under any choice of local coordinates.

This Riemannian-geometry approach is extended to an important class of multi-body dynamicsphysically interacting with a rigid object or environment through holonomic or non-holonomicconstraints. The concept of stability of motion around a Riemannian equilibrium submanifoldis renewed in the case of redundancy of degrees-of-freedom. A design method for robot positioncontrol under such redundancy is suggested on the basis of Morse-Lyapunov's functions and an extension of Dirichlet-Lagrange's stability to a redundant system is presented.

The latter part of the talk discusses position/force hybrid control of an endeffector of a multi-joint redundant (or nonredundant) robot under a nonholonomic constraint is reinterpreted interms of "submersion" in Riemannian geometry. A force control signal constructed in the image space of the constraint gradient can be regarded as a lifting (or pressing) in the direction orthogonal to the kernel space of the gradient. By means of the Riemannian distance on the constraint submanifold, stability on a manifold for a redundant system under holonomic constraints is discussed. Second, modeling, control and stabilization of dynamics of two-dimensional object grasping and manipulation by using a pair of multi-joint robot fingers are tackled, when a rigid object is given with arbitrary shape. Then, it is shown that rolling contact constraints induce the Euler equation of motion in an implicit function form, in which constraint forces appear as wrench vectors affecting on the object. The Riemannian metric can be introduced in a natural way on a constraint submanifold by restricting admissible tangent vectors to the kernel space as an othogonal complement to the image of whole gradients of both the contact constraints and the rolling constraints. An explicit form of the quotient dynamics expressed in the kernel space is also presented, accompanied with a set of first-order differential equation expressing the object posture in terms of curvatures of the second fundamental form. A control signal called "blind grasping" is defined and shown to be effective in stabilization of grasping without using the details of information of object shape and parameters or external sensing. The concept of stability of the closed-loop system under constraints is renewed in order to overcome the degree of- freedom redundancy problem. An extension of Dirichlet-Lagrange's stability theorem to a system of DOF-redundancy under constraints is presented by using a Morse-Lyapunov function.

G. Zhu
Electrostatic MEMS: Modeling, Control, and Applications

In the last few years, there has been a surge of interest in thetechnology of micro-electro-mechanical systems (MEMS). Currently availableMEMS fabrication techniques enable the construction of devices withhigh-precision displacement and high-quality surface required for highperformance applications. However, MEMS devices are highly nonlinear andinherently unstable for a big portion of their operational range, a phenomenon referred as “pull-in.” This introduces the need of adequate control which would ensure the overall system performance and allow betterexploiting the capability the MEMS technology can offer. This talk deals with the control of a very poplar type of MEMS: electrostaticmicro-actuators. It presents the modeling of electrostatic MEMS, an overviewof latest nonlinear control strategies reported in the literature, solutionsfor enhancing the robustness vis-à-vis modeling error, and some perspectiveon future works in this area.

B. Kiss
Time-scaling in the Control of Mechatronic Systems

Time-scaling is not a new concept in the theory of dynamical systems.
It has been used to modify the time distribution along the reference paths (Hollerbach, 1984) and also to transform a system by changing the clock with which it evolves. The motivation to introduce time-scaling is often to gain useful properties for the system which evolves ccording to the modified time. It is shown in (Sampei & Furuta, 1986) that such a property to gain with time-scaling may be feedback linearizability. The notion of orbital flatness introduced by Fliess et al. (Fliess et al.1995, 1999) involves also time-scaling to define an equivalence between a class of nonlinear systems and chains of integrators. The problem to check the orbital flatness of single input systems is addressed in (Respondek, 1998) and (Guay, 1999) together with the example of the kinematic car with constant longitudinal velocity which is shown to be orbitally flat.
The time-scaling introduced by most of these concepts involves the state variables to express the relation between the different time scales, hence the time-scaling does not involve any new input or variable external to the system.
Another concept for time-scaling is to use the tracking error in closed loop to modify the time distribution of the reference path (Lévine, 2004).
Such methods change the traveling time of the reference path according to the actual tracking error by decelerating if the motion is not accurate enough and by accelerating if the errors are small or vanish.
This talk presents a time-scaling scheme which is not driven only by the state variables of the system but also by a new input, referred to as the time-scaling input. In the setup suggested, the new input variable, which is not an input of the original physical system, is also used to drive the time-scaling of the reference in closed loop.
The usefulness of our approach is demonstrated for the nonholonomic model of the kinematic car with one input. Notice that solutions to the motion planning and tracking algorithms are reported to the kinematic car with two inputs (Cuesta and Ollero, 2005) exploiting its differentially flatness property or using other methods (Dixon et al., 2001). We show that the kinematic car with one input, such that the longitudinal velocity does not vanish, can track any smooth trajectory with non-vanishing and bounded longitudinal velocity such that the tracking error is reduced along the path using time-scaling and a dynamical feedback similar to the differentially flat case.

H. Aschemann
Sliding-Mode Control of a High-Speed Linear Axis Driven by Pneumatic Muscle Actuators

This contribution presents two cascaded sliding-mode control schemes for a new pneumatic linear axis that could be seen as alternative to an electric direct linear drive. Its guided carriage is driven by a nonlinear mechanism consisting of a rocker with an antagonistic pair of pneumatic muscle actuators arranged at both sides. This innovative drive concept allows for both an increased workspace of approx. 1 m as well as higher carriage velocities of approx. 1.3 m/s as compared to a direct actuation. Modelling of the muscle driven positioning system leads to a system of four nonlinear differential equations including polynomial approximations of the volume characteristic as well as the force characteristic of the pneumatic muscles. The differential flatness of the system is exploited in combination with sliding-mode techniques to stabilise the error dynamics in view of unmodelled dynamics. The proposed control structures have a cascade structure: the internal pressure of each pneumatic muscle is controlled by a fast underlying control loop. Hence, the control design for the outer control loop can be simplified by considering these controlled muscle pressures as ideal control inputs. The control design of the outer control loop involves a decoupling of rocker angle as well as mean internal pressure of both pneumatic muscles as flat outputs. Additionally, model uncertainties in the equation of motion like nonlinear friction are directly counteracted by an observer-based disturbance compensation which reduces the chattering problem. As alternative for the outer control loop, a proxy-based sliding-mode controller was designed as well. Proxy-based sliding-mode is a modified version of sliding-mode control as well as an extension of PID control. It guarantees accurate tracking during normal operation and a smooth, well damped recovery in the case of large position errors after unexpected incidents. Experimental results show an excellent control performance for both control approaches.
Keywords: Mechatronics, sliding-mode, pneumatic muscle, disturbance observer

S.Bonnabel
Industrial Crane Control: a Survey

The aim of this talk is to review some control laws for crane control and anti-sway systems that have been or could possibly be applied in industry. We will present open loop and feedback laws from the literature, and the several sensors used to control cranes. Some ideas from industrial patents as well as anti-sway systems sold in the industry will be presented. The talk will possibly be illustrated by commercial videos. We will also show videos of an experimental 2 meters high crane recently built.