ABSTRACTS

Chapter 1. **On statistical change detection for FDI.** Detecting changes in signals and dynamical systems has been the topic of a number of both theoretical and practical investigations for more than thirty years. Early investigations of statistical change detection took place in the area of quality control and trace back to the thirties. More recent applications to various monitoring problems (structural health monitoring of bridges and aircrafts, monitoring low consumption components of road vehicles, handling climate changes, navigation systems monitoring, intrusion detection in information systems, anomaly detection in communication channels) have highlighted the relevance of the statistical model-based change detection methodology when investigating the problems of fault or damage detection, isolation and diagnosis. The purpose of this chapter is to discuss the key issues in the design of monitoring algorithms based on that methodology. Basic concepts are introduced. The application to real fault or damage detection problems is reported. – M. Basseville.

Chapter 2. **Fault diagnosis and fault tolerant control: an optimization based approach. A general architecture for fault tolerant control is proposed.** The architecture is based on the (primary) Youla-Kucera parameterization of all stabilizing compensators, and uses the dual Youla-Kucera 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 are 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. – J. Stoustrup.

Chapter 3. **Fault-tolerant model predictive control.** Model predictive control (MPC) has developed considerably in the last decades both in industry and in academia. This success is due to the fact that MPC is perhaps the most general way of posing the control problem in the time domain. Although the technique originated in industry, the academic research community has contributed, during the last two decades, important results, specially in the stability domain, where stability and robustness conditions for MPC have been well established. One of the main advantages of MPC is that model uncertainties can be taken explicitly into account and this allows for the consideration of faulty process behavior. The receding control strategy used in MPC can be extended to the case of system identification by parameter bounding and furthermore to determine if a model is consistent with the obtained data in a receding horizon manner and this implicitly allows for fault detection. The chapter addresses these issues, it shows how concepts arising from the fault detection and fault-tolerant design methods can be incorporated in an MPC framework and the advantages that can be gained by using MPC in this context. – E.F. Camacho, T. Alamo, D.M. de la Peña.

Chapter 4. **Fault-tolerant control — is it possible?** A real demand now exists for fault-tolerant control systems. This chapter gives some examples in which this arises, drawn from process control, automotive and aerospace applications. But fault-tolerance is a very ambitious objective; the paper examines critically what has been achieved so far, and what it might be possible to achieve. It also speculates a little on how it might be achieved. The chapter is illustrated by examples from real applications, particularly from the aerospace sector. – J.M. Maciejowski.

Chapter 5. **Integrate Design of Wireless Fault Tolerant Networked Control Systems**. This chapter consists of two parts. In the first part, a design scheme for achieving a fault tolerant wireless NCS is presented. The core of this scheme is the integrated design of the controllers, observers and the communication network in a multi-layer system structure. The second part presents the advanced experimentation platform WiNC, on which the proposed design scheme can be realized. – S. Ding.

Chapter 6. Advances of IR-thermal diagnostics in medicine. The chapter presents advances of quantitative IR thermal imaging QIRT. This technology during last twenty years is in the phase of rapid development. Just recently the importance of QIRT in civil applications including medical diagnostics should be underlined. This is due to the significant decrease of equipment prices and the increased availability of mature technology based on uncooled FPA (focal plane array) IR-detectors. New developments in this field include early approaches to thermal tomography TT, and to visualization using stereovision thermal systems STS. In the chapter experiences of the Department of Biomedical Engineering in the frontal edges of ADT, TT and STS, are discussed. Basic problems related to practical applications of QIRT in medical diagnostics – in cardio-surgery, in burn diagnostics and in thermal mammography – are presented. It is worth emphasizing that medical applications of QIRT seem to be most difficult as heat transfers in living tissues are far more complicated as compared to technical applications using nondestructive testing based on thermal IR imaging (NDT TI). – A. Nowakowski, M. Kaczmarek, M. Bajorek, M. Moderhak, M. Suchowirski.

Chapter 7. **A concept for fault tolerant controllers.** This chapter describe 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 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 allow the different feedback controllers to apply different sets of sensors and actuators. – H. Niemann, N.K. Poulsen.

Chapter 8. **Actuator fault-tolerant control for satellites in rendezvous mission.** This chapter presents some preliminary results on control and actuator fault-tolerance for a satellite system in a *rendezvous* mission. The mission consists in capturing a sample (called target) using a chaser satellite. The study considers the position and attitude dynamics of the chaser equipped with 12 thrusters. Firstly, a controller is designed for the chaser using flatness. The controller aims to move the system from an initial position/attitude to the position of the target with the adequate attitude. Since the chaser is an over-actuated system, a control allocation scheme is used to allocate over the thrusters, the efforts and moments generated by the controller. Secondly, actuator faults are considered. The chaser's thrusters are subject to two types of faults: jamming in closed position and jamming in open position. Using actuator redundancy, a control re-allocation scheme is used to accommodate actuator faults. The efficiency of the control and the FTC approaches are investigated in simulation. – A. Chamseddine, C. Join, D. Theilliol.

Chapter 9. Fault tolerant control in MFC/IMC structure. An ordinary MFC/IMC (*Model Following Control / Internal Model Control*) structure possesses two controllers: main and auxiliary (corrective). The task of the main controller is to control the nominal process. The role of the auxiliary controller is counteraction to structured or unstructured object uncertainty. This chapter presents an advanced MFC/IMC structure with an additional adaptive-fault controller. The modified structure improves the property of MFC/IMC system also in the presence of faults or large disturbances. The proposed system belongs to the passive-active fault-tolerant control type. In this work the basic relationships have been given and simulating investigations of the new structure have been performed. – J. Brzózka.

Chapter 10. Towards a fault-robust GPC implementation. Hardware faults that appear during system operation may result in logical errors at the application level. The analysis of their effects on the control system is crucial as they can negatively influence economic efficiency or even safety of controlled processes. This chapter studies the dependability of software implementation of a GPC algorithm applied to a multivariable chemical reactor. The algorithm consists in on-line solving a quadratic programming problem with constraints at each iteration. Its dependability is analyzed with a software implemented fault injector adapted to reactive applications. The GPC setup is described. Erroneous situations provoked by single bit-flips are presented. Low cost software improvements of the system are proposed and examined. The idea of using explicit GPC realization to validate the numerical algorithm proved to be an effective way of getting fault robustness. – P. Gawkowski, M. Ławryńczuk, P. Marusak, J. Sosnowski, P. Tatjewski.

Chapter 11. Fault accommodation in dynamic systems: logic-dynamic approach. Solution of the problem of fault accommodation in nonlinear dynamic systems is related to constructing the control law which provides full decoupling with respect to fault effects. The so-called logic-dynamic approach to solve this problem is used. Existing conditions are formulated and calculating relations are given for the control law. – A. Shumsky, A. Zhirabok, E. Bobko.

Chapter 12. **Active fault isolation and estimation**. An active fault diagnosis (AFD) method is applied in this chapter for fault isolation and fault estimation. Periodic signals are applied as auxiliary inputs. The fault isolation and estimation are derived by an investigation of the signature from the auxiliary input in the residual vector. Confidence areas are calculated so it is possible to guarantee fault isolation. Further, it is also used for calculation of the estimation error. **–** N.K. Poulsen, H. Niemann.

Chapter 13. **Parameters estimation methods in the robust fault diagnosis.** The chapter deals with the problem of robust fault diagnosis. The main objective was to develop robust fault diagnosis scheme based on the parameters estimation of the diagnosed system. For this purpose the least mean square method, the bounded-error approach and the outer bounding ellipsoid algorithms were taken into consideration. The effectiveness of the proposed approaches was shown on the model of brushless DC motor. **–** M. Mrugalski, J. Korbicz.

Chapter 14. **Asynchronous distributed state estimation based on continuous time stochastic model**. In this chapter the problem of state estimation in an asynchronous distributed multi-sensor system is considered. In such a system the state of an object of interest is estimated by a group of local estimators, which, based on Kalman filters, perform fusion of data from its local sensor and remote processors to compute possibly best state estimates. In performing data fusion, however, two important issues need to be addressed: unknown correlation between data in local processors and the problem of asynchronism of local processors. In this chapter a multi-sensor asynchronous estimation algorithm is presented. The problem of unknown correlation is solved by the covariance intersection method. In order to deal with asynchronous data a continuous-time stochastic object model is introduced. Simulated tests illustrate the effectiveness of the proposed approach. **–** Z. Kowalczuk, M. Domżalski.

Chapter 15. Continuous-time delay systems identification insensitive to measurement faults. In this chapter specific estimation algorithms are used to identify the parameters of continuous-time delay systems. With the aid of integrating filters an original differential equation is transformed into an equivalent discrete-time regression representation. Since the resultant description retains the original parameterization of the continuous domain, a classical LS scheme can be applied immediately to complete the identification procedure. In order to robustify the estimation process against occasional measurement faults, an alternative identification routine derived from minimization of a non-quadratic goal function is put into practice. Finally, in the reported numerical simulation study, a developed estimator of least absolute error quality along with periodic excitations are used to demonstrate the performance of the off-line identification of the parameters and the delay of the observed system**.** – J. Kozłowski, Z. Kowalczuk.

Chapter 16. **An industrial approach to active sensor configuration validation.** This chapter proposes a relatively simple approach to configuration validation of sensor devices in a typical display case that is used in supermarket refrigeration systems. In particular, the focus is on the evaporator as it is the key element for controlling the goods' temperature in the display case. The approach is as follows: by analyzing the dynamic behavior of the system, sets of measures are established. A simple control strategy is then designed in order to excite the system dynamics while observing the system's operational safety conditions. The obtained data are then used to derive the suggested measures, which are then used to identify or validate the corresponding sensors. The considered problem is not a conventional FDI problem as: (a) the controller does not have advanced knowledge of the parameters that characterize the dynamics of the display case; (b) the developed algorithm should be applicable on a large class of display cases (and evaporators); (c) only generic dynamical behavior of a display case and its corresponding evaporator is available. – R. Izadi-Zamanabadi, L. F. S. Larsen, C. Thybo.

Chapter 17. **Mobile sensor routing for detection of moving contamination sources – part 1: optimal control formulation**. Assume that a number of mobile sensors can be deployed in a spatial area to measure the concentration of a contaminant whose evolution is governed by a known mathematical model. The objective is to use these observations to localize the contamination source and determine the spatiotemporal concentration of the chemical dispersion. By parameterizing the paths of the moving sources, this problem is reduced to that of parameter estimation. Based on a scalar measure of performance defined on the Fisher information matrix related to unknown parameters, the problem is converted to an optimal control one with state-variable inequality representing geometric constraints induced by the admissible measurement regions and allowable distances between the sensors. On the account of the dynamic models of vehicles carrying the sensors, the problem is reduced to determination of both the control forces of the sensors and initial sensor positions. Attempts are also made at applying a nonlinear model-predictive-control-like approach to make the scheme near-real-time. – D. Uciński, M. Patan.

Chapter 18. **Mobile sensor routing for detection of moving contamination sources – part 2: algorithms and results**. In this second part of the work we develop computationally efficient methods and algorithms to determine optimal trajectories of mobile sensor nodes for source identification in distributed parameter systems. In contrast to standard approaches commonly used in distributed sensor networks, the knowledge of the mathematical model of DPS is a basis for optimization. Thus the important information about the model governing the physical phenomenon is not lost and will be to the profit of early detection of chemical or biological threats. In numerical examples we use two-dimensional advection-diffusion partial differential equations, which makes the proposed approach closer to practical applications than most situations considered in the literature. Moreover, in order to provide an adaptivity for estimation of system parameters what leads to dynamic data-driven computations a nonlinear model-predictive-control-like approach was also applied to address this issue. – M. Patan, D. Uciński.

Chapter 19. **Designing optimal and safe control strategies for time-varying dynamical systems**. This chapter presents a fitting method of designing optimal and safe control strategies for time-variant dynamical processes. The main point lies in utilizing a flow (state-space) graph structure to represent principal properties of autonomous dynamics in a time-state space through a segmentation procedure. For each segment of the time-state space a graph node is assigned. The flow values are proportional to the cost of driving the operational point of the dynamical process between centers of adjacent segments (in line to the definition of adjacency). The final step consists in applying a discrete optimization algorithm which searches for the cheapest path connecting the node representing the segment containing initial points with the node which represents the segment containing terminal points of the sought trajectory. The cheapest path represents a piecewise linear optimal trajectory of the operational points in the time-state space. Additional assumptions concerning forbidden zones for the operational points can be made. In such a case the nodes representing the segments which partially or entirely belong to the forbidden zones are extracted from the state-space graph structure. – Z Kowalczuk, K.E. Olinski.

Chapter 20. Diagnostic-relation determination assist on the ground of extended process graphs. Extended process graphs used to describe the cause-effect relations between process inputs, state variables, measured variables, faults and process components is presented in this chapter. The approach is an extension of the process graphs GP. The rules of defining binary diagnostic matrix based on the analysis of the structure of the proposed graph, were formulated. These rules applies the assumed methods/paths of propagation of fault consequences onto measurements used by the detection algorithms and onto the diagnostic tests themselves. Proposed approach was illustrated with use of simple example of two tank system. **–** M. Syfert.

Chapter 21. A modified algorithm of fault isolation in decentralized structures. In this chapter a modified algorithm of fault isolation in decentralized structures for industrial processes was formulated. Modifications are principally connected with improving diagnosis on the supervisory level and simplifying the diagnostic system structure. The multiple fault issue was also addressed. The presented algorithm utilized complete knowledge about the uncertainty of fault symptoms carried by the fuzzy diagnostic signals. **–** M. Syfert.

Chapter 22. The issue of diagnostic reasoning in the case of variability of diagnosed system structures. The chapter deals with the problem of reconfiguration of diagnostic reasoning algorithms resulting from the changes in the process structure and in the set of available diagnostic system components. First, an extended description of the diagnosed process and the diagnostic system components is given. Then, the reasons why the changes have to be done along with a required action that have to be carried out, are stated. Finally, some ideas about the method of describing the diagnostic relation which is robust to the required monitoring process and the diagnostic system changes (including diagnostic relations) is presented. **–** M. Syfert, J.M. Kościelny.

Chapter 23. **Diagnostic tool for detecting malfunctions in district heating objects based on power-flow models.** Major malfunctions in heating systems used to be related to unusual energy consumption level causing attention of consumers. Once heat demand is held within acceptable limits, a potential to minimize costs of heat transportation and maximize primary side efficiency still remains. In this chapter the tool for detecting anomalous values of parameters related to the efficiency on the primary side of district heating systems is presented. Two variables were chosen during investigation as most relevant for detecting inefficient flow control. Results are based on the analysis of statistical properties of regressive models binding hourly energy consumption and volume from the billing system. Analysis of variability of model parameters and their statistics along a large population of houses is included. **–** S. Kiluk.

Chapter 24. **A constraint satisfaction framework for diagnostic problems**. The chapter presents a formal framework of constraint satisfaction for automated diagnosis of technical systems. The use of qualitative constraints, in the form of rules, allows to better describe potential diagnoses with deviations sign and eliminate inconsistent ones. **–** A. Ligęza.

Chapter 25. **Locally recurrent networks for fault approximation and accommodation**. The work presented in this chapter deals with a fault tolerant control system designed for the boiler unit. The core of the proposed approach is the so-called on-line fault approximator (FA) constructed using a locally recurrent neural network. On-line training of FA is developed for monitoring the controlled system. In order to construct the FA, the nominal system should be known as well as the state vector should be available for measurement. In the chapter the nominal system is represented by the linear state-space model derived using the process data. In turn, the state vector is determined by means of the state observer. The achieved fault estimator is then used for fault detection and accommodation. Computer experiments are provided to illustrate the performance of the proposed methodology. **–** K. Patan.

Chapter 26. **Locally recurrent neural networks and recurrence quantification analysis in fault detection of dynamical processes**. This chapter presents a robust fault detection scheme for any abrupt and incipient class of faults that can affect the state of different kinds of non-linear dynamical processes. The proposed method is based on locally recurrent neural networks with unknown inputs and recurrence quantification analysis. Neural models are used to generate residual signals that should be sensitive to faults only, even in the presence of model-reality differences, whereas recurrence quantification analysis is used to increase the robustness of residual evaluation. Finally, an intelligent servo-actuator, proposed as a benchmark test in the framework of European RTN DAMADICS, is employed to illustrate the application of these two techniques to robust fault detection. **–** P. Przystałka.

Chapter 27. **Cytological image segmentation using fuzzy clustering**. This chapter presents the stage of research concerning an automatic diagnosis system of breast cancer based on cytological images of FNB (*Fine Needle Biopsy*). The work concentrates on the image segmentation phase, which is employed to find nucleus in cytological images. The accuracy and correctness of the image segmentation algorithm is a critical factor for successful diagnosis due to the fact that case classification is based on morphometrical features extracted form segmented nucleus. The approach to image nucleus segmentation is based on the FCMS (*Fuzzy C-Means with Shape function*) clustering algorithm. Traditional approaches using clustering consider clustering pixels in color space in order to recognize objects. The novelty of the presented approach results from the fact that the clustering process is conducted in color space but the searched objects can have an arbitrarily defined shape. Simulations and experimental results are included in the work to illustrate the effectiveness of the proposed approach. – M. Kowal, A. Obuchowicz.

Chapter 28. Application of probabilistic neural networks for fault detection in rotating machinery. The chapter presents overview of applications of neural networks for diagnostic of rotating machinery. Theoretical background of the probabilistic neural networks (PNN) is submitted. The PNN architecture is presented and discussed. The proposed network was used for classification of unbalance and misalignment faults on a test rig. Faults were introduced in various locations and in various degrees. The key contribution of the work is the selection of an optimal feature set. Statistical and harmonic features were tested, out of which the amplitudes of eight or more harmonics were found to contain information sufficient to detect 100 % of faults. Another important contribution lies in the comparison of the PNN performances with various sensor combinations. It was found that removing of the axial vibration sensor information results in highest decrease of the network performance**. –** T. Barszcz, A. Bielecki, T. Romaniuk.