Hans Henrik Niemann - DTU Orbit (21/10/2019)
Hans Henrik Niemann

Organisations

Associate Professor, Department of Electrical Engineering
04/07/2003 → present
hhn@elektro.dtu.dk
VIP

Automation and Control
25/02/2012 → present
VIP

Associate Professor, Department of Automation
04/07/2003 → 07/04/2016 Former
hhn@elektro.dtu.dk
VIP

Research outputs:

A Controller Architecture With Anti-Windup
This letter presents a framework for anti-windup controllers based on the Youla-Jabr-Bongiorno-Kucera (YJBK) parameterization. Applying this architecture gives an additional YJBK matrix transfer function related to the input saturation. This additional YJBK transfer function can be applied for optimizing the feedback loop around the input saturation. Further, the connection with other anti-windup controller architectures is also considered in this letter.

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Adaptive and Sliding Mode Friction-Resilient Machine Tool Positioning - Cascaded Control Revisited
Needs for high-accuracy tool positioning and accurate trajectory following have renewed the focus on controller design for machine tools. While state-of-the-art solutions, based on Proportional (P) and Proportional-Integral (PI) cascades, achieve sufficient nominal performance, axis positioning accuracy quickly degrades in the presence of additional wear-related friction. Sliding-mode and nonlinear adaptive controllers with no cascaded architecture can alleviate such performance deterioration at the cost, however, of significantly increased design complexity. This is mainly due to the fact that such architectures facilitate addressing more nonlinear phenomena, such as load dynamic friction. This paper investigates three nonlinear controllers with cascaded architecture for machine tool axis positioning. A comparative analysis of the positioning solutions is carried out and it is shown that a cascaded scheme comprising a proportional and a super-twisting sliding-mode controller offers superior friction-resilient axis positioning. Moreover, its design complexity is comparable to that of the conventional P-PI solution. Experimental results obtained from a single-axis test setup equipped with commercial industrial equipment validate the theoretical findings.
Parametric Fault Diagnosis of an Active Gas Bearing

Recently research into active gas bearings has had an increase in popularity. There are several factors that can make the use of gas bearings favourable. Firstly gas bearings have extremely low friction due to the usage of gas as the lubricant which reduce the needed maintenance. Secondly gas bearings is a clean technology which makes it possible to use for food processing, air condition and applications with similar requirements. Active gas bearings are therefore useful for applications where downtime is expensive and dirty lubricants such as oil are inapplicable. In order to keep as low downtime as possible it is important to be able to determine when a fault occurs. Fault diagnosis of active gas bearings is able to minimize the necessary downtime by making certain the system is only taken offline when a fault has occurred. Usually industry demands the removal of any sensor redundancy in systems. This makes it impossible to isolate faults using passive fault diagnosis. Active fault diagnosis methods have been shown able to isolate faults when there is no sensor redundancy. This makes active fault diagnosis methods relevant for industrial systems. It is in this paper shown possible to apply active fault diagnosis to diagnose parametric faults on a controllable gas bearing. The fault diagnosis is based on a statistical detector which is able to quantify the quality of the diagnosis scheme.
Robust Backlash Estimation for Industrial Drive-Train Systems—Theory and Validation

Backlash compensation is used in modern machinetool controls to ensure high-accuracy positioning. When wear of a machine causes deadzone width to increase, high-accuracy control may be maintained if the deadzone is accurately estimated. Deadzone estimation is also an important parameter to indicate the level of wear in a machine transmission, and tracking its development is essential for condition-based maintenance. This paper addresses the backlash estimation problem using sliding-mode and adaptive estimation principles and shows that prognosis of the development of wear is possible in both theory and practice. This paper provides the proof of asymptotic convergence of the suggested estimator, and it shows how position offset between motor and load is efficiently utilized in the design of a very efficient estimator. The algorithm is experimentally tested on a drive-train system with the state-of-the-art Siemens equipment. The experiments validate the theory and show that expected performance and robustness to parameter uncertainties are both achieved.

An Architecture for Controller Parameterization

The focus in this paper is on the YJBK (after Youla, Jabr, Bongiorno and Kucera) parameterization of all stabilizing feedback controllers for a given system. A new formulation of YJBK controller architecture is presented and the relation with the double Bezout equation is described. In the standard formulation, a full order model of the system is required for an implementation of the YJBK controller architecture. Here, implementation of the YJBK parameterization will be based on reduced order model, obtained by e.g. model reduction of the full order models or by using identification methods. The controller architecture based on reduced order models will be analyzed with respect to closed-loop stability.
Closed Loop Fault Detectability Based on a Gap-metric

Systems are often controlled using feedback loops. Fault diagnosis schemes are usually designed assuming that there is no feedback loop. Therefore fault diagnosis methods need to accommodate for the feedback loop. One such method is active fault diagnosis based on a fault signature system. This method is derived using the YJBK parametrisation, named after Youla, Jabr, Bongiorno and Kucera. It uses the derived fault signature system to determine the detectability of possible faults in the system. Deriving the fault signature system requires knowledge about the controller. This paper demonstrates the possibility of estimating the detectability of faults in the fault signature system using a gap-metric. The gap-metric has the advantage of only requiring knowledge about the plant. By using the gap-metric it is possible to estimate the detectability of faults without using information about the controller.

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Closed loop identification of a piezoelectrically controlled radial gas bearing: Theory and experiment

Gas bearing systems have extremely small damping properties. Feedback control is thus employed to increase the damping of gas bearings. Such a feedback loop correlates the input with the measurement noise which in turn makes the assumptions for direct identification invalid. The originality of this article lies in the investigation of the impact of using different identification methods to identify a rotor-bearing systems' dynamic model when a feedback loop is active. Two different identification methods are employed. The first method is open loop Prediction Error Method, while the other method is the modified Hansen scheme. Identification based on the modified Hansen scheme is conducted by identifying the Youla deviation system using subspace identification. Identification of the Youla deviation system is based on the Youla–Jabr–Bongiorno–Kucera parametrisation of plant and controller. By using the modified Hansen scheme, identification based on standard subspace identification methods can be used to identify the Youla deviation system of the gas bearing. This procedure ensures the input to the Youla deviation system, and the noise is uncorrelated even though the system is subject to feedback control. The effect of identifying the Youla deviation system compared to direct subspace identification of the gas bearing is further investigated through a simulation example. Experiments are conducted on the piezoelectrically controlled radial gas bearing. A dynamic model is identified using the modified Hansen scheme as well as using Prediction Error Method identification. The resulting models are compared for different imperfect nominal models, to examine under which conditions each method should be used.

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Detector design for active fault diagnosis in closed-loop systems

Fault diagnosis of closed-loop systems is extremely relevant for high-precision equipment and safety critical systems. Fault diagnosis is usually divided into 2 schemes: active and passive fault diagnosis. Recent studies have highlighted some advantages of active fault diagnosis based on dual Youla-Jabr-Bongiorno-Kucera parameters. In this paper, a method for closed-loop active fault diagnosis based on statistical detectors is given using dual Youla-Jabr-Bongiorno-Kucera parameters. The goal of this paper is 2-fold. First, the authors introduce a method for measuring a residual signal subject to white noise. Second, an optimal detector design is presented for single and multiple faults using the amplitude and phase shift of the residual signal to conduct diagnosis. Here, both the optimal case of a perfect model and the suboptimal case of a model with uncertainties are discussed. The method is successfully tested on a simulated system with parametric faults.

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Estimating the Density of Fluid in a Pipeline System with an Electropump
To transfer petroleum products, a common pipeline is often used to continuously transfer various products in batches. Separating the different products requires detecting the interface between the batches at the storage facilities or pump stations along the pipelines. The conventional technique to detect the product in the pipeline is to sample the fluid in a laboratory and perform an offline measurement of its physical characteristics. The measurement requires sophisticated laboratory equipment and can be time-consuming and susceptible to human error. In this paper, for performing the online detection and separation of the batches, two methods are suggested that do not need extra equipment and are more
practical. Because different petroleum products have different densities, the goal of both methods was to estimate the density of each product to detect its type. To estimate the fluid density, the first method used a recursive Kalman filtering algorithm and a model that defined the relationship among the pump's differential pressure, the volume flow rate, and the rotational speed. The second method was suggested for the cases when the measurement of pressure and flow rate are not possible but the motor current and rotational speed are directly measurable. For that purpose, first the load torque was estimated. Then, by using a model that has parameters that depend on the density and that defines the relationship between the required pump torque and its rotational speed, the parameters of this model and consequently the density of the fluid were estimated. (C) 2018 American Society of Civil Engineers.

Friction-resilient position control for machine tools—Adaptive and sliding-mode methods compared
Robust trajectory tracking and increasing demand for high-accuracy tool positioning have motivated research in advanced control design for machine tools. State-of-the-art industry solutions employ cascades of Proportional (P) and Proportional-Integral (PI) controllers for closed-loop servo control of position and velocity of the machine axes. Although these schemes provide the required positioning accuracy in nominal conditions, performance deteriorates with increased friction and wear of the machine. With conventional control, re-tuning is necessary during the lifetime if specified accuracy shall be maintained. This paper investigates whether nonlinear and adaptive controllers can cope with typical levels of friction increase without loss of performance. It evaluates the performance of a state-of-art industry solution with that obtainable with adaptive and sliding mode positioning controls. The main finding is that an adaptive backstepping control is resilient to unknown and increasing friction at realistic levels of wear, where the P-PI control fall short with respect to accuracy. A single-axis test rig with adjustable friction is used to assess the performance of different controllers.
Method for determining a deadzone angle of a backlash in a mechanical drive-train system, method for controlling a drive motor controller as well as drive-train system

The invention relates to a method for determining a deadzone angle ($\delta$) of a backlash in a mechanical drive-train system (1), wherein the drive train-system (1) comprises a drive motor (2), a load (3) and a shaft (4) for connecting the drive motor (2) with the load (3), the method comprising the steps: estimating an interconnection torque ($T_I$) in the deadzone, determining the deadzone angle ($\delta$) depending on the interconnecting torque ($T_I$) by means of an adaptive estimator, wherein in the adaptive estimator the backlash is modelled in terms of a variable stiffness ($K_{BL}$) of the shaft (4).

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Contributors: Papageorgious, D., Blanke, M., Niemann, H. H., Richter, J. H.
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Sensors Faults: A YJBK Approach for Compensation

The focus in this paper is on compensation for sensor faults. Virtual sensors or compensation using the YJBK controller architecture (after Youla, Jabr, Bongiorno and Kucera) are two ways to compensate sensor faults without changing the nominal controller directly. Design of virtual sensors is quite simple due to the separation between the nominal controller and the virtual sensor. A short analysis of the virtual sensor in connection with the YJBK controller architecture is given. Further, a reformulation of the YJBK controller architecture is given and the connection with the Bezout equation is described. It is shown that this new formulation makes it easy to change the sensors in the system without changing the nominal controller, but only extend the included system matrices. System uncertainties in connection with sensor faults will also be considered in connection with the YJBK controller architecture.

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Verification of Real-Time Optimization for Multi-stage Spray Dryer Operation with Polynomial Optimization

Using polynomial optimization, we demonstrate computationally that the local optima determined by a Newton method (interior-point algorithm) for real-time optimization of multi-stage spray dryer operation are identical to the global optimum. In the first major step, we transform the optimization problem for the multi-stage spray dryer operation into a polynomial optimization problem. In this form, the global optimum can be computed by polynomial optimization. In the second major step, we compare the global optimum with the potential local optima obtained by a Newton method for three operational points of a pilot-size plant and for one operational point of an industrial plant. For each case, the Newton method is initialized at 10,000 different initial points. All the computed potential local optima computed by the Newton method are identical to the global optima computed by polynomial optimization. Consequently, based on this extensive computational evidence, we conclude that the Newton method converges to the global optima for the multi-stage spray dryer real-time optimization problem.

Condition monitoring of a rotor arrangement in particular a wind turbine

The present invention relates to a method of determining the condition of a device comprising a rotor arrangement. The rotor arrangement comprising a rotational shaft and a number rotor blades each connected at the root to the rotational shaft and extending radially from the rotational shaft. Sensors are arranged to measure for each rotor blade corresponding values of one or more of the following parameters: azimuth angle (Φ) (or a parameter related to the azimuth angle), root bending moment(s) (q), such as the edgewise and/or flapwise root bending moments. The method comprises, while the arrangement rotates, recording corresponding values of azimuth angle and edgewise and flapwise root bending moments for a plurality of rotations of rotor arrangement, transforming by use of e.g. a multi blade coordinate transformation, a Park’s transformation or similar transformation the recorded edgewise and flapwise root bending moments (q) into a coordinate system rotating with the rotational shaft, thereby obtaining transformed root bending moments (qf). The method further comprising identifying periodicity in each of the transformed root bending moments, determining the condition of the rotor arrangement to be faulty, in case the one or more periodicities are identified in the transformed root bending moments.
An experimentally validated simulation model for a four-stage spray dryer

In this paper, we develop a dynamic model of an industrial type medium size four-stage spray dryer. The purpose of the model is to enable simulations of the spray dryer at different operating points, such that the model facilitates development and comparison of control strategies. The dryer is divided into four consecutive stages: a primary spray drying stage, two heated fluid bed stages, and a cooling fluid bed stage. Each of these stages in the model is assumed ideally mixed and the dynamics are described by mass- and energy balances. These balance equations are coupled with constitutive equations such as a thermodynamic model, the water evaporation rate, the heat transfer rates, and an equation for the stickiness of the powder (glass transition temperature). Laboratory data is used to model the equilibrium moisture content and the glass transition temperature of the powder. The resulting mathematical model is an index-1 differential algebraic equation (DAE) model with 12 states, 9 inputs, 8 disturbances, and 30 parameters. The parameters in the model are identified from well-excited experimental data obtained from the industrial type spray dryer. The simulated outputs of the model are validated using independent well-excited experimental data from the same spray dryer. The simulated temperatures, humidities, and residual moistures in the spray dryer compare well to the validation data. The model also provides the profit of operation, the production rate, the energy consumption, and the energy efficiency. In addition, it computes stickiness of the powder in different stages of the spray dryer. These facilities make the model well suited as a simulation model for comparison of the process economics associated to different control strategies.

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Backlash Estimation for Industrial Drive-Train Systems

Backlash in gearing and other transmission components is a common positioning-degrading phenomenon that develops over time in industrial machines. High-performance machine tool controls use backlash compensation algorithms to maintain accurate positioning of the tool to cope with such deadzone phenomena. As such, estimation of the magnitude of deadzones is essential. This paper addresses the generic problem of accurately estimating the width of the deadzone in a single-axis mechanical drive train. The paper suggests a scheme to estimate backlash between motor and load, employing a sliding mode observer and a nonlinear adaptive estimator. The efficacy of the approach is illustrated via simulations
Comparison of three control strategies for optimization of spray dryer operation

Spray drying is the preferred process to reduce the water content of many chemicals, pharmaceuticals, and foodstuffs. A significant amount of energy is used in spray drying to remove water and produce a free flowing powder product. In this paper, we present and compare the performance of three controllers for operation of a four-stage spray dryer. The three controllers are a proportional-integral (PI) controller that is used in industrial practice for spray dryer operation, a linear model predictive controller with real-time optimization (MPC with RTO, MPC-RTO), and an economically optimizing nonlinear model predictive controller (E-NMPC). The MPC with RTO is based on the same linear state space model in the MPC and the RTO layer. The E-NMPC consists of a single optimization layer that uses a nonlinear system of ordinary differential equations for its predictions. The PI control strategy has a fixed target that is independent of the disturbances, while the MPC-RTO and the E-NMPC adapt the operating point to the disturbances. The goal of spray dryer operation is to optimize the profit of operation in the presence of feed composition and ambient air humidity variations; i.e. to maximize the production rate, while minimizing the energy consumption, keeping the residual moisture content of the powder below a maximum limit, and avoiding that the powder sticks to the chamber walls. We use an industrially recorded disturbance scenario in order to produce realistic simulations and conclusions. The key performance indicators such as the profit of operation, the product flow rate, the specific energy consumption, the energy efficiency, and the residual moisture content of the produced powder are computed and compared for the three controllers. In this simulation study, we find that the economic performance of the MPC with RTO as well as the E-NMPC is considerably improved compared to the PI control strategy used in industrial practice. The MPC with RTO improves the profit of operation by 8.61%, and the E-NMPC improve.
Enhancing damping of gas bearings using linear parameter-varying control
Journal bearings can be lubricated through controllable injectors using pressurised fluids, whose viscosity highly
determines the dynamic responses of the rotating machine. The use of fluids with low viscosity is attracting a growing
interest due to the reduced friction forces and consequent losses when the machine is in operation. However low viscosity
also entails poor damping properties, which may lead to degraded performance or even instability when the rotating
machine operates at or near one of the modal frequencies. This issue can be properly addressed by employing active
feedback control systems to regulate the injection pressure of the fluid. Due to the strong dependencies of system
performance on system parameters, the sought controller should be robust over a large range of operational conditions.
This paper addresses the damping enhancement of controllable gas bearings through robust control approaches. Through
an extensive experimental campaign the paper evaluates two robust controllers, a linear parameter-varying (LPV)
controller and \(\infty\) controller, on their capability to guarantee stability and performance of a gas bearing across the large
operational envelopes in rotational speed and injection pressure. The control systems are designed applying state-of-the-
art methods in the respective areas. The experimental results clearly demonstrate the feasibility of enhancing the damping
properties of a gas bearing by means of robust control methods.

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Fault diagnosis and condition monitoring of wind turbines
This paper describes a model-free method for the fault diagnosis and condition monitoring of rotor systems in wind
turbines. Both fault diagnosis and monitoring can be achieved without using a model for the wind turbine, applied
controller, or wind profiles. The method is based on measurements from standard sensors on modern wind turbines,
including moment sensors and rotor angle sensors. This approach will allow the method to be applied to existing wind
turbines without any modifications. The method is based on the detection of asymmetries in the rotor system caused by
changes or faults in the rotor system. A multiblade coordinate transformation is used directly on the measured flap-wise
and edge-wise moments followed by signal modulation. Changes or faults in the rotor system will result in unique
signatures in the set of modulation signals. These signatures are described through the amplitudes and phase information
of the modulation signals. It is possible to detect and isolate which blade is faulty or has been changed based on these
signatures. Furthermore, the faulty component can be isolated, ie, the actuator, sensor or blade, and the type of fault can
be determined. The method can be used both on- and off-line.

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Stability Boundaries for Offshore Wind Park Distributed Voltage Control

In order to identify mechanisms causing slow reactive power oscillations observed in an existing offshore wind power plant, and to avoid similar events in the future, voltage control is studied in this paper for a plant with a static synchronous compensator, type-4 wind turbines and a park pilot control. Using data from the actual wind power plant, all stabilizing subsystem voltage proportional-integral controller parameters are first characterized based on their Hurwitz signature. Inner loop current control is then designed using Internal Mode Control principles, and guidelines for feedforward filter design are given to obtain required disturbance rejection properties. The paper contributes by providing analytical relations between power plant control, droop, sampling time, electrical parameters and voltage control characteristics, and by assessing frequencies and damping of reactive power modes over a realistic envelope of electrical impedances and control parameters.

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Active Fault Detection Based on a Statistical Test

In this paper active fault detection of closed loop systems using dual Youla-Jabr-Bongiorno-Kucera (YJBK) parameters is presented. Until now all detector design for active fault detection using the dual YJBK parameters has been based on CUSUM detectors. Here a method for design of a matched filter detector is proposed instead, based upon the Neyman-Pearson criterion for optimal detector design. Furthermore alternative ways to design the excitation signal which relates to indirect identification methods are presented. Examples are given on detection of actuator faults using a simulated gas bearing for both one and multiple possible parametric faults.

An application of gain-scheduled control using state-space interpolation to hydroactive gas bearings

Sinusoidal disturbances are common, especially in rotordynamics where mass imbalance causes undesirable vibrations. When the frequency of the disturbance is constant and known, it can be rejected using robust control techniques by including notches in the weights. For a known time-varying frequency, it is possible to design a gain-scheduled controller using multiple controllers optimised for a single frequency. Gain-scheduling strategies using the Youla parametrisation can guarantee stability at the cost of increased controller order and performance loss in the interpolation region. This paper contributes with a gain-scheduling strategy using state-space interpolation, which avoids both the performance loss and the increase of controller order associated to the Youla parametrisation. The proposed state-space interpolation for gain-scheduling is applied for mass imbalance rejection for a controllable gas bearing scheduled in two parameters. Comparisons against the Youla-based scheduling demonstrate the superiority of the state-space interpolation.
control, state-space methods, time-varying systems, rotordynamics, disturbance frequency, notches, time-varying frequency, gain-scheduled controller, Youla parametrisation, controller order, performance loss, gain-scheduling strategy, state-space interpolation region, mass imbalance rejection, controllable gas bearing, Youla-based scheduling, sinusoidal disturbances

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**Diagnosis of wind turbine rotor system**
This paper describes a model free method for monitoring and fault diagnosis of the elements in a rotor system for a wind turbine. The diagnosis as well as the monitoring is done without using any model of the wind turbine and the applied controller or a description of the wind profile. The method is based on available standard sensors on wind turbines. The method can be used both on-line as well as off-line. Faults or changes in the rotor system will result in asymmetries, which can be monitored and diagnosed. This can be done by using the multi-blade coordinate transformation. Changes in the rotor system that can be diagnosed and monitored are: actuator faults, sensor faults and internal blade changes as e.g. change in mass of a blade.

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**Industrial application of model predictive control to a milk powder spray drying plant**
In this paper, we present our first results from an industrial application of model predictive control (MPC) with real-time steady-state target optimization (RTO) for control of an industrial spray dryer that produces enriched milk powder. The MPC algorithm is based on a continuous-time transfer function model identified from data and states estimated by a time-varying Kalman filter. The RTO layer utilizes the same linear model and a nonlinear economic objective function for calculation of the economically optimized targets. We demonstrate, by industrial application of the MPC, that this method provides significantly better control of the residual moisture content, increases the throughput and decreases the energy consumption compared to conventional PI-control. The MPC operates the spray dryer closer to the residual moisture constraint of the powder product. Thus, the same amount of feed produces more powder product by increasing the average water content. The value of this is 186,000 €/year. In addition, the energy savings account to 6,900 €/year.

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Model Predictive Control of Sewer Networks

The developments in solutions for management of urban drainage are of vital importance, as the amount of sewer water from urban areas continues to increase due to the increase of the world’s population and the change in the climate conditions. How a sewer network is structured, monitored and controlled have thus become essential factors for efficient performance of waste water treatment plants. This paper examines methods for simplified modelling and controlling a sewer network. A practical approach to the problem is used by analysing simplified design model, which is based on the Barcelona benchmark model. Due to the inherent constraints the applied approach is based on Model Predictive Control.

Active Fault Diagnosis in Sampled-data Systems

The focus in this paper is on active fault diagnosis (AFD) in closed-loop sampled-data systems. Applying the same AFD architecture as for continuous-time systems does not directly result in the same set of closed-loop matrix transfer functions. For continuous-time systems, the LFT (linear fractional transformation) structure in the connection between the parametric faults and the matrix transfer function (also known as the fault signature matrix) applied for AFD is not directly preserved for sampled-data system. As a consequence of this, the AFD methods cannot directly be applied for sampled-data systems. Two methods are considered in this paper to handle the fault signature matrix for sampled-data systems such that standard AFD methods can be applied. The first method is based on a discretization of the system such that the LFT structure is preserved resulting in the same LFT structure in the fault signature matrix as obtained for continuous-time systems. The other method is an approximation method, where the same structure is obtained for small parametric faults.
Adaptive Backstepping Control of Lightweight Tower Wind Turbine
This paper investigates the feasibility of operating a wind turbine with lightweight tower in the full load region exploiting an adaptive nonlinear controller that allows the turbine to dynamically lean against the wind while maintaining nominal power output. The use of lightweight structures for towers and foundations would greatly reduce the construction cost of the wind turbine, however extra features ought be included in the control system architecture to avoid tower collapse. An adaptive backstepping collective pitch controller is proposed for tower point tracking control, i.e. to modify the angular deflection of the tower with respect to the vertical axis in response to variations in wind speed. The controller is shown to guarantee asymptotic tracking of the reference trajectory. The performance of the control system is evaluated through deterministic and stochastic simulations including an extreme wind gust event, and the feasibility of stabilizing the tower position while maintaining the rated power output is shown.

Closed loop identification using a modified Hansen scheme: Paper
It is often not feasible or even impossible to identify a plant in open loop. This might be because the plant contains unstable poles, or it is simply too expensive to remove the plant from its intended operation, among other possibilities. There are several methods for identifying a plant in closed loop [4], and one such method is the Hansen scheme [1]. Standard identification using Hansen scheme demands generating the identification signals indirectly. In this paper it is instead proposed to use the relationship between the Youla factorization of a plant and its stabilizing controller to directly measure the signals used for identification. A simulation example and identification of a gas bearing is given to show the method in action. Rotors supported by controllable gas bearings are open loop stable systems. However as the rotational speed is increased feedback control is necessary in order to keep the system stable. Furthermore because the dynamics of such a system depends on the rotational speed it is needed to conduct an identification while the system is part of a closed loop scheme. The authors believe the paper able to contribute towards a simpler and more direct way of identifying closed loop plants using Hansen scheme.
Comparison of Linear and Nonlinear Model Predictive Control for Optimization of Spray Dryer Operation

In this paper, we compare the performance of an economically optimizing Nonlinear Model Predictive Controller (E-NMPC) to a linear tracking Model Predictive Controller (MPC) for a spray drying plant. We find in this simulation study, that the economic performance of the two controllers are almost equal. We evaluate the economic performance with an industrially recorded disturbance scenario, where unmeasured disturbances and model mismatch are present. The state of the spray dryer, used in the E-NMPC and MPC, is estimated using Kalman Filters with noise covariances estimated by a maximum likelihood (ML) method.

Estimation of Parametric Fault in Closed-loop Systems

The aim of this paper is to present a method for estimation of parametric faults in closed-loop systems. The key technology applied in this paper is coprime factorization of both the dynamic system as well as the feedback controller. Using the Youla-Jabr-Bongjian-Rowe (YJBK) parameterization, it is shown that a certain matrix transfer function, the fault signature matrix, is an LFT (linear fractional transformation) of the parametric faults. Further, for limit parametric faults, the fault signature matrix transfer function can be approximated with a linear matrix function of the parametric faults.
Experimental Investigations of Decentralised Control Design for The Stabilisation of Rotor-Gas Bearings

Rotor-gas bearings are attracting increasing interest because of their high speed capabilities, low friction and clean operation. However, hydrostatic rotor-gas bearings show reduced damping characteristics, which makes it challenging to operate the rotating machine at and about the resonance frequencies. Active lubrication of the journal during operations could enhance the damping and stabilisation characteristics of the systems, and this could be achieved by means of stabilising controllers. This paper investigates the feasibility of using reduced order models obtained through Grey-Box identification for the design of stabilising controllers, capable of enabling the active lubrication of the journal. The root locus analysis shows that two different control solutions are feasible for the dampening of the first two eigenfrequencies of the rotor-gas bearing in the horizontal and vertical directions. Hardening and softening $P$-lead controllers are designed based on the models experimentally identified, and salient features of both controllers are discussed. Both controllers are implemented and validated on the physical test rig. Experimental results confirm the validity of the proposed approach.

Fault diagnosis based on controller modification

Detection and isolation of parametric faults in closed-loop systems will be considered in this paper. A major problem is that a feedback controller will in general reduce the effects from variations in the systems including parametric faults on the controlled output from the system. Parametric faults can be detected and isolated using active methods, where an auxiliary input is applied. Using active methods for the diagnosis of parametric faults in closed-loop systems, the amplitude of the applied auxiliary input need to be increased to be able to detect and isolate the faults in a reasonable time. A negative effect of increasing the amplitude of the auxiliary input is that the disturbances in the external output will be increased and consequently reduce the closed-loop performance. This problem can be handled by using a modification of the feedback controller. Applying the YJBK-parameterization (after Youla, Jabr, Bongiorno and Kucera) for the controller, it is possible to modify the feedback controller with a minor effect on the closed-loop performance in the fault-free case and at the same time optimize the detection and isolation in a faulty case. Controller modification in connection with both fault detection and isolation will be discussed. Also passive fault diagnosis methods based on controller modification will be discussed.
Fault Tolerance for Industrial Actuators in Absence of Accurate Models and Hardware Redundancy

This paper investigates Fault-Tolerant Control for closed-loop systems where only coarse models are available and there is lack of actuator and sensor redundancies. The problem is approached in the form of a typical servomotor in closed-loop. A linear model is extracted from input/output data to describe the system over a frequency range. Two methods based on the Kalman Filter and Statistical Change Detection techniques are proposed for detecting degradation faults and component failures, respectively. Finally, a reference correction setup is used to compensate for degradation faults.

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Contributors: Papageorgiou, D., Blanke, M., Niemann, H. H., Richter, J. H.
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Gas Bearing Control for Safe Operation in Critical Speed Regions - Experimental Verification: Paper

Gas bearings are popular for their high speed capabilities, low friction and clean operation, but require low clearances and suffer from poor damping properties. The poor damping properties cause high disturbance amplification near the natural frequencies. These become critical when the rotation speed coincides with a natural frequency. In these regions, even low mass unbalances can cause rub and damage the machine. To prevent rubbing, the variation of the rotation speed of machines supported by gas bearings has to be carefully conducted during run-ups and run-downs, by acceleration and deceleration patterns and avoidance of operation near the critical speeds, which is a limiting factor during operation, specially during run-downs. An approach for reducing the vibrations is by feedback controlled lubrication. This paper addresses the challenge of reducing vibrations in rotating machines supported by gas bearings to extend their operating range. Using H∞-design methods, active lubrication techniques are proposed to enhance the damping, which in turn reduces the vibrations to a desired safe level. The control design is validated experimentally on a laboratory test rig, and shown to allow safe shaft rotation speeds up to, in and above the two first critical speeds, which significantly extends the operating range.

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Identifying parameters in active magnetic bearing system using LFT formulation and Youla factorization

In this paper, a method for identifying uncertain parameters in a rotordynamic system composed of a flexible rotating shaft, rigid discs and two radial active magnetic bearings is presented. Shaft and disc dynamics are mathematically described using a Finite Element (FE) model while magnetic bearing forces are represented by linear springs with negative stiffness. Bearing negative stiffness produces an unstable rotordynamic system, demanding implementation of feedback control to stabilize the rotordynamic system. Thus, to identify the system parameters, closed-loop system identification techniques are required. The main focus of the paper relies on how to effectively identify uncertain parameters, such as stiffness and damping force coefficients of bearings and seals in rotordynamic systems. Dynamic condensation method, i.e. pseudo-modal reduction, is used to obtain a reduced order model for model-based control design and fast identification. The paper elucidates how nodal parametric uncertainties, which are easily represented in the full FE coordinate system, can be represented in the new coordinate system of the reduced model. The uncertainty is described as a single column vector of the system matrix A of the full FE model while it is represented as several elements spread over multiple rows and columns of the system matrix of the reduced model. The parametric uncertainty, for both the full and reduced FE model, is represented using Linear Fractional Transformation (LFT). In this way the LFT matrices represent the mapping of the uncertainty in and out of the full and reduced FE system matrices. Scaling the LFT matrices easily leads to the amplitudes of the uncertainty parameters. Youla Parametrization method is applied to transform the identification problem into an open-loop stable problem, which can be solved using standard optimization methods. An example shows how to decouple and identify an uncertainty in the linear bearing stiffness of a reduced FE rotordynamic system.

General information

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Modelling and Identification for Control of Gas Bearings

Gas bearings are popular for their high speed capabilities, low friction and clean operation, but suffer from poor damping, which poses challenges for safe operation in presence of disturbances. Enhanced damping can be achieved through active lubrication techniques using feedback control laws. Such control design requires models with low complexity, able to describe the dominant dynamics from actuator input to sensor output over the relevant range of operation. The mathematical models based on first principles are not easy to obtain, and in many cases, they cannot be directly used for control design due to their complexity and parameter uncertainties. As an alternative, this paper presents an experimental technique for “in situ” identification of low complexity models of the entire rotor-bearing-actuator system. Using grey-box identification techniques, the approach is shown to be easily applied to industrial rotating machinery with gas bearings and to allow for subsequent control design. The paper shows how piezoelectric actuators in a gas bearing are efficiently used to perturb the gas film for identification over relevant ranges of rotational speed and gas injection pressure. Parameter-varying linear models are found to capture the dominant dynamics of the system over the range of operation. Based on the identified models, decentralised proportional control is designed and is shown to obtain the required damping in theory as well as in a laboratory test rig.

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On Early Conflict Identification by Requirements Modeling of Energy System Control Structures

Control systems are purposeful systems involving goal-oriented information processing (cyber) and technical (physical) structures. Requirements modeling formalizes fundamental concepts and relations of a system architecture at a high-level design stage and can be used to identify potential design issues early. For requirements formulation of control structures, cyber and physical aspects need to be jointly represented to express interdependencies, check for consistency and discover potentially conflicting requirements. Early identification of potential conflicts may prevent larger problems at later design stages. However, languages employed for requirements modeling today do not offer the expressiveness necessary to represent control purposes in relation to domain level interactions and therefore miss several types of interdependencies. This paper introduces the idea of control structure modeling for early requirements checking using a suitable modeling language, and illustrates how this approach enables the identification of several classes of controller conflict.

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Organisations: Department of Electrical Engineering, Automation and Control, Center for Electric Power and Energy, Energy System Management
Contributors: Heussen, K., Gehrke, O., Niemann, H. H.
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Wind turbine inverter robust loop-shaping control subject to grid interaction effects

An H∞ robust control of wind turbine inverters employing an LCL filter is proposed in this paper. The controller dynamics are designed for selective harmonic filtering in an offshore transmission network subject to parameter perturbations. Parameter uncertainty in the network originates from the grid and the number of wind turbines connected. Power converter based turbines inject harmonic currents, which are attenuated by passive filters. A robust high order active filter controller is proposed to complement the passive filtering. The H∞ design of the control loop enables desired tracking with integral effect while bounding the induced change. The design was tested in an aggregated model of the London Array offshore wind power plant and compared with traditional PI controller designs. Robust stability and performance and a reduction of control effort by 25% are obtained over the full envelope of operation.

Active fault detection in MIMO systems

The focus in this paper is on active fault detection (AFD) for MIMO systems with parametric faults. The problem of design of auxiliary inputs with respect to detection of parametric faults is investigated. An analysis of the design of auxiliary inputs is given based on analytic transfer functions from auxiliary input to residual outputs. The analysis is based on a singular value decomposition of these transfer functions. Based on this analysis, it is possible to design auxiliary input as well as design of the associated residual vector with respect to every single parametric fault in the system such that it is possible to detect these faults.
Active Fault Isolation in MIMO Systems

Active fault isolation of parametric faults in closed-loop MIMO systems are considered in this paper. The fault isolation consists of two steps. The first step is group-wise fault isolation. Here, a group of faults is isolated from other possible faults in the system. The group-wise fault isolation is based directly on the input/output signals applied for the fault detection. It is guaranteed that the fault group includes the fault that had occurred in the system. The second step is individual fault isolation in the fault group. Both types of isolation are obtained by applying dedicated auxiliary inputs and the associated residual outputs.

Adaptive Passivity Based Individual Pitch Control for Wind Turbines in the Full Load Region

This paper tackles the problem of power regulation for wind turbines operating in the top region by an adaptive passivity based individual pitch control strategy. An adaptive nonlinear controller that ensures passivity of the mapping aerodynamic torque-regulation error is proposed, where the inclusion of gradient based adaptation laws allows for the on-line compensation of variations in the aerodynamic torque. The closed-loop equilibrium point of the regulation error dynamics is shown to be UGAS (uniformly globally asymptotically stable). Numerical simulations show that the proposed control strategy succeeds in regulating the power output of the wind turbine despite fluctuations of the wind field due to wake and turbulence, without overloading the pitch actuators.
Application of Constrained Linear MPC to a Spray Dryer

In this paper we develop a linear model predictive control (MPC) algorithm for control of a two stage spray dryer. The states are estimated by a stationary Kalman filter. A non-linear first-principle engineering model is developed to simulate the spray drying process. The model is validated against experimental data and able to precisely predict the temperatures, the air humidity and the residual moisture in the dryer. The MPC controls these variables to the target and reject disturbances. Spray drying is a cost-effective method to evaporate water from liquid foods and produces a free flowing powder. The main challenge of spray drying is to meet the residual moisture specification and prevent powder from sticking to the chamber walls. By simulation we compare the performance of the MPC against the conventional PID control strategy. During an industrially recorded disturbance scenario, the MPC increases the production rate by 7.9%, profit of production by 8.2% and the energy efficiency by 4.1% on average.

A Simple Method for Estimation of Parameters in First order Systems

A simple method for estimation of parameters in first order systems with time delays is presented in this paper. The parameter estimation approach is based on a step response for the open loop system. It is shown that the estimation method does not require a complete step response, only a part of the response and the steady state value of the system before the step is applied. Further, for calculation of the time delay, it is also required that the time for the step is known.
Controller modification applied for active fault detection

This paper is focusing on active fault detection (AFD) for parametric faults in closed-loop systems. This auxiliary input applied for the fault detection will also disturb the external output and consequently reduce the performance of the controller. Therefore, only small auxiliary inputs are used with the result that the detection and isolation time can be long. In this paper it will be shown, that this problem can be handled by using a modification of the feedback controller. By applying the YJBK-parameterization (after Youla, Jabr, Bongiorno and Kucera) for the controller, it is possible to modify the feedback controller with a minor effect on the external output in the fault free case. Further, in the faulty case, the signature of the auxiliary input can be optimized. This is obtained by using a band-pass filter for the YJBK parameter that is only effective in a small frequency range where the frequency for the auxiliary input is selected. This gives that it is possible to apply an auxiliary input with a reduced amplitude. An example is included to show the results.

Economic Optimization of Spray Dryer Operation using Nonlinear Model Predictive Control

In this paper we investigate an economically optimizing Nonlinear Model Predictive Control (E-NMPC) for a spray drying process. By simulation we evaluate the economic potential of this E-NMPC compared to a conventional PID based control strategy. Spray drying is the preferred process to reduce the water content for many liquid foodstuffs and produces a free flowing powder. The main challenge in controlling the spray drying process is to meet the residual moisture specifications.
and avoid that the powder sticks to the chamber walls of the spray dryer. We present a model for a spray dryer that has been validated on experimental data from a pilot plant. We use this model for simulation as well as for prediction in the E-NMPC. The E-NMPC is designed with hard input constraints and soft output constraints. The open-loop optimal control problem in the E-NMPC is solved using the single-shooting method combined with a quasi-Newton Sequential Quadratic Programming (SQP) algorithm and the adjoint method for computation of gradients. The E-NMPC improves the cost of spray drying by 26.7% compared to conventional PI control in our simulations.

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Contributors: Petersen, L. N., Poulsen, N. K., Niemann, H. H., Utzen, C., Jørgensen, J. B.
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Experimental Grey Box Model Identification of an Active Gas Bearing
Gas bearings have inherent dynamics that gives rise to low damping and potential instability at certain rotational speeds. Required damping and stabilization properties can be achieved by active flow control if bearing parameters are known. This paper deals with identification of parameters in a dynamic model of an active gas bearing and subsequent control loop design. A grey box model is determined based on experiments where piezo actuated valves are used to perturb the journal and hence excite the rotor-bearing system. Such modelling from actuator to output is shown to efficiently support controller design, in contrast to impact models that focus on resonance dynamics. The identified model is able to accurately reproduce the lateral dynamics of the rotor-bearing system in a desired operating range, in this case around the first two natural frequencies. The identified models are validated and used to design a model-based controller capable of improving the damping of the gas bearing. Experimental impact responses show an increase in damping by a factor nine for the investigated conditions.

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Contributors: Theisen, L. R. S., Pierart Vásquez, F. G., Niemann, H. H., Santos, I., Blanke, M.
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Model based active power control of a wind turbine
In recent decades there has been increasing interest in green energies, of which wind energy is one of the most important. Wind turbines are the most common wind energy conversion systems and are hoped to be able to compete with traditional
power plants in near future. This demands better technology to increase competitiveness of the wind power plants. One way to increase competitiveness of wind power plants is to offer grid services (also called ancillary services) that are normally offered by traditional power plants. One of the ancillary services is called reserve power. There are instants in the electricity market that selling the reserve power is more profitable than producing with the full capacity. Therefore wind turbines can be down-regulated and sell the differential capacity as the reserve power. In this paper we suggest a model based approach to control wind turbines for active power reference tracking. We use model predictive control (MPC) as our control method. We compare three different control strategies, namely Max-Ω, Constant-Ω and Constant-λ and discuss their drawbacks and benefits by presenting analysis of the steady state operating points and simulations on a high fidelity wind turbine model.

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Contributors: Mirzaei, M., Soltani, M., Poulsen, N. K., Niemann, H. H.
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**Modelling of Rotor-gas bearings for Feedback Controller Design**
Controllable rotor-gas bearings are popular owing adaptability, high speed operation, low friction and clean operation. Rotor-gas bearings are however highly sensitive to disturbances due to the low friction of the injected gas. These undesirable damping properties call for controllers, which can be designed from suitable models describing the relation from actuator input to measured shaft position. Current state of the art models of controllable gas bearings however do not provide such relation, which calls for alternative strategies. The present contribution discusses the challenges for feedback controller design using the state of the art method, and an alternative data driven modelling approach is pursued based on Grey-Box system identification. The method allows development of models of the rotor-gas bearing suitable for controller design, which can be identified from data over the range of operation and are shown to accurately describe the dynamical behaviour of the rotor-gas bearing. Design of a controller using the identified models is treated and experiments verify the improvement of the damping properties of the rotor-gas bearing.

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A Grey-Box Model for Spray Drying Plants

Multi-stage spray drying is an important and widely used unit operation in the production of food powders. In this paper we develop and present a dynamic model of the complete drying process in a multi-stage spray dryer. The dryer is divided into three stages: The spray stage and two fluid bed stages. Each stage is assumed ideally mixed and described by mass- and energy balances. The model is able to predict the temperature, the residual moisture and the particle size in each stage. Process constraints are also proposed to predict deposits due to stickiness of the powder. The model predictions are compared to datasets gathered at GEA Process Engineering’s test facility. The identified grey-box model parameters are identified from data and the resulting model fits the data well. The complexity of the model has been selected such that it is suitable for development of real-time optimization algorithms in an economic optimizing MPC framework.
**Exhaust Gas Recirculation Control for Large Diesel Engines - Achievable Performance with SISO Design**

This paper investigates control possibilities for Exhaust Gas Recirculation (EGR) on large diesel engines. The goal is to reduce the amount of NOx in the exhaust gas by reducing the oxygen concentration available for combustion. Control limitations imposed by the system are assessed using linear analysis of the highly non-linear dynamics. Control architectures are investigated and performance in terms of disturbance rejection and reference tracking are investigated under model uncertainty. Classical feed-forward and feedback controller designs are investigated using classical and Quantitative Feedback Theory (QFT) designs. Validation of the controller is made on the model with focus on disturbance reduction ability.

**Fault tolerant control of systems with saturations**

This paper presents framework for fault tolerant controllers (FTC) that includes input saturation. The controller architecture known from FTC is based on the Youla-Jabr-Bongiorno-Kucera (YJBK) parameterization is extended to handle input saturation. Applying this controller architecture in connection with faulty systems including input saturation gives an additional YJBK transfer function related to the input saturation. In the fault free case, this additional YJBK transfer function can be applied directly for optimizing the feedback loop around the input saturation. In the faulty case, the design problem is a mixed design problem involved both parametric faults and input saturation.

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Contributors: Hansen, J. M., Blanke, M., Niemann, H. H., Vejlgaard-Laursen, M.
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Frequency weighted model predictive control of wind turbine

This work is focused on applying frequency weighted model predictive control (FMPC) on three blade horizontal axis wind turbine (HAWT). A wind turbine is a very complex, non-linear system influenced by a stochastic wind speed variation. The reduced dynamics considered in this work are the rotational degree of freedom of the rotor and the tower for-aft movement. The MPC design is based on a receding horizon policy and a linearised model of the wind turbine. Due to the change of dynamics according to wind speed, several linearisation points must be considered and the control design adjusted accordingly. In practice is very hard to measure the effective wind speed, this quantity will be estimated using measurements from the turbine itself. For this purpose stationary predictive Kalman filter has been used. Stochastic simulations of the wind turbine behaviour with applied frequency weighted model predictive controller are presented. Statistical comparison between frequency weighted MPC, standard MPC and baseline PI controller is shown as well.

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Organisations: Department of Applied Mathematics and Computer Science, Dynamical Systems, Department of Electrical Engineering, Automation and Control, Slovak University of Technology
Contributors: Klauco, M., Poulsen, N. K., Mirzaei, M., Niemann, H. H.
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Model Predictive Control of Wind Turbines using Uncertain LIDAR Measurements

The problem of Model predictive control (MPC) of wind turbines using uncertain LIDAR (LIght Detection And Ranging) measurements is considered. A nonlinear dynamical model of the wind turbine is obtained. We linearize the obtained nonlinear model for different operating points, which are determined by the effective wind speed on the rotor disc. We take the wind speed as a scheduling variable. The wind speed is measurable ahead of the turbine using LIDARs, therefore, the scheduling variable is known for the entire prediction horizon. By taking the advantage of having future values of the scheduling variable, we simplify state prediction for the MPC. Consequently, the control problem of the nonlinear system is simplified into a quadratic programming. We consider uncertainty in the wind propagation time, which is the traveling time of wind from the LIDAR measurement point to the rotor. An algorithm based on wind speed estimation and measurements from the LIDAR is devised to find an estimate of the delay and compensate for it before it is used in the controller. Comparisons between the MPC with error compensation, the MPC without error compensation and an MPC with re-linearization at each sample point based on wind speed estimation are given. It is shown that with appropriate signal processing techniques, LIDAR measurements improve the performance of the wind turbine controller.

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Plant-wide dynamic and static optimisation of supermarket refrigeration systems

Optimising the operation of a supermarket refrigeration system under dynamic as well as steadystate conditions is addressed in this paper. For this purpose an inappropriate performance function that encompasses food quality, system efficiency, and also component reliability is established. The choice of setup parameters, which are necessary for system
performance optimisation, depends on whether the system operates under steady state or dynamic conditions. While operating under steady state conditions, the total system performance is shown to predominantly be influenced by the suction pressure. The dynamic optimisation requires use of dedicated excitation signals. A method for designing such signals under realistic operational conditions is proposed. A derivative free optimisation technique based on Invasive Weed Optimisation (IWO) is utilised to optimise the parameters of the controllers in the system. Simulation results is used to substantiate the suggested methodology.

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The Potential of Economic Model Predictive Control for Spray Drying Plants
In 2015 the milk quota system in the European Union will be completely liberalized. As a result, analysts expect production of skimmed and whole milk powder to increase by 5-6% while its price will decline by about 6-7%. Multi-stage spray drying is the prime process for the production of food powders. The process is highly energy consuming and capacity depends among other factors on correct control of the dryer. Consequently efficient control and optimization of the spray drying process has become increasingly important to accommodate the future market challenges.

The goal of the presentation is to present our results regarding modeling of the process and how the efficiency and probability can be lifted by introducing an economic optimizing MPC scheme.

Firstly, we develop a first-principle engineering model that can be used to simulate spray drying processes with high accuracy. The model can be adjusted to describe drying of various products and describes the complete drying process of a multi-stage spray dryer. The dryer is divided into three stages, the spray stage and two uid bed stages. Each stage is assumed ideally mixed and described by mass- and energy balances. The model is able to predict outlet temperatures, the residual moisture and particle size of the product. We also give a novel approach to predict deposits due to stickiness of the powder. The model predictions are compared to datasets gathered at GEA Process Engineering's test facility. The identified model parameters are identified from data and the resulting model is the data well.

Secondly, the effect of disturbances, ambient air humidity and solids content in the feed, is studied by simulation. We show that conventional control is insufficient at controlling the product quality as well as driving the plant to the most economic conditions. Furthermore, we show that the efficiency can be increased by correct adjustment of heat and inlet air ow at each stage.

The recent focus in research has shifted from reference tracking MPC to optimization of economic objective functions. We will discuss how this optimization can be performed by advanced process control techniques, such as Economic Model Predictive Control (E-MPC). We suggest adding an E-MPC based supervisory control layer on top of the contemporary PI-controllers. The strong interconnection between drying stages and process onstraints are well suited for MPC.

General information
A model-based approach to fault-tolerant control

A model-based controller architecture for Fault-Tolerant Control (FTC) is presented in this paper. The controller architecture is based on a general controller parameterization. The FTC architecture consists of two main parts, a Fault Detection and Isolation (FDI) part and a controller reconfiguration part. The theoretical basis for the architecture is given followed by an investigation of the single parts in the architecture. It is shown that the general controller parameterization is central in connection with both fault diagnosis as well as controller reconfiguration. Especially in relation to the controller reconfiguration part, the application of controller parameterization results in a systematic technique for switching between different controllers. This also allows controller switching using different sets of actuators and sensors.

Designing Trailing Edge Flaps of Wind Turbines using an Integrated Design Approach

In this paper designing a controller for trailing edge flaps (TEF) as well as optimizing its position on the wind turbine blade will be considered. An integrated design approach will be used to optimize both TEF placement and controller simultaneously. Youla parameterization will be used to parameterize the controller and the plant. The goal is to maximize blade root bending moments while minimizing actuator activity. An optimization with linear matrix inequalities (LMI) constraints will be used to optimize the H1 norm of the system.
Fault diagnosis of a Wind Turbine Rotor using a Multi-blade Coordinate Framework

Fault diagnosis of a wind turbine rotor is considered. The faults considered are sensor faults and blades mounted with a pitch offset. A fault at a single blade will result in asymmetries in the rotor, which can be applied for fault diagnosis. The diagnosis is derived by using the multiblade coordinate (MBC) transformation also known as the Coleman transformation together with active fault diagnosis (AFD). This transforms the setup from rotating to fixed frame coordinates. The rotor speed acts as the auxiliary input for the active diagnosis. The applied method takes the varying rotor speed into account. Operation at different mean wind speeds is examined and it is discussed how to exploit the findings acquired by the investigation of the various faults.

Individual Pitch Control Using LIDAR Measurements

In this work the problem of individual pitch control of a variable-speed variable-pitch wind turbine in the full load region is considered. Model predictive control (MPC) is used to solve the problem. However as the plant is nonlinear and time varying, a new approach is proposed to simplify the optimization problem. Nonlinear dynamics of the wind turbine is derived by combining blade element momentum (BEM) theory and first principle modeling of the flexible structure. Then the nonlinear model of the system is linearized using Taylor series expansion around its operating points and a family of linear models are obtained. The operating points are determined by LIDAR measurements both for the current and predicted future operating points. The obtained controller is applied on a full complexity, high fidelity wind turbine model. Finally simulation results show improved load reduction on out-of-plane blade root bending moments and a better transient response compared to a benchmark PI individual pitch controller.
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Model Predictive Control of a Nonlinear System with Known Scheduling Variable
Model predictive control (MPC) of a class of nonlinear systems is considered in this paper. We will use Linear Parameter Varying (LPV) model of the nonlinear system. By taking the advantage of having future values of the scheduling variable, we will simplify state prediction. Consequently the control problem of the nonlinear system is simplified into a quadratic programming. Wind turbine is chosen as the case study and we choose wind speed as the scheduling variable. Wind speed is measurable ahead of the turbine, therefore the scheduling variable is known for the entire prediction horizon.

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Research > peer-review

Monitoring of a Wind Turbine Rotor using a Multi-blade Coordinate Framework
In this paper a method to detect asymmetric faults in a wind turbine rotor is presented. The paper describes how fault diagnosis using an observer-based residual generator approach is able to distinguish between the nominal and faulty case by the injection of e.g. a sinusoidal excitation signal into the system. In the case of a wind turbine, an excitation signal is automatically generated by the rotation of the rotor in a turbulent wind field. Using the multi-blade coordinate transformation, the detection of asymmetries in the rotor of the wind turbine is greatly improved.

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Operation Design of Wind Turbines in Strong Wind Conditions

In order to reduce the impact on the electrical grid from the shutdown of MW wind turbines at wind speeds higher than the cut-out wind speed of 25 m/s, we propose in this paper to run the turbines at high wind speeds up to 40 m/s. Two different operation designs are made for both constant speed and variable speed pitch regulated wind turbines. The variable speed design is more suitable for wind turbines to run at very high wind speeds which can help the turbine braking system to stop the turbine at the new "cut-out" wind speed. Reference power, rotational speed and pitch angle have been designed optimally. In order to reduce the possible increased loading, fatigue due to the wind gusts, control strategies have been considered for both constant speed and variable speed pitch regulated wind turbines. The control study shows that the designed controllers can reduce the standard deviations efficiently for wind turbines at some selected wind high speeds.

Optimising performance in steady state for a supermarket refrigeration system

Using a supermarket refrigeration system as an illustrative example, the paper postulates that by appropriately utilising knowledge of plant operation, the plant wide performance can be optimised based on a small set of variables. Focusing on steady state operations, the total system performance is shown to predominantly be influenced by the suction pressure. Employing appropriate performance function leads to conclusions on the choice of set-point for the suction pressure that are contrary to the existing practice. Analysis of the resulting data leads to a simple method for finding optimal pressure set-point for given load situations.
Plant-wide performance optimisation – The refrigeration system case
This paper investigates the problem of plant-wide performance optimisation seen from an industrial perspective. The refrigeration system is used as a case study, because it has a distributed control architecture and operates in steady state conditions, which is common for many industrial applications in the process industry. The paper addresses the fact that dynamic performance of the system is important, to ensure optimal changes between different operation conditions. To enable optimisation of the dynamic controller behaviour a method for designing the required excitation signal is presented. Furthermore, invasive weed optimisation is used to find the optimal parameters for local controllers based on the plant wide performance measure.

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Robust Model Predictive Control of a Nonlinear System with Known Scheduling Variable and Uncertain Gain
Robust model predictive control (RMPC) of a class of nonlinear systems is considered in this paper. We will use Linear Parameter Varying (LPV) model of the nonlinear system. By taking the advantage of having future values of the scheduling variable, we will simplify state prediction. Because of the special structure of the problem, uncertainty is only in the B matrix (gain) of the state space model. Therefore by taking advantage of this structure, we formulate a tractable minimax optimization problem to solve robust model predictive control problem. Wind turbine is chosen as the case study and we choose wind speed as the scheduling variable. Wind speed is measurable ahead of the turbine, therefore the scheduling variable is known for the entire prediction horizon.

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Robust Model Predictive Control of a Wind Turbine

In this work the problem of robust model predictive control (robust MPC) of a wind turbine in the full load region is considered. A minimax robust MPC approach is used to tackle the problem. Nonlinear dynamics of the wind turbine are derived by combining blade element momentum (BEM) theory and first principle modeling of the turbine flexible structure. Thereafter the nonlinear model is linearized using Taylor series expansion around system operating points. Operating points are determined by effective wind speed and an extended Kalman filter (EKF) is employed to estimate this. In addition, a new sensor is introduced in the EKF to give faster estimations. Wind speed estimation error is used to assess uncertainties in the linearized model. Significant uncertainties are considered to be in the gain of the system (B matrix of the state space model). Therefore this special structure of the uncertain system is employed and a norm-bounded uncertainty model is used to formulate a minimax model predictive control. The resulting optimization problem is simplified by semidefinite relaxation and the controller obtained is applied on a full complexity, high fidelity wind turbine model. Finally simulation results are presented. First a comparison between PI and robust MPC is given. Afterwards simulations are done for a realization of turbulent wind with uniform profile based on the IEC standard.

A concept for a bachelor program in electrical engineering

The main concept for the Bachelor of Science in Engineering (BScE) in electrical engineering at Technical University of Denmark (DTU) will be described in this paper. A new curriculum was introduced from the start of the autumn semester in 2010. The curriculum was the result of more than one year of work with first description of competences followed by a more detailed description of the single main areas. Finally, the new study plan was implemented through a number of courses satisfying some general rules for bachelor study plans.

A μ-Synthesis Approach to Robust Control of a Wind Turbine

The problem of robust control of a wind turbine is considered in this paper. A set of controllers are designed based on a 2 degrees of freedom linearized model of a wind turbine. An extended Kalman filter is used to estimate effective wind speed and the estimated wind speed is used to find the operating point of the wind turbine. Due to imprecise wind speed estimation, uncertainty in the obtained linear model is considered. Uncertainties in the drivetrain stiffness and damping parameters are also considered as these values are lumped parameters of a distributed system and therefore they include inherent uncertainties. We include these uncertainties as parametric uncertainties in the model and design robust controllers using the DK-iteration method. Based on estimated wind speed a pair of controllers are chosen and convex combination of their outputs is applied to the plant. The resulting set of controllers is applied on a full complexity simulation model and simulations are performed for stochastic wind speed according to relevant IEC standard.
Constraint Handling within a Multi-blade Coordinate Framework of a Wind Turbine

In this paper, the control of a horizontal axis pitch controlled wind turbine using Model Predictive Control is presented. The multi-blade coordinate transformation is utilized to turn the rotating frame time-varying system description into a time-invariant fixed frame system description. Constraints in the rotating frame of reference are not easily described in the fixed frame and a Model Predictive Control formulation accommodating this problem is presented. The presented method is tested with satisfactory results in a numerical simulation.

Design of excitation signals for active system monitoring in a performance assessment setup

This paper investigates how the excitation signal should be chosen for an active performance setup. The signal is used in a setup where the main purpose is to detect whether a parameter change of the controller has changed the global performance significantly. The signal has to be able to excite the dynamics of the subsystem under investigation both before and after the parameter change. The controller is well known, but there exists no detailed knowledge about the dynamics of the subsystem.
Detecting asymmetries in the rotor of a wind turbine using the multi-blade coordinate transformation

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DK-iteration robust control design of a wind turbine
The problem of robust control of a wind turbine is considered in this paper. A controller is designed based on a 2 degrees of freedom linearized model. An extended Kalman filter is used to estimate effective wind speed and the estimated wind speed is used to find the operating point of the wind turbine. Due to imprecise wind speed estimation, uncertainty in the obtained linear model is considered. Uncertainties in the drivetrain stiffness and damping parameters are also considered as these values are lumped parameters of a distributed system and therefore they include inherent uncertainties. We include these uncertainties as parametric uncertainties in the model and design a robust controller using DK-iteration method. The controller is applied on a full complexity simulation model and simulations are performed for wind speed step changes.

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H∞ Control of a Wind Turbine
Performance improvement clarification for refrigeration system using active system monitoring

This paper addresses the problem of determining whether a refrigeration plant has the possibility of delivering a better performance of the operation. The controllers are well-known but detailed knowledge about the underlying dynamics of the refrigeration plant is not available. Thus, the question is if it is possible to achieve a better performance by changing the controller parameter. An approach to active system monitoring, based on active fault diagnosis techniques, is employed in order to evaluate changes in the system performance under operation.

Robust stability in constrained predictive control through the Youla parameterisations

In this article we take advantage of the primary and dual Youla parameterisations to set up a soft constrained model predictive control (MPC) scheme. In this framework it is possible to guarantee stability in face of norm-bounded uncertainties. Under special conditions guarantees are also given for hard input constraints. In more detail, we parameterise the MPC predictions in terms of the primary Youla parameter and use this parameter as the on-line optimisation variable. The uncertainty is parameterised in terms of the dual Youla parameter. Stability can then be guaranteed through small gain arguments on the loop consisting of the primary and dual Youla parameter. This is included in the MPC optimisation as a constraint on the induced gain of the optimisation variable. We illustrate the method with a numerical simulation example.
Active fault diagnosis by controller modification

Two active fault diagnosis methods for additive or parametric faults are proposed. Both methods are based on controller reconfiguration rather than on requiring an exogenous excitation signal, as it is otherwise common in active fault diagnosis. For the first method, it is assumed that the system considered is controlled by an observer-based controller. The method is then based on a number of alternate observers, each designed to be sensitive to one or more additive faults. Periodically, the observer part of the controller is changed into the sequence of fault sensitive observers. This is done in a way that guarantees the continuity of transition and global stability using a recent result on observer parameterization. An illustrative example inspired by a field study of a drag racing vehicle is given. For the second method, an active fault diagnosis method for parametric faults is proposed. The method periodically adds a term to the controller that for a short period of time renders the system unstable if a fault has occurred, which facilitates rapid fault detection. An illustrative example is given.

Active Sensor Configuration Validation for Refrigeration Systems

Major faults in the commissioning phase of refrigeration systems are caused by defects related to sensors. With a number of similar sensors available that do not differ by type but only by spatial location in the plant, interchange of sensors is a common defect. With sensors being used quite differently by the control system, fault-finding is difficult in practice and defects are regularly causing commissioning delays at considerable expense. Validation and handling of faults in the sensor configuration are therefore essential to cut costs during commissioning. With passive fault-diagnosis methods falling short on this problem, this paper suggests an active diagnosis procedure to isolate sensor faults at the
commissioning stage, before normal operation has started. Using statistical methods, residuals are evaluated versus multiple hypothesis models in a minimization process to uniquely identify the sensor configuration. The method as such is generic and is shown in the paper to work convincingly on refrigeration systems with significant nonlinear behaviors.

**A model-based approach for fault-tolerant control**

A model-based controller architecture for fault-tolerant control (FTC) is presented in this paper. The controller architecture is based on the Youla-Jabr-Bongiorno-Kucera (YJBK) parameterization. The FTC architecture consists of two central parts, fault detection and isolation (FDI) part and a controller reconfiguration part. The theoretical basis for the architecture will be given followed by an investigation of the single parts in the architecture. At last, system interconnection will be considered with respect to the described controller architecture.

**Control switching in high performance and fault tolerant control**

The problem of reliability in high performance control and in fault tolerant control is considered in this paper. A feedback controller architecture for high performance and fault tolerance is considered. The architecture is based on the Youla-Jabr-Bongiorno-Kucera (YJBK) parameterization. By using the nominal controller in the architecture as a simple and robust controller, it is possible to use the YJBK transfer function for optimization of the closed-loop performance. This can be done both in connections with normal operation of the system as well as in connection with faults in the system. The architecture will also allow changing the applied sensors and/or actuators when switching between different controllers. This switching gets particular simple for open-loop stable systems.
On the choice of performance assessment criteria and their impact on the overall system performance: The refrigeration system case study

The aim of this paper is to illuminate the impact of the choice of a system’s performance criteria on the quality of the corresponding monitoring system’s assessment results. Special attention is given to the performance issues that are caused by or can be solved by control actions. The compressor capacity gap issue in the supermarket refrigeration systems is used as a case study to elaborate on the problem through employment of both real life field data as well as simulation data. A performance function that can capture the compressor capacity gap problem is presented in the paper and used to evaluate both data from the real supermarket system and the data generated by the simulation model.

Robust stability in predictive control with soft constraints

In this paper we take advantage of the primary and dual Youla parameterizations for setting up a soft constrained model predictive control (MPC) scheme for which stability is guaranteed in face of norm-bounded uncertainties. Under special conditions guarantees are also given for hard input constraints. In more detail, we parameterize the MPC predictions in terms of the primary Youla parameter and use this parameter as the online optimization variable. The uncertainty is parameterized in terms of the dual Youla parameter. Stability can then be guaranteed through small gain arguments on the loop consisting of the primary and dual Youla parameter. This is included in the MPC optimization as a constraint on the induced gain of the optimization variable. We illustrate the method with a numerical simulation example.

Stochastic wind turbine control in multiblade coordinates

In this paper we consider wind turbine load attenuation through model based control. Asymmetric loads caused by the wind field can be reduced by pitching the blades individually. To this end we investigate the use of stochastic models of the wind which can be included in a model based individual pitch controller design. In this way the variability of the wind can be estimated and compensated for by the controller. The wind turbine model is in general time-variant due to its rotational nature. For this reason the modeling and control is carried out in so-called multiblade coordinates. A controller based on the H2 methodology is designed and tested in simulations.
A Concept for fault tolerant controllers
This paper describes a concept for fault tolerant controllers (FTC) based on the YJBK (after Youla, Jabr, Bongiorno and Kucera) parameterization. This controller architecture will allow to change the controller on-line in the case of faults in the system. In the described FTC concept, a safe mode controller is applied as the basic feedback controller. A controller for normal operation with high performance is obtained by including certain YJBK parameters (transfer functions) in the controller. This will allow a fast switch from normal operation to safe mode operation in case of critical faults in the system. The described FTC architecture allows the different feedback controllers to apply different sets of sensors and actuators.

Active Fault Diagnosis - A Stochastic Approach

Active Fault Diagnosis for Systems with Reduced Model Information
Active Fault Isolation and Estimation

Active system monitoring applied on wind turbines

Attenuating wind turbine loads through model based individual pitch control
Controller Architectures for Switching
This paper investigates different controller architectures in connection with controller switching. The controller switching is derived by using the Youla-Jabr-Bongiorno-Kucera (YJBK) parameterization. A number of different architectures for the implementation of the YJBK parameterization are described and applied in connection with controller switching. An architecture that does not include inversion of the coprime factors is introduced. This architecture will make controller switching particularly simple.

Fault tolerant control - a residual based set-up
A new set-up for fault tolerant control (FTC) for stable systems is presented in this paper. The new set-up is based on a simple implementation of the Youla-Jabr-Bongiorno-Kucera (YJBK) parameterization. This implementation of the YJBK parameterization will allow a direct and simple reconfiguration of the feedback controller. Another central part of fault tolerant control is fault diagnosis. The controller implementation can be applied directly in connection with both passive diagnosis (PFD) as well as with active fault diagnosis (AFD). The presented FTC set-up is investigated with respect to sensor reconfiguration. Actuator reconfiguration can be dealt with in a similar way.
Interconnection of subsystems in closed-loop systems

The focus in this paper is analysis of stability and controller design for interconnected systems. This includes both the case with known and unknown interconnected sub-system. The key element in both the stability analysis and controller design is the application of the Youla-Jabr-Bongiorno-Kucera (YJBK) parameterization. The dual YJBK transfer function is applied in connection with the closed-loop stability analysis. The primary YJBK parameterization is applied in connection with design of controllers. Further, it is shown how it is possible to obtain a direct estimation of a connected sub-system without having a direct access to it.

Stochastic wind turbine modeling for individual pitch control

By pitching the blades of a wind turbine individually it is possible to attenuate the asymmetric loads caused by a non-uniform wind field - this is denoted individual pitch control. In this work we investigate how to set up a simplified stochastic and deterministic description of the wind and a simplified description of the aerodynamics with sufficient detail to design model-based individual pitch controllers. Combined with a simplified model of the wind turbine, we exemplify how to use the model elements to systematically design an individual pitch controller. The design is investigated in simulations.
Towards a modern concept for teaching control engineering
A new concept for teaching an introduction course in control engineering is described. The main issue is that the concept is based directly on the students' knowledge from previous courses in math, physics and electronics. This will provide students with a more direct and clear link between these previous courses and the introduction course in control theory. As a direct consequence, it is now possible to introduce and use feedback control from the first lecture. The new teaching concept has had a major effect on the exam results. In the two semesters before the changes, only 53% of the students passed the course. In the first two semesters after the changes, 86% of the students passed the course.

Active fault diagnosis based on stochastic tests
The focus of this paper is on stochastic change detection applied in connection with active fault diagnosis (AFD). An auxiliary input signal is applied in AFD. This signal injection in the system will in general allow us to obtain a fast change detection/isolation by considering the output or an error output from the system. The classical cumulative sum (CUSUM) test will be modified with respect to the AFD approach applied. The CUSUM method will be altered such that it will be able to detect a change in the signature from the auxiliary input signal in an (error) output signal. It will be shown how it is possible to apply both the gain and the phase change of the output signal in CUSUM tests. The method is demonstrated using an example.
Estimation of Model Uncertainties in Closed-loop Systems

This paper describes a method for estimation of parameters or uncertainties in closed-loop systems. The method is based on an application of the dual YJBK (after Youla, Jabr, Bongiorno and Kucera) parameterization of all systems stabilized by a given controller. The dual YJBK transfer function is a measure for the variation in the system seen through the feedback controller. It is shown that it is possible to isolate a certain number of parameters or uncertain blocks in the system exactly. This is obtained by modifying the feedback controller through the YJBK transfer function together with pre- and post-filters. The estimation is then derived using standard methods.

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Individual pitch control of wind turbines using local inflow measurements

This paper describes a model-based control approach for individually adjusting the pitch of wind turbine blades and thereby attenuating the effect of asymmetric wind loads. It is assumed that measurements of local inflow along each blade are available. This effectively provides an estimate of the load distribution along the blades. The load estimates are used in a predictive setup where inflow measured by one blade is used as basis for calculating future loads for the other blades. Simulations with a full stochastic wind field illustrate the effectiveness of the individual pitch controller as compared to controlling the pitch collectively.

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Information Based Fault Diagnosis
Fault detection and isolation, (FDI) of parametric faults in dynamic systems will be considered in this paper. An active fault diagnosis (AFD) approach is applied. The fault diagnosis will be investigated with respect to different information levels from the external inputs to the systems. These inputs are disturbance inputs, reference inputs and auxiliary inputs. The diagnosis of the system is derived by an evaluation of the signature from the inputs in the residual outputs. The changes of the signatures form the external inputs are used for detection and isolation of the parametric faults.

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MPC for uncertain systems using the Youla parameterizations
Several approaches have been taken in the past to deal with uncertainty in constrained predictive control. The major drawbacks of these efforts are usually either conservativeness and/or on-line computational complexity. In this work we examine the possibility of dealing with uncertainty through the use of the primary and the dual Youla parameterizations. The dual Youla parameter can be seen as a frequency weighted measure of the uncertainty and the primary Youla parameter can be seen as a controller for this uncertainty. The work is an application of the methodology in [12] to constraint control.

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A Multi-Model Approach for System Diagnosis
A multi-model approach for system diagnosis is presented in this paper. The relation with fault diagnosis as well as performance validation is considered. The approach is based on testing a number of pre-described models and find which one is the best. It is based on an active approach,i.e. an auxiliary input to the system is applied. The multi-model approach is applied on a wind turbine system.
Stochastic Change Detection based on an Active Fault Diagnosis Approach

The focus in this paper is on stochastic change detection applied in connection with active fault diagnosis (AFD). An auxiliary input signal is applied in AFD. This signal injection in the system will in general allow to obtain a fast change detection/isolation by considering the output or an error output from the system. The classical CUSUM (cumulative sum) method will be modified such that it will be able to detect change in the signature from the auxiliary input signal in the (error) output signal. It will be shown how it is possible to apply both the gain as well as the phase change of the output vector in the CUSUM test.
Active fault diagnosis by temporary destabilization
An active fault diagnosis method for parametric or multiplicative faults is proposed. The method periodically adds a term to the controller that for a short period of time renders the system unstable if a fault has occurred, which facilitates rapid fault detection. An illustrative example is given.

Active fault diagnosis in closed-loop uncertain systems
Fault diagnosis of parametric faults in closed-loop uncertain systems by using an auxiliary input vector is considered in this paper, i.e. active fault diagnosis (AFD). The active fault diagnosis is based directly on the so-called fault signature matrix, related to the YJBK (Youla, Jabr, Bongiorno and Kucera) parameterization. Conditions are given for exact detection and isolation of parametric faults in closed-loop uncertain systems.

A setup for active fault diagnosis
A setup for active fault diagnosis (AFD) of parametric faults in dynamic systems is formulated in this paper. It is shown that it is possible to use the same setup for both open loop systems, closed loop systems based on a nominal feedback controller as well as for closed loop systems based on a reconfigured feedback controller. This will make the proposed AFD approach very useful in connection with fault tolerant control (FTC). The setup will make it possible to let the fault diagnosis part of the fault tolerant controller remain unchanged after a change in the feedback controller. The setup for AFD is based on the YJBK (after Youla, Jabr, Bongiorno and Kucera) parameterization of all stabilizing feedback controllers and the dual YJBK parameterization. It is shown that the AFD is based directly on the dual YJBK transfer function matrix. This matrix will be named the fault signature matrix when it is used in connection with AFD.
Fault isolability conditions for linear systems with additive faults

In this paper, we shall show that an unlimited number of additive single faults can be isolated under mild conditions if a general isolation scheme is applied. Multiple faults are also covered. The approach is algebraic and is based on a set representation of faults, where all faults within a set can occur simultaneously, whereas faults belonging to different fault sets appear disjoint in time. The proposed fault detection and isolation (FDI) scheme consists of three steps. A fault detection (FD) step is followed by a fault set isolation (FSI) step. Here the fault set is isolated wherein the faults have occurred. The last step is a fault isolation (FI) of the faults occurring in a specific fault set, i.e. equivalent with the standard FI step.

Fault tolerant control for uncertain systems with parametric faults

A fault tolerant control (FTC) architecture based on active fault diagnosis (AFD) and the YJBK (Youla, Jarbi, Bongiorno and Kucera) parameterization is applied in this paper. Based on the FTC architecture, fault tolerant control of uncertain systems with slowly varying parametric faults is investigated. Conditions are given for closed-loop stability in case of false alarms or missing fault detection/isolation.
Parameterization of extended systems
The YJBK parameterization (of all stabilizing controllers) is extended to handle systems with additional sensors and/or actuators. It is shown that the closed loop transfer function is still an affine function in the YJBK parameters in the nominal case. Further, some closed-loop stability results are also given for uncertain systems. These results are important in connection with fault tolerant control.

Rapprochement between Active Fault Diagnosis and Change Detection in ARMAX Systems
The connection between AFD (Active Fault Diagnosis), ARMAX systems and RST controllers etc. are considered in this paper. It is shown that the applied setup in modern AFD for closed loop systems can be considered as a generalization of the setup used in connection with traditional methods for system identification and controller design in the polynomial setting.
An architecture for fault tolerant controllers
A general architecture for fault tolerant control is proposed. The architecture is based on the (primary) YJBK parameterization of all stabilizing compensators and uses the dual YJBK parameterization to quantify the performance of the fault tolerant system. The approach suggested can be applied for additive faults, parametric faults, and for system structural changes. The modeling for each of these fault classes is described. The method allows to design for passive as well as for active fault handling. Also, the related design method can be fitted either to guarantee stability or to achieve graceful degradation in the sense of guaranteed degraded performance. A number of fault diagnosis problems, fault tolerant control problems, and feedback control with fault rejection problems are formulated/considered, mainly from a fault modeling point of view. The method is illustrated on a servo example including an additive fault and a parametric fault.

Active fault diagnosis in closed-loop systems
Active fault diagnosis (AFD) of parametric faults is considered in connection with closed loop feedback systems. AFD involves auxiliary signals applied on the closed loop system. A fault signature matrix is introduced in connection with AFD and it is shown that if a limited number of faults can occur in the system, a fault separation in the fault signature matrix can be obtained. Then the single elements in the matrix only depend of a reduced number of parametric faults. This can directly be applied for fault isolation. If it is not possible to obtain this separation, it is shown how the fault signature matrix can be applied for a dynamical fault isolation, i.e. fault isolation based on the dynamic characteristic of the fault signature matrix as function of the different parametric faults.
A fault tolerant control approach for descriptor systems
Fault tolerant control (FTC) of descriptor systems is considered in this paper. A general FTC architecture for descriptor systems is proposed.

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Design and Analysis of Controllers for an Double Inverted Pendulum
A physical control problem is studied with the H_inf and the SSV methodology. The issues of modelling, uncertainty modelling, performance specification, controller design and laboratory implementation are discussed. The laboratory experiment is a double inverted pendulum placed on a cart. The limitations in the system with respect to performance are the limitation in the control signal and the limitation of the movement of the cart. It is shown how these performance limitations will effect the design of H_inf and SSV controllers for the system.

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Fault tolerant control based on active fault diagnosis
An active fault diagnosis (AFD) method will be considered in this paper in connection with a Fault Tolerant Control (FTC) architecture based on the YJBK parameterization of all stabilizing controllers. The architecture consists of a fault diagnosis (FD) part and a controller reconfiguration (CR) part. The FTC architecture can be applied for additive faults, parametric faults, and for system structural changes. Only parametric faults will be considered in this paper. The main focus in this paper is on the use of the new approach of active fault diagnosis in connection with FTC. The active fault diagnosis approach is based on including an auxiliary input in the system. A fault signature matrix is introduced in connection with AFD, given as the transfer function from the auxiliary input to the residual output. This can be considered as a
generalization of the passive fault diagnosis case, where the diagnosis is only based on a residual vector. The fault diagnosis is then derived by on-line tests by using the residual vector.

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**Passive fault tolerant control of a double inverted pendulum - a case study**
A passive fault tolerant control scheme is suggested, in which a nominal controller is augmented with an additional block, which guarantees stability and performance after the occurrence of a fault. The method is based on the YJBK parameterization, which requires the nominal controller to be implemented in observer based form. The proposed method is applied to a double inverted pendulum system, for which an H_inf controller has been designed and verified in a lab setup. In this case study, the fault is a degradation of the tacho loop.

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Fault tolerant control for unstable systems: A linear time varying approach
In (passive) fault tolerant control design, the objective is to find a fixed compensator, which will maintain a suitable performance - or at least stability - in the event that a fault should occur. A major theoretical obstacle to obtain this objective, is that even if the system models corresponding to the occurrence of various faults are simultaneously stabilizable by a linear, time-invariant compensator, this compensator might have to be of very high order, as shown in a recent publication. In this paper, we propose a design procedure for a time-varying compensator, which overcomes the obstacle for any finite number of faults with a controller order of no more than the plant order. The performance of this compensator might be poor, but a heuristic procedure for improving the performance is also shown, and an example demonstrates that this improvement can be truly significant.

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Fault tolerant controllers for sampled-data systems
A general compensator architecture for fault tolerant control (FTC) for sampled-data systems is proposed. The architecture is based on the Youla-Jabr-Bongiorno-Kucera (YJBK) parameterization of all stabilizing controllers, and uses the dual YJBK parameterization to quantify the performance of the fault tolerant system. The FTC architecture is based on a discrete-time nominal feedback controller and with the FTC part also in discrete-time. Further, a number of problems for the design of the controller reconfiguration part in the FTC architecture is considered. It is shown how these design problems can be transformed into standard design problems for feedback controllers.

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Contributors: Niemann, H. H., Stoustrup, J.
Publication date: 2004

Switching Between Multivariable Controllers
A concept for implementation of multivariable controllers is presented in this paper. The concept is based on the Youla-Jabr-Bongiorno-Kucera (YJBK) parameterization of all stabilizing controllers. By using this architecture for implementation of multivariable controllers, it is shown how it is possible to smoothly switch between multivariable controllers with guaranteed closed-loop stability. This includes also the case where one or more controllers are unstable. The concept for smooth online changes of multivariable controllers based on the YJBK architecture can also handle the start up and shut down of multivariable systems. Furthermore, the start up of unstable multivariable controllers can be handled as well. Finally, implementation of (unstable) controllers as a stable Q parameter in a Q-parameterized controller can also be achieved.

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Research output: Chapter in Book/Report/Conference proceeding – Article in proceedings – Annual report year: 2004

Controller reconfiguration based on LTR design
Design of controller reconfiguration (CR) for systems with sensor faults are considered in this paper. One way to accommodate a failing sensor, is by replacing it by an observer based on the remaining outputs. A similar approach can be applied for a faulty actuator by duality. By including observers in the loop to replace faulty components, the nominal feedback controller does not need to be redesigned. The CR observer design problem for the faulty sensors or actuators can be rewritten into a standard loop transfer recovery (LTR) design problem, to which standard LTR design methods can be applied. Finally, it is shown that this CR architecture, where an CR observer is included in the feedback loop in between the system and the nominal controller, can be transformed into a more general fault tolerant controller (FTC) architecture based on the Youla parameterization.

Dual Youla parameterization
A different aspect of using the parameterisation of all systems stabilised by a given controller, i.e. the dual Youla parameterisation, is considered. The relation between system change and the dual Youla parameter is derived in explicit form. A number of standard uncertain model descriptions are considered and the relation with the dual Youla parameter given. Some applications of the dual Youla parameterisation are considered in connection with the design of controllers and model/performance validation.
Iterative Identification for Control and Robust Performance of Bioreactor

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Optimal threshold functions for fault detection and isolation

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Passitive fault tolerant control of an inverted double pendulum - A case study example

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Structural Analysis - A case study of the Rømer Satellite

Spacecraft systems increase in functionality and complexity. At the same time, requirements increase to autonomy in order to cut expensive ground station support. Complexity and autonomy combine to a problem that is very difficult to analyze by traditional means. Structural analysis is a tool that in theory has the potential to cope with this complexity, but the technique is not yet in widespread use. This paper shows how structural analysis can be used in practice to aid in the design of the autonomy related parts of an entire spacecraft subsystem.

Applying parameteric fault detection to a mechanical system

Detection of parametric faults
Fault estimation - A standard problem approach
This paper presents a range of optimization based approaches to fault diagnosis. A variety of fault diagnosis problems are reformulated in the so-called standard problem set-up introduced in the literature on robust control. Once the standard problem formulations are given, the fault diagnosis problems can be solved by standard optimization techniques. The proposed methods include (1) fault diagnosis (fault estimation, (FE)) for systems with model uncertainties; FE for systems with parametric faults, and FE for a class of nonlinear systems. Copyright
Performance based fault diagnosis

Different aspects of fault detection and fault isolation in closed-loop systems are considered. It is shown that using the standard setup known from feedback control, it is possible to formulate fault diagnosis problems based on a performance index in this general standard setup. It is also shown that feedback controllers can be applied directly as residual generators in some cases.

Reliable control using the primary and dual Youla parameterizations

Different aspects of modeling faults in dynamic systems are considered in connection with reliable control (RC). The fault models include models with additive faults, multiplicative faults and structural changes in the models due to faults in the systems. These descriptions are considered in connection with reliable control and feedback control with fault rejection. The main emphasis is on fault modeling. A number of fault diagnosis problems, reliable control problems, and feedback control with fault rejection problems are formulated/considered, again, mainly from a fault modeling point of view. Reliability is introduced by means of the (primary) Youla parameterization of all stabilizing controllers, where an additional loop is closed around a diagnostic signal. In order to quantify the level of reliability, the dual Youla parameterization is introduced which can be used to analyze how large faults can be tolerated without losing, e.g., stability.
Robust control, fault diagnosis and fault tolerant control - a standard setup approach

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Rømer Subsystem Analysis for Fault Detection Design

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Towards high performance in industrial refrigeration systems

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Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 2002 › Research › peer-review
Fault diagnosis for non-minimum phase systems using $\mathcal{H}_\infty$ optimization

The analysis and design algorithms for residual generators for nonminimum phase systems are given. It is shown that the $\mathcal{H}_\infty$ optimization of residual generators applied directly to systems including nonminimum phase zeros can be very conservative. To remove this conservatism in the $\mathcal{H}_\infty$ optimization of the residual generators, a factorization of the nonminimum phase system into a minimum phase part and an all-pass factor including the nonminimum phase zeros can be applied. The optimization of the residual generator can then be done with respect to the minimum phase part of the system only. It is shown that the effect from the all-pass factor will not affect the $2$-norm of the residual vector.

Fault tolerant feedback control using the Youla parameterization

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Faults in fault detection and isolation

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Application of an H\textsubscript{\textinfty} based FDI and control scheme for the three tank system

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Design of fault detectors using H\textsubscript{\textinfty} optimization
The problem of detecting and/or isolating faults in dynamical systems is assessed. In contrast to previous approaches, the residual vector is considered to be a design variable as a free transfer function in addition to the actual filter which is supposed to minimize the residual. Some main directions are suggested, and a numerical algorithm implementing part of these is proposed.

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Editorial - special issue on fault detection and identification

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Fundamental problems in fault detection and identification
A number of different fundamental problems in fault detection and fault identification are formulated in this paper. The fundamental problems include exact, almost, generic and class-wise fault detection and identification. Necessary and sufficient conditions for the solvability of the fundamental problems are derived. These conditions are weaker than the ones found in the literature since we do not assume any particular structure for the residual generator. At the end of the paper, a time domain synthesis procedure based on state-space methods to construct appropriate residual generators is given. Copyright (C) 2000 John Wiley & Sons, Ltd.

Optimal fault estimation
This paper describes the application of the Youla parameterization of all stabilizing controllers and the dual Youla parameterization of all systems stabilized by a given controller in connection with tuning of controllers. In the uncertain
An architecture for implementation of multivariable controllers


References Cited: 7 INSPEC Accession Number: 6403075 Digital Object Identifier : 10.1109/ACC.1999.786292 Date of Current Version : 06 august 2002 Abstract An architecture for implementation of multivariable controllers is presented in this paper. The architecture is based on the Youla-Jabr-Bongiorno-Kucera parameterization of all stabilizing controllers. By using this architecture for implementation of multivariable controllers, it is shown how it is possible to change from one multivariable controller to another multivariable controller online in a smooth way with guarantee for closed loop stability. This includes also the case where the controllers are unstable. Gain scheduled controllers can be implemented in this architecture. The general architecture for smooth online changes of multivariable controllers can also handle the start up and close down of multivariable systems. Furthermore, the start up of unstable multivariable controllers can also be handled in this architecture. Finally, implementation of (unstable) controllers as a stable Q parameter in a Q-parameterized controller can also be achieved.
Application of the dual Youla parameterization

Different applications of the parameterization of all systems stabilized by a given controller, i.e. the dual Youla parameterization, are considered in this paper. It will be shown how the parameterization can be applied in connection with controller design, adaptive controllers, model validation and fault detection. Further, some of the limitation in connection with the parameterization are also investigated.

Dynamic orders of decentralized $H_{\infty}$ controllers

Exact, almost and delayed fault detection: an observer based approach

Considers the problem of fault detection and isolation while using zero or almost zero threshold. A number of different fault detection and isolation problems using exact or almost exact disturbance decoupling are formulated. Solvability conditions are given for the formulated design problems. The I-step delayed fault detection problem is also considered for discrete-time systems.
Gain scheduling using the Youla parameterization

Gain scheduling controllers are considered in this paper. The gain scheduling problem where the scheduling parameter vector cannot be measured directly, but needs to be estimated is considered. An estimation of the scheduling vector has been derived by using the Youla parameterization. The use of the Youla parameterization in connection with estimation of the vector directly gives a validation method for the estimate of the vector. The validation part is an integrated part of the estimation method. This will make it possible to estimate the parameter vector very precisely. This is important in connection with $H_{\infty}$ gain scheduling controllers.

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Norm based design of fault detectors

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An application of LTR design in fault detection

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Fault detection for nonlinear systems - A standard problem approach

Multi Objective Design Techniques applied to Fault Detection and Isolation

Static Decoupling in fault detection
Design of integrated systems for control and detection of actuator/sensor faults.

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Organisations: Department of Automation, Aalborg University, University of Strathclyde
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Fault detection using (PI) observers.

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Integration of control and fault detection: Nominal and robust design.

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Multi Objective Control for Multivariable Systems with Mixed Sensitivity Specifications

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Publication status: Published
Organisations: Department of Mathematics
Contributors: Niemann, H. H., Stoustrup, J.
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Publication date: 1997
Near optimal decentralized H∞ control: Bounded vs. unbounded controller orders.

Robust fault detection in open loop vs. closed loop
The robustness aspects of fault detection and isolation (FDI) for uncertain systems are considered. The FDI problem is considered in a standard problem formulation. The FDI design problem is analyzed both in the case where the control input signal is considered as a known external input signal (open loop) and when the input signal is generated by a feedback controller.

Starting up unstable multivariable controllers safety.
μ-synthesis for the coupled mass benchmark problem

A robust controller design for the coupled mass benchmark problem is presented in this paper. The applied design method is based on a modified D-K iteration, i.e. μ-synthesis which take care of mixed real and complex perturbations sets. This μ-synthesis method for mixed perturbation sets is a straightforward extension of the standard D-K iteration for complex perturbation sets.

An LMI Approach to Fixed Order LTR Controller

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An LMI approach to fixed order LTR controller

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Design of Integrated Devices for Control and Detection of Actuator: Sensor Faults

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Dynamical Orders of Decentralized H-infinity Controllers

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Fault Detection and Isolation using Multi Objective Controller Design Techniques

General information
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Organisations: Department of Mathematics
Contributors: Stoustrup, J., Niemann, H. H.
Number of pages: 7
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Fault Detection in Closed Loop by Standard H-infinity Methods

General information
Publication status: Published
Organisations: Department of Mathematics
Contributors: Kilsgaard, S., Rank, M. L., Niemann, H. H., Stoustrup, J.
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Filter design for failure detection and isolation in the presence of modeling errors and disturbances
The design problem of filters for robust failure detection and isolation, (FDI) is addressed in this paper. The failure
detection problem will be considered with respect to both modeling errors and disturbances. Both an approach based on
failure detection observers as well as an approach based on a standard setup optimization is presented in this paper.

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Publication status: Published
Organisations: Department of Automation, Department of Mathematics
Contributors: Niemann, H. H., Stoustrup, J.
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Filter Design for Failure Detection and Isolation in the Presence of Modeling Erros and Disturbances

General information
Publication status: Published
Organisations: Department of Mathematics
Contributors: Stoustrup, J., Niemann, H. H.
Number of pages: 11
Publication date: 1996

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Improved Recovery in H-infinity/LTR Design

General information
Publication status: Published
Organisations: Department of Mathematics
Contributors: Niemann, H. H., Stoustrup, J., Shafai, B.
Publication date: 1996

Host publication information
Title of host publication: Improved Recovery in H-infinity/LTR Design
Source: orbit
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Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 1996 ›
Research › peer-review
Loop Transfer Recovery for Sampled-data Systems

General information
Publication status: Published
Organisations: Department of Mathematics
Contributors: Niemann, H. H., Stoustrup, J., Rank, M. L., Shafai, B.
Publication date: 1996

Host publication information
Title of host publication: Loop Transfer Recovery for Sampled-data Systems
Source: orbit
Source ID: 166337
Research output: Chapter in Book/Report/Conference proceeding › Article in proceedings – Annual report year: 1996 › Research › peer-review

LTR Design of Discrete-time Proportional-integral Observers

General information
Publication status: Published
Organisations: Department of Automation, Department of Mathematics
Contributors: Shafai, B., Niemann, H. H., Stoustrup, J., Beale, S.
Pages: 1056-1062
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Journal: I E E E Transactions on Automatic Control
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Sensitivity Synthesis for MIMO Systems: A Multi Objective H^2 Approach

General information
Publication status: Published
Organisations: Department of Mathematics
Contributors: Stoustrup, J., Niemann, H. H.
Number of pages: 15
Publication date: 1996

Publication information
Original language: English
Source: orbit
Source ID: 166351
Research output: Book/Report › Report – Annual report year: 1996 › Research › peer-review

An introduction to the special issue on loop transfer recovery

General information
Publication status: Published
Organisations: Department of Electrical Engineering, Automation and Control
Contributors: Niemann, H. H.
Pages: 611-613
Publication date: 1995
Peer-reviewed: No

Publication information
Journal: International Journal of Robust and Nonlinear Control
Volume: 5
ISSN (Print): 1049-8923
Original language: English
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LTR Design of proportional integral observers
This paper applies the proportional-integral (PI) observer in connection with loop transfer recovery (LTR) design for continuous-time systems. We show that a PI observer makes it possible to obtain time recovery, i.e., exact recovery for $t \to +\infty$, under mild conditions. Based on an extension of the LQG/LTR method of proportional (P) observers, a systematic LTR design method is derived for the PI observer. Our recovery design method allows time recovery and frequency (normal) recovery to be done independently. Furthermore, we give explicit expressions for the recovery error when asymptotic recovery cannot be obtained. A design example demonstrates the advantages of time recovery in the nonminimum phase case.

General information
Publication status: Published
Organisations: Department of Electrical Engineering, Automation and Control, Northeastern University
Contributors: Niemann, H. H., Stoustrup, J., Shafai, B., Beale, S.
Pages: 671-693
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Volume: 5
ISSN (Print): 1049-8923
Original language: English
Keywords: Loop transfer recovery, Proportional-integral observer, Non-minimum phase systems
Source: PublicationPreSubmission
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Research output: Contribution to journal → Journal article – Annual report year: 1995 → Research → peer-review

Robust Performance of Systems with Structured Uncertainties in State Space
This paper considers robust performance analysis and state feedback design for systems with time-varying parameter uncertainties. The notion of a strongly robust % performance criterion is introduced, and its applications in robust performance analysis and synthesis for nominally linear systems with time-varying uncertainties are discussed and

Electronic versions:
1995-RNCb.pdf
Source: dtu
Source ID: u::5552
Research output: Contribution to journal → Journal article – Annual report year: 1995 → Research
compared with the constant scaled small gain criterion. It is shown that most robust performance analysis and synthesis problems under this strongly robust performance criterion can be transformed into linear matrix inequality problems, and can be solved through finite-dimensional convex programming. The results are in general less conservative than those using small gain type criteria.

General information
Publication status: Published
Organisations: Department of Electrical Engineering, Automation and Control, Louisiana State University, University of Michigan, Ann Arbor
Pages: 249-255
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Journal: Automatica
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Keywords: Robust control, State feedback, Convex programming

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H-infinity Optimization of the Recovery Matrix

General information
Publication status: Published
Organisations: Department of Electrical Engineering, Automation and Control, SimCorp A/S
Contributors: Niemann, H. H., Seggaard-Andersen, P., Stoustrup, J.
Pages: 547-564
Publication date: 1993
Peer-reviewed: Yes

Publication information
Journal: Control-Theory And Advanced Technology
Volume: 9
Issue number: 2
Original language: English
Keywords: Loop transfer recovery, Robust control, Observer-based controller

Electronic versions:
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Source ID: u::5555
Research output: Contribution to journal › Journal article – Annual report year: 1993 › Research › peer-review

State-space solutions to the h_infinity design problem

The LTR design problem using an JC optimality criterion is presented for two types of recovery errors, the sensitivity recovery error and the input-output recovery error. For both errors two different approaches are presented. First, following the classical LTR design philosophy, a Luenberger observer based approach is proposed, where the Z part of the controller is appended to a standard full-order observer. Second, allowing for general controllers, an JC state-space problem is formulated directly from the recovery errors. Both approaches lead to controller orders of at most 2n. In the minimum phase case, though, the order of the controllers can be reduced to n in all cases. The control problems corresponding to the various controller types are given as four different singular state-space problems, and the solutions are given in terms of the relevant equations and inequalities.

General information
Publication status: Published
Organisations: Department of Electrical Engineering, Automation and Control
Contributors: Niemann, H. H.
Pages: 1-45
Loop transfer recovery for general observer architecture
A general and concise formulation is given of the loop transfer recovery (LTR) design problem based on recovery errors. Three types of recovery errors are treated: open loop recovery, sensitivity recovery and input-output recovery errors. The three corresponding versions of the asymptotic recovery problem turn out to be equivalent, since the minimization of the recovery errors all amount to the minimization of a certain matrix, the recovery matrix. Using the recovery error definitions, simple necessary and sufficient conditions for the controllers are derived both for the exact and asymptotic recovery cases. This general recovery formulation covers all known observer based compensator types as special cases. The conditions given in this setting are effectively the aim of all known LTR design methods. The recovery formulation is interpreted in terms of a model-matching problem as well, which is examined by means of the Q-parametrization. It is shown how the general controller obtained by the Q-parametrization can be written as a Luenberger observer based controller. In all cases, n controller states suffice to achieve recovery. The compensators are characterized for errors both on the input- and on the output-node (dual case).

A Frequency Domain Design Method For Sampled-Data Compensators
A new approach to the design of a sampled-data compensator in the frequency domain is investigated. The starting point is a continuous-time compensator for the continuous-time system which satisfy specific design criteria. The new design method will graphically show how the discrete-time compensator and the sampling period should be selected so the sampled-data feedback system approximate the continuous-time feedback system as good as possible.
An Analysis Of Pole/zero Cancellation In LTR-based Feedback Design

The pole/zero cancellation in LTR-based feedback design will be analyzed for both full-order as well as minimal-order observers. The asymptotic behaviour of the sensitivity function from the LTR-procedure are given in explicit expressions in the case when a zero is not cancelled by an equivalent pole. It will be shown that the non-minimum phase case is included as a special case. The results are not based on any specific LTR-method.

A parametric LTR solution for discrete-time systems

A parametric LTR (loop transfer recovery) solution for discrete-time compensators incorporating filtering observers which achieve exact recovery is presented for both minimum- and non-minimum-phase systems. First the recovery error, which defines the difference between the target loop transfer and the full loop transfer function, is manipulated into a general form involving the target loop transfer matrix and the fundamental recovery matrix. A parametric LTR solution based on the recovery matrix is developed. It is shown that the LQR/LTR (linear quadratic Gaussian/loop transfer recovery) solution is included in this new parametric solution as a special case.
New Results in Discrete-Time Loop Transfer Recovery

For discrete-time compensators incorporating prediction observers asymptotic loop transfer recovery is not feasible. Instead loop transfer recovery objectives must be satisfied via exact recovery techniques. In this note the model-based compensators which achieve exact recovery are parametrized in terms of the system zeros and the corresponding zero-directions. Full-order as well as minimal-order observers are treated. Further it is shown how exact recovery is also applicable to non-minimum phase plants. In this case the achievable performance is parameterized explicitly.

Stability Margins for Discrete-Time Optimal Regulators

A simple equation for guaranteed gain and phase margins for LQ state feedback in discrete-time systems will be presented. The results are based on the feedback gain and are made for SISO systems. An extension to MIMO systems are also showed. These new equations can also be used to find guaranteed gain and phase margins for optimal eigenvalue design methods.
Projects:

**Model Predictive Control in Urban Systems**  
Svensen, J. L., PhD Student, Department of Mathematics  
Poulsen, N. K., Main Supervisor  
Falk, A. K. V., Supervisor  
Madsen, H., Supervisor  
Niemann, H. H., Supervisor  
Samfinansieret - Andet  
15/09/2017 → 14/09/2020  
Award relations: Model Predictive Control in Urban Systems  
Project: PhD

**Detection and evaluation of abnormal events in complex industrial processes**  
Hallgrimsson, A. D., PhD Student, Department of Electrical Engineering  
Niemann, H. H., Main Supervisor  
Lind, M., Supervisor  
Eksternt finansieret virksomhed  
15/08/2017 → 14/08/2020  
Award relations: Detection and evaluation of abnormal events in complex industrial processes  
Project: PhD

**Learning-based Model Predictive Control of Spray Dryers**  
Miklos, R., PhD Student, Department of Electrical Engineering  
Niemann, H. H., Main Supervisor  
Jørgensen, J. B., Supervisor  
Petersen, L. N., Supervisor  
Poulsen, N. K., Supervisor  
Utzen, C., Supervisor  
Industrial PhD  
01/01/2017 → 31/12/2019  
Award relations: Learning-based Model Predictive Control of Spray Dryers  
Project: PhD

**Ulineær optimal robust styring og vindmølle regulering**  
Thomsen, S. C., PhD Student, Department of Informatics and Mathematical Modeling  
Poulsen, N. K., Main Supervisor  
Niemann, H. H., Supervisor  
Jørgensen, J. B., Examiner  
Stoustrup, J., Examiner  
DTU stipendium  
15/10/2006 → 29/09/2010  
Award relations: Ulineær optimal robust styring og vindmølle regulering  
Project: PhD

**Fejldiagnose og fejlhåndtering til autonome fly**  
Hansen, S., PhD Student, Department of Electrical Engineering  
Blanke, M., Main Supervisor  
Adrian, J., Supervisor  
Niemann, H. H., Examiner  
Gustafsson, F., Examiner  
Henry, D., Examiner  
Ansat eksternt  
01/06/2009 → 21/02/2013  
Award relations: Fejldiagnose og fejlhåndtering til autonome fly  
Project: PhD
**Data-driven Condition Monitoring of Switches and Crossings**
Barkhordari, P., PhD Student, Department of Electrical Engineering
Galeazzi, R., Main Supervisor
Blanke, M., Supervisor
Markine, V. L., Examiner
Simani, S., Examiner
Niemann, H. H., Examiner
Roberts, C., Supervisor
Forskningsrådfinsansiering
01/06/2016 → 31/05/2019
Award relations: Data-driven Condition Monitoring of Switches and Crossings
Project: PhD

**Fault Diagnosis and Optimal Control of Electro - Mechanical systems**
Sekunda, A. K., PhD Student, Department of Electrical Engineering
Niemann, H. H., Main Supervisor
Poulsen, N. K., Supervisor
Santos, I., Supervisor
Galeazzi, R., Examiner
Kinnaert, M., Examiner
Kallesæe, C. S., Examiner
Technical University of Denmark
15/12/2014 → 03/05/2018
Award relations: Fault Diagnosis and Optimal Control of Electro - Mechanical systems
Project: PhD

**Optimisation of Combine Harvesters Yield Using Model-Based Control**
Hermann, D., PhD Student, Department of Electrical Engineering
Ravn, O., Main Supervisor
Andersen, N. A., Supervisor
Bilde, M. L., Supervisor
Niemann, H. H., Examiner
Herlitzius, T., Examiner
Hågglund, T., Examiner
Industrial PhD
01/12/2014 → 15/08/2018
Award relations: Optimisation of Combine Harvesters Yield Using Model-Based Control
Project: PhD

**high Accuracy Nonlinear Control anhs Estimation for Machine Tool Systems**
Papageorgiou, D., PhD Student, Department of Electrical Engineering
Blanke, M., Main Supervisor
Niemann, H. H., Supervisor
Santos, I., Examiner
Edwards, C., Examiner
Johansen, T. A., Examiner
Richter, J. H., Supervisor
Eksternt finansieret virksomhed
15/08/2014 → 11/10/2017
Award relations: high Accuracy Nonlinear Control anhs Estimation for Machine Tool Systems
Project: PhD

**Economic Model Predictive Control for Spray Drying Plants**
Petersen, L. N., PhD Student, Department of Mathematics
Jørgensen, J. B., Main Supervisor
Niemann, H. H., Supervisor
Poulsen, N. K., Supervisor
Utzen, C., Supervisor
Huusom, J. K., Examiner
Engell, S., Examiner
Pannocchia, G., Examiner
Situation Assessment for Mobile Robots
Beck, A. B., PhD Student, Department of Electrical Engineering
Ravn, O., Main Supervisor
Andersen, N. A., Supervisor
Risager, C., Supervisor
Niemann, H. H., Examiner
Andersen, G. L., Examiner
Jensfelt, P., Examiner
ErhvervsPhD-ordningen VTU
01/07/2009 → 21/06/2013
Award relations: Situation Assessment for Mobile Robots
Project: PhD

Active performance assessment and system monitoring for refrigeration systems
Green, T., PhD Student, Department of Electrical Engineering
Niemann, H. H., Main Supervisor
Izadi-Zamanabadi, R., Supervisor
Skovrup, M. J., Supervisor
Ravn, O., Examiner
Hågglund, T., Examiner
Stetter, R., Examiner
ErhvervsPhD-ordningen VTU
01/12/2008 → 27/09/2012
Award relations: Active performance assessment and system monitoring for refrigeration systems
Project: PhD

High performance low cost digital controlled power conversion technology
Jakobsen, L. T., PhD Student, Department of Electrical Engineering
Andersen, M. A. E., Main Supervisor
Niemann, H. H., Supervisor
Thomsen, O. C., Supervisor
Tøttrup, P., Supervisor
Sparsø, J., Examiner
Arefeen, M., Examiner
Nelms, R. M., Examiner
InnovationsPhD
01/10/2004 → 29/08/2008
Award relations: High performance low cost digital controlled power conversion technology
Project: PhD

Udviklingskoncept for Robust og Optimal Regulatordimensionering
Beran, E. B., PhD Student
Niemann, H. H., Main Supervisor
Stoustrup, J., Supervisor
Madsen, H., Examiner
Perram-John, W., Examiner
Forskningsrådsstipendium
01/10/1994 → 21/01/1998
Award relations: Udviklingskoncept for Robust og Optimal Regulatordimensionering
Project: PhD

Robust og optimal regulering af samplede systemer
Rank, M. L., PhD Student, Department of Electrical Engineering
Niemann, H. H., Main Supervisor
Parkum, J. E., Supervisor
Stoustrup, J., Supervisor
DTU stipendium
01/01/1995 → 21/02/1999  
Award relations: Robust og optimal regulering af samplede systemer  
Project: PhD  

**Control Architecture for Future Power Systems**  
Heussens, K., PhD Student, Department of Electrical Engineering  
Niemann, H. H., Main Supervisor  
Lind, M., Supervisor  
Østergaard, J., Examiner  
Jiang, J., Examiner  
Rehtanz, C., Examiner  
DTU stipendium  
01/04/2008 → 21/02/2012  
Award relations: Control Architecture for Future Power Systems  
Project: PhD  

**Fejltolerante powersystemer**  
Nesgaard, C., PhD Student, Department of Electrical Engineering  
Andersen, M. A. E., Main Supervisor  
Niemann, H. H., Examiner  
Nymand, M., Examiner  
Weinberg, S. H., Examiner  
DTU stipendium  
01/02/2001 → 27/07/2004  
Award relations: Fejltolerante powersystemer  
Project: PhD  

**Offshore Wind Park Control Assessment Methodologies to Assure Robustness and Fault tolerance**  
Gryning, M. P. S., PhD Student, Department of Electrical Engineering  
Blanke, M., Main Supervisor  
Andersen, K. H., Supervisor  
Niemann, H. H., Supervisor  
Sørensen (fratrådt), T., Supervisor  
Wu, Q., Supervisor  
Cutululis, N. A., Examiner  
Erlich, I., Examiner  
Stoustrup, J., Examiner  
ErhvervsPhD-ordningen VTU  
01/09/2012 → 20/01/2016  
Award relations: Offshore Wind Park Control Assessment Methodologies to Assure Robustness and Fault tolerance  
Project: PhD  

**Concurrent Aero-Servo-Elastic analysis and Design of wind turbines**  
Mirzaei, M., PhD Student, Department of Informatics and Mathematical Modeling  
Poulsen, N. K., Main Supervisor  
Niemann, H. H., Supervisor  
Jørgensen, J. B., Examiner  
Stoustrup, J., Examiner  
Bottasso, C. L., Examiner  
DTU, Samfinansiering  
15/08/2009 → 07/03/2013  
Award relations: Concurrent Aero-Servo-Elastic analysis and Design of wind turbines  
Project: PhD  

**Validation of Control Services in Future Sustainable Power Systems**  
Bondy, D. E. M., PhD Student, Department of Electrical Engineering  
Bindner, H. W., Main Supervisor  
Heussens, K., Supervisor  
Niemann, H. H., Supervisor  
Wu, Q., Examiner  
Mathieu, J. L., Examiner  
Kamphuis, R., Examiner
Consequence Reasoning in Multilevel Flow Modeling and its Application
Zhang, X., PhD Student, Department of Electrical Engineering
Ravn, O., Main Supervisor
Lind, M., Supervisor
Niemann, H. H., Examiner
Cameron, I., Examiner
Gofuku, A., Examiner
Technical University of Denmark
01/03/2012 → 07/09/2016
Award relations: Consequence Reasoning in Multilevel Flow Modeling and its Application
Project: PhD

Advanced Control of Smart Materials Applied to Sustainable Technology
Theisen, L. R. S., PhD Student, Department of Electrical Engineering
Niemann, H. H., Main Supervisor
Galeazzi, R., Supervisor
Santos, I., Supervisor
Andreasen, C. S., Examiner
Verhaegen, M., Examiner
Grigoriadis, K. M., Examiner
Technical University of Denmark
01/05/2013 → 07/09/2016
Award relations: Advanced Control of Smart Materials Applied to Sustainable Technology
Project: PhD

Emergency Control in Power Transmission
Pedersen, A. S., PhD Student, Department of Electrical Engineering
Blanke, M., Main Supervisor
Jóhannsson, H., Supervisor
Tabatabaeipour, M., Supervisor
Niemann, H. H., Examiner
Erlich, I., Examiner
Stoustrup, J., Examiner
Technical University of Denmark
01/11/2012 → 20/01/2016
Award relations: Emergency Control in Power Transmission
Project: PhD

Fault-Tolerant Control with Coarse Models in industrial Application
Papageorgiou, D., Project Participant, Department of Electrical Engineering, Automation and Control
Blanke, M., Main Supervisor, Department of Electrical Engineering, Automation and Control
Niemann, H. H., Supervisor, Department of Electrical Engineering, Automation and Control
15/08/2014 → 15/08/2017
Keywords: Fault-tolerant control, fault diagnosis, fault estimation, nonlinear control, nonlinear systems, industrial motors
Project: Research

Fundamental fault detection
The area for this project is to develop a basic for the investigation of fault detection, fault identification and fault estimation.

One of the main problems in fault detection, fault identification and fault estimation is that there does not exist a well defined fundament, where on the research can be based. As a consequence of this, it will in general be impossible to validate residual generators (components for fault detection/identification/estimation) with respect to e.g. optimality.

The first part of the project deals with formulating a number of fundamental fault detection/identification/estimation problems and derive the solvability conditions for these problems. These problems describe the optimal/the best that can be obtained.

Niemann, H. H., Project Manager, Department of Automation
Saberi, A., Project Participant, Washington State University
Design of observer based controllers
This project deals with the design of observers in connection with feedback control. The concept of loop transfer recovery (LTR) has been investigated for the design of observers as well as design of fixed order LTR controllers. In the usual LTR setting, design rules are developed based on sufficient conditions for recovery only. A consequence of this is that the design rules might not necessary point out the 'best' controller from an LTR point of view. Another drawback lies in the assumed controller architecture in previous approaches. Thus, it has not been investigated if different choices of controller types would yield better general performance, or, conversely, which special performance properties are associated with different classes of compensators. The LTR concept has, in this project, been applied on continuous-time, discrete-time and sampled data systems. Further, there has been focus on both design methods as well as on new observer/controller architectures for increasing the controller performance. In the area of design methods, new methods have been derived out from standard induced norm based methods. Two new architectures have been derived for increasing the specific performance conditions of the controller. The first architecture is the so-called PI observer which makes it possible to increase the performance at low frequencies. This is quite relevant in connection with non minimum phase systems, where it is not possible to obtain good performance at low frequencies by using a standard observer architecture. The other new architecture is related with fixed order LTR controller design. A linear matrix inequality (LMI) design approach for fixed order controllers has been derived.

Fault detection in dynamic systems
In the control of industrial systems, it is rare that a control system functions continuously without shutdown throughout the scheduled life cycle of the plant and controller hardware. Owing to ware of mechanical and electrical components, both actuators, sensor and internal components can fail in more or less critical ways. For safety critical processes, it is of paramount importance to detect when faults are likely to happen and then to identify these faults as fast as possible once they have occurred. To meet such industrial needs, a number of schemes for fault detection and isolation (FDI) have been set up. Much of the research has dealt with the design of filters which monitor a process and generate alarms when faults have occurred. In most cases, the filters are model based devices which act independently of the computer implemented digital controller. In this project, the focus is on both analysis and design of fault detectors as well as the task of combining control algorithm and FDI filters in a single module. In the area of analysis and design of fault detectors, both observer based detectors as well as more general filters are applied. The work done in this area has primarily been focus on the possibility to apply systematic standard methods from robust and optimal control for the analysis and design of fault detectors. The work done until now in the area of combining fault detector and controller has just been started. A general setup for the design of a combined fault detector and controllers has been formulated using standard methods from robust control. It has been shown by examples, that it is possible to obtain a very large reduction the dynamic order of the control module compared to the case when separate fault detector and controller are applied.

Multi Criterion Regulation
The literature on modern Theory of Regulation contains numerous publications concerned with the optimization based design of regulators based on specific criteria. However, a realistic design problem would rather contain a range of specifications. Hence, optimization based methods are to a large extent inapplicable, until it has been made possible to impose multiple specifications on the same control problem. Many control problems may be formulated with constraints on sensitivity functions and a number of results have been achieved for this kind of problems. The results within this area has in particular been applied in connection with active damping of rolling of ships by steering the rudder.
Yielding Capacities for Control Systems with Uncertain Parameters

Modelling physical and dynamical systems there will inevitably be a discrepancy between the model and the real system. Sometimes even minor discrepancies may have serious consequences for certain desired properties. The present project considers input/output characteristics for these type of systems, allowing nonlinear uncertainties on the parameters. Results have been established, which for certain classes of systems provide explicit expressions for the largest allowable deviations, considering quadratic norm conditions on the input/output properties.

Stoustrup, J., Project Manager, Department of Mathematics
Niemann, H. H., Project Participant, Department of Automation
01/01/1996 → 31/12/1997

Loop Transfer Recovery

Loop Transfer Recovery (LTR) is a general method for designing linear control systems. The idea is, that the demands to the dimensioning are formulated as frequency domain properties, by prescribing desired behaviours for a number of transfer functions in the control system. Traditionally, linear and quadratic optimization has been applied in connection with LTR design methods. However, it is by far more natural to define the final demands in H-infinity norm, since the final target almost always contains a specification of robustness, which is easily handled with H-infinity Theory. Through several publications it has been described how H-infinity Theory may be applied for this purpose in theory as well as in practice.

Stoustrup, J., Project Manager, Department of Mathematics
Niemann, H. H., Project Participant, Department of Automation
01/01/1996 → 31/12/1997

Error Diagnosis in Dynamical Control Systems

A control system generates control signals to a dynamical system, based on a number of measurements. The set of measurements are established by one or more sensors. The control signals change the behaviour of the dynamical system via a number of actuators. In several applications it is important to be able to determine whether the actuators and/or sensors fail. The present project studies analytical methods for determining whether the function of actuators and sensors are satisfactory, by investigating whether correlated values (in functional spaces) of control signal and measurements are consistent with the differential equations modelling the system. A number of results has been achieved, that reveals advantages and disadvantages in integrating the dimensioning process for control and diagnosis system. Moreover, explicit algorithms for the integrated design are given.

Stoustrup, J., Project Manager, Department of Mathematics
Niemann, H. H., Project Participant, Department of Automation
01/01/1996 → 31/12/1997

Multivariable controller starting up.

In several industrial environments as e.g. power plants, installing a full multivariable controller is difficult due to safety requirements. Often the starting point is a plant which is already controlled by several single loop controllers, for instance PI or PID controllers. The new controller is then introduced in parallel, varying the control signal continuously by a tuning procedure.

This project focus on the start up and close down of multivariable controllers in a safe way. Further, the change of controller and/or controller structure is also investigated. There the main problem is to reject transients in the response due to the controller change.

Niemann, H. H., Project Manager, Department of Automation
01/01/1997 → …

Decentral H_inf design.

The problem of design of decentralized H_inf controllers are considered in this project. It is shown that in the case when we have a sequency of decentralized controllers in series, that there will not exist optimal controllers of bounded order. Moreover, neither does there exist an infinity dimensional optimal controller.

Niemann, H. H., Project Manager, Department of Automation
01/01/1997 → 31/12/1997

Robust controller design

A 1 year research project at Australian National University, Canberra Australia. The research project deals with robust controller design and robust fault detection in connection with dynamic uncertain systems.
Niemann, H. H., Project Manager, Department of Automation
01/08/1997 → 31/07/1998
Project: Research