Preface

In the recent years there has been growing interest in industrial systems and in particular in robotic manipulators and mobile robot systems. As the cost of robots goes down and as robots become more compact, the number of industrial applications of robotic systems increases. Moreover, there is need to design industrial systems with intelligence, autonomous decision making capabilities, and self-diagnosing properties.

The design of intelligent industrial systems requires the synergism of several research areas, such as robotics, control, estimation and sensor fusion, fault diagnosis, optimization and machine intelligence. Incorporating intelligence in industrial and mobile robots can help to increase productivity, cut-off production costs, and to improve working conditions and safety in industrial environments. This need has resulted in the rapid development of modeling and control methods for industrial systems and robots, of fault detection and isolation methods for the prevention of critical situations in industrial work-cells and production plants, of optimization methods aiming at a more profitable operation of industrial installations and of machine intelligence methods aiming at reducing human intervention in industrial systems operation.

Intelligence for industrial systems is characterized by two main features: (i) learning and (ii) uncertainty handling. Learning indicates the capability of the industrial system to adapt its behavior according to operating conditions and to accumulate information from sensor inputs so as to make it's functioning more efficient. Learning can be succeeded by gradient-based algorithms (neural and adaptive fuzzy systems, automata networks and intelligent agents) or gradient-free algorithms (evolutionary and particle methods). Uncertainty handling is also important for successful operation of industrial systems since precise mathematical models are in several cases intractable or the modeling procedure is on its own too complicated. Stochastic modeling can be performed in terms of fuzzy or probabilistic models and stochastic estimation algorithms.

The book is organized in four sections: (i) industrial and mobile robotics, (ii) stochastic modeling for industrial systems, (iii) electric power systems, and (iv) fault diagnosis.

(i) In the area of industrial and mobile robotics one can consider various problems ranging from dynamic or kinematic modeling and control, to path planning, sensor fusion and machine vision. The application areas mainly include (a) industrial robots designed for compliance tasks (such as deburring, milling, cutting and assembling), as well as industrial robots designed for non-contact tasks (such as welding and painting), (b) mobile robots, autonomous vehicles and multi-robot systems designed for hazardous inspection, underwater or space exploration, transportation, search and rescue, and underground exploitation of energy resources. Some examples of military applications are guarding, escorting, patrolling (surface surveillance), and strategic behaviours, such as stalking and attacking, (c) service

robots for domestic use, assistance of the elderly, as well as medical robots. In all these applications robot intelligence is of primary importance for successful operation in varying and uncertain environments.

(ii) in the area of stochastic modeling for industrial systems one can consider (a) the problem of identification of a dynamical system's model from numerical data which in turn consists of various sub-problems such as selection of the structure and the order of the model, optimization of the model parameters, model simplification and model validation, (b) the problem of filtering and state estimation from measurements of the inputs and outputs of the dynamical system which enables sensorless control and fault diagnosis tasks. Identification and state estimation are critical for control and fault monitoring of industrial systems in real operating conditions. There can be nonparametric approximators such as neural and wavelet networks or other basis functions expansions, fuzzy (possibilistic) models or probabilistic models such as Bayesian networks and stochastic automata, and stochastic filtering algorithms in terms of Kalman Filter or particle filters.

(iii) In the area of electric power systems one can consider intelligent algorithms for improving the operation and the safety of power generation and distribution systems. Among the problems faced in this field one can distinguish (a) dynamic modeling of the power grid, forecasting of its behavior on short or long-term basis and optimization of its operation (b) adaptive compensation of undesirable power system characteristics and robust power system stabilization, (c) monitoring and fault diagnosis for the various components of the power generation transmission and distribution grid,

(iv) In the area of fault diagnosis one can consider various methods for fault detection where the aim is to recognize that a fault happened and fault isolation where the aim is to find the fault and the location of the fault. Fault diagnosis is applied to robotics and industrial production systems, transportation systems, the electric power grid, civil and mechanical structures etc. Advanced methods of fault detection are based on (i) signal processing, statistics and system theory approaches, (ii) artificial intelligence approaches. The monitored system can be represented either by a continuous/discrete time model or a discrete event model. Important issues in fault diagnosis of industrial systems, which are examined in this book, are identification of dynamical systems and residual generation, fault detection with state observers and state estimation, fault threshold selection and change detection criteria, fault diagnosis in the frequency domain, fault diagnosis with parity equations and pattern recognition methods.

The book contains 17 chapters on the aforementioned topics. The main results of each chapter are summarized as follows.

SECTION 1: INDUSTRIAL AND MOBILE ROBOTICS

Chapter 1 "Intelligent Automatic Guided Vehicles" (S. Berman and Y. Edan)

In this chapter automatic guided vehicles (AGV) for material handling systems are studied. The use of AGVs in flexible manufacturing systems is reviewed showing that they have become the best approach for transporting pallets and parts between workstations. The primary advantages of AGV are summarized, e.g. routing flexibility, space utilization, safety, and reduced overall operational cost. Key issues to address during the design of an AGV system are explained, including selection of AGV platform, flow path design and fleet size determination. Issues associated with system functionality during AGVs run time are analyzed, such as: system management, (AGV allocation), navigation (establishing conflict free routes) and, load transfer (material pick up and deposit mechanisms). The presented case studies

give the state-of-the-art in AGV systems (concentrating on AGV run time functionality and AGV system performance measurement) and show that autonomous AGV systems offer numerous advantages in comparison to traditional systems.

Chapter 2 "Towards Application of Collective Robotics in Industrial Environment" (S. Kernbach)

The chapter is concerned with a significant area of modern robotics, which is multiple robots working as one group, team, swarm or organisms. The notion of taxonomy is introduced and an overview of cooperative, networked, swarm and nano-robotics is given. The chapter analyzes also reconfigurable robotics as a tool for improving granularity and adaptive functionality. The development of symbiotic self-reconfigurable systems is discussed and a survey of artificial self-organization is provided. Advantages provided by robots working in collective way are demonstrated, such as: advanced flexibility and adaptivity; possibilities to evolve behaviours, functions and structures; extended reliability of swarm and symbiotic systems; economic considerations related to agility of enterprises. Finally, emphasis is given to a more "difficult issue" which is artificial self-organization. It is shown that technical collective systems may exhibit self-organizing phenomena, despite the fact that they are artificially designed.

Chapter 3 "Fault Tolerant Control of Nonholonomic Mobile Robot Formations" (T. Dierks, B. Thumati and S. Jagannathan)

In this chapter, a fault tolerant kinematic/torque control law is developed using back stepping control for a leader-follower multi-robot formation. In contrast to kinematic-based formation controllers, the proposed control scheme aims at accommodating the dynamics of the robots and the formation. First, nominal control laws are derived for the leader and follower robots under the assumption of normal operation (no faults), and the stability of the individual robots and the formation is verified using Lyapunov methods. Subsequently, in the presence of state faults such as actuator fault, flat-tire etc., which could be incipient or abrupt in nature, an online fault detection and accommodation (FDA) scheme, is derived to mitigate the effects of a fault by modifying the nominal controller. In other words, an additional term is introduced to the existing control law to minimize the effects of the fault, and this additional term is a function of the unknown fault dynamics which are recovered using the online learning capabilities of a neural network. The chapter provides additional mathematical stability results using Lyapunov theory, and shows that both the FDA scheme and the formation errors are guaranteed to render asymptotic stability in the presence of faults. Numerical/simulation results are given to verify the theoretical conjectures.

Chapter 4 "Path Planning and Path Tracking of Industrial Mobile Robots" (S. Blažič, El-Hadi Guechi, J. Lauber, M. Dambrine and G. Klancar)

The purpose of this chapter is to give an overview of the state of the art and to propose some new approaches in the area of path planning and path tracking for wheeled mobile robots. The main part of the chapter is devoted to the methods that ensure stable tracking of the prescribed reference trajectories. Particular emphasis is given to approaches that result in global stability of the tracking model dynamics, such as (i) Lyapunov-based control and (ii) parallel distributed compensation (PDC) and particularly Takagi-Sugeno fuzzy control. The effects of discretization of the tracking-error model and the effects of measurements delay on the controller's performance are also analysed. The second part of the chap-

ter is devoted to path planning (trajectory design). Physical limitations in the robot's motion (slipping avoidance and keeping the wheels in contact with the ground) are analyzed and as obstacle avoidance issues are studied.

Chapter 5 "Technical Analysis and Implementation Cost Assessment of Sigma-Point Kalman Filtering and Particle Filtering in Autonomous Navigation Systems" (G. Rigatos)

The chapter provides technical analysis and implementation cost of Sigma-Point Kalman Filtering and Particle Filtering in autonomous navigation systems. As a case study, the sensor fusion-based navigation of an unmanned aerial vehicle (UAV) is examined. The UAV is considered to track a desirable flight trajectory by fusing measurements coming from its Inertial Measurement Unit (IMU) and measurements which can be received from a satellite or ground-based positioning system (e.g. GPS or radar). The estimation of the UAV's state vector is performed with (i) Sigma-Point Kalman Filtering (SPKF), (ii) Particle Filtering (PF). Trajectory tracking is succeeded by a nonlinear controller which is derived according to flatness-based control theory and which uses the UAV's state vector estimated through filtering. The performance of the autonomous navigation system which is based on the aforementioned state estimation methods is evaluated through simulation tests. Implementation cost assessment shows that PF requires more sample points than SPKF to approximate the state distribution. Therefore the PF is a computationally more demanding method which needs more costly computing machines. However, as pointed out in this chapter, the PF is a nonparametric filter which means that it can be applied to any kind of noise and state distribution, while the SPKF state estimators are still based on the assumption of a Gaussian process and measurement noise.

Chapter 6 "Visual Feedback for Nonholonomic Mobile Robots: An Homography Based Approach" (A. Usai and P. Di Giemberardino)

In this chapter, the problem of image-based visual servoing for autonomous robotic vehicles is examined. The chapter describes a homographic approach to vision-based feedback for non holonomic mobile robots control. Unlike other approaches based on homographic or fundamental matrix, the proposed method has been developed to be robust to reference features loss, during the robot movement. This allows the implementation of an arbitrary control law without the need of a teach-by-showing stage. The chapter investigates the use of a stereo camera system to improve the observer accuracy and to perform an auto-calibration of the stereo-head pose. Experimental results are provided to show the performances of the proposed system state estimation, using an eye-in-hand mobile robotic platform.

SECTION 2: STOCHASTIC MODELING FOR INDUSTRIAL SYSTEMS

Chapter 7 "Stochastic Methods for Hard Optimization. Application to Robust Control and Fault Diagnosis of Industrial Systems" (R. Toscano)

This chapter aims at solving difficult optimization problems arising in many engineering areas. To this end, a brief review of the main stochastic methods which can be used for solving continuous non-convex

constrained optimization problems is presented i.e.: Simulated annealing (SA), Genetic algorithm (GA), and Particle swarm optimization (PSO). In addition to that, the chapter presents a recently developed optimization method called Heuristic Kalman Algorithm (HKA) which seems to be, in some cases, an interesting alternative to conventional approaches. The performance of these methods depends significantly on the feasible search domain used to find out a solution as well as the initialization of the various user-defined parameters. From this point of view, some practical indications concerning these issues are given. Another objective of this chapter is to show that the stochastic methods, notably the Heuristic Kalman Algorithm, can be efficiently used to solve robust synthesis problems in the area of structured control and fault diagnosis systems. More precisely, the chapter examines the following problems: the synthesis of a robust controller with a given fixed structure and the design of a robust residual generator. Some numerical experiments exemplify the resolution of this kind of problems.

Chapter 8 "Identification of Linear Time-Varying Systems: Kalman Filter Approach" (V. Asutkar and B.M. Patre)

This chapter deals with identification of linear time-varying systems using the Kalman filter approach. The chapter shows that time-varying autoregressive models with exogenous input (TVARX) can be efficient in modeling time-varying systems. Moreover, it proposes the Kalman filter for optimal estimation of the changing parameters of time-varying systems. The chapter summarized some of the known features of the Kalman Filter, such as, (i) suitability for recursive estimation, (ii) good performance when there are abrupt changes in the system parameters, (ii) optimal parameter estimation under the assumption of white Gaussian noises. The chapter provides results on dynamical system identification with the use of a TVARX model, the parameters of which are estimated using recursive Kalman filter method. The system parameters are varied in continuous and abruptly changing manner to reveal the physical situation. To evaluate the performance of the Kalman Filter estimator, simulation examples with fast parameter changes and different noise conditions are provided. The simulation examples illustrate the efficacy of the proposed Kalman filter based approach for identification of time-varying systems.

Chapter 9 "An Advanced IDE for Designing Transparent Fuzzy Agents" (G. Acampora, E. Fischetti, A. Gisolfi and V. Loia)

This chapter introduces integrated development environment (IDE) supporting software developers in the design of fuzzy rule bases for control purposes. The proposed framework is realized by integration of theoretical methodologies such as fuzzy logic and labeled tree, together with Open Source Software tools such as JaxMe2. The chapter overviews controller design principle based on fuzzy rule bases and proposes labeled tree structures for representation of the fuzzy controller elements. The tree view of the fuzzy logic controller (FLC) allows embedding the controller in a multi-agent environment in a fast and simple way. The chapter shows how that the joint use of the labeled tree and the multi-agent environment results in an advanced graphical tool which facilitates the development and reprogramming of control systems, on different hardware, without repeating design and implementation steps.

SECTION 3 ELECTRIC POWER SYSTEMS

Chapter 10 "Artificial Neural Networks to Improve Current Harmonics Identification and Compensation" (P. Wira, D. Ould Abdelslam and J. Mercklé)

In this chapter, Artificial Neural Networks (ANNs) are employed for on-line control of an Active Power Filter (APF), so as to improve its performance. The chapter overviews the use of Artificial Neural Networks (ANNs) properties in dynamical system modelling and approximation and in adaptive control laws, and shows that ANN can find particular application in current harmonics identification. The proposed ANN-based identification and control scheme is employed for compensation of the changing harmonic distortions introduced in a power distribution system by unknown nonlinear loads. In the case study contained in this chapter, the implementation of the ANNs has been optimized on a digital signal processor for real-time experiments. The feasibility of the neural compensation scheme is validated and its improved performance when compared to conventional approaches is exhibited. The chapter points out that due to their learning capabilities, ANNs are able to take into account time-varying parameters such as voltage sags and harmonic content changes. Thus ANN-based identification and control schemes can significantly improve the performance of the APF compared to the one obtained with traditional compensating methods.

Chapter 11 "Intelligent Control and Optimal Operation of Complex Electric Power Systems Using Hierarchical Neural Networks" (D. Chen and R. Mohler)

This chapter aims at developing a unified neural network-based framework that can be used in prediction and control of complex dynamic systems. As explained in the chapter, in power systems, accurate prediction of system load behavior provides vital information which allows for optimal planning and most economic operation; on the other hand, the real-time system stability must be maintained against various random factors, disturbances and contingencies. Hierarchical neural networks are proposed for load forecasting, as well as for optimization and control. Unified design techniques are developed for providing control robustness, optimality and prediction accuracy. In the case studied in the chapter, hierarchical neural networks are used for power system stabilization considering a nonlinear single-machine infinite-bus model. Moreover, the hierarchical neural networks are used for load prediction. The design methodology of the chapter represents an attempt to address the challenge of adaptive controller design for power systems. On the other hand, this design methodology allows expert information to be incorporated in the construction of hierarchical neural networks for load forecast. Thus reasonably accurate (short term and very short term) load profiles can be provided for economical and reliable operations of ever growing power systems.

Chapter 12 "An Adaptive Framework for Power Components Dynamic Loadability" (A. Piccolo, P. Siano and G. Rigatos)

In this chapter a new approach, based on grey-box modeling, is applied to thermal state prediction for power components. As explained in the chapter, the prediction of the Hot Spot Temperature (HST) of power transformers represents a critical factor since it is essential to assess the thermal stress of the transformer's components, the loss of insulation life and to evaluate the consequent risks of both techni-

cal and economical nature. The proposed approach, integrates physical modeling with adaptive fuzzy modeling and is shown to be more reliable with respect to the top-oil-rise model based on nameplate values. As demonstrated by experimental results on a mineral-oil-immersed transformer, the proposed method is able to dynamically update the components capability curves and to automatically detect if a contingency could bring the system to violate the real equipment loading limits. Apart from providing predictions with great accuracy, the method is also characterized by reduced complexity, and achieves the best performance in terms of memory occupancy and computational time. The proposed modeling approach can guarantee a high flexibility and accuracy when working with power components having different design characteristics. The chapter's results are important for maintaining the secure operation of the electric power grid and of interconnected electric power systems, under dynamic changes of the loadability of its components.

SECTION 4 FAULT DIAGNOSIS FOR INDUSTRIAL SYSTEMS

Chapter 13 "Robust Fault Detection Based on State Observers for Networked Control Systems" (Z. Zhu and C. Chen)

In this chapter, Fault Diagnosis (FD) for Networked Controlled Systems (NCS) is studied using observer-based FD methods. First, aiming at a networked control system with short time-delays (in discrete-time description), its H_∞ and H_2/H_∞ state observer are designed and a robust fault diagnosis method is proposed. Second, state observer and fault diagnosis methods for networked control systems with uncertain long time-delays are designed in the time domain. Then the states observer is designed and robust fault diagnosis is achieved for NCS with uncertain long time-delays and external disturbances. Finally, examples are demonstrated for all the proposed methods and the results show the effectiveness of the proposed observer-based FDI scheme. The chapter's results are significant since networked control systems (NCS) for industrial applications have been widely developed and set in operation during the last years.

Chapter 14 "Fault Detection, Isolation and Characterisation for Discrete Event Systems Based on Petri Nets Models" (D. Lefebvre, E. Leclercq and S. Ould)

This chapter addresses two problems. The first one is the structure design and parameters identification of Petri net models according to the observation and analysis of sequences of events. The chapter is concerned with deterministic and stochastic-time Petri nets. The proposed method is based on a statistical analysis of data and has a practical interest as long as sequences of events are already saved by supervision systems. The second problem concerns the use of the resulting Petri net models to detect, isolate and characterize faults in discrete event systems. This contribution includes the characterization of intermittent faults. This issue is important because faults are often progressive from intermittent to definitive and early faults detection and isolation improve productivity and save money and resources. The results of the chapter are important since there is increasing demand for monitoring and early fault detection in various manufacturing, robotic, communication and transportation systems which are represented as discrete-event models. The use of Petri-nets contributes to the development of tools for fault detection, isolation and characterisation for these systems.

Chapter 15 "Monitoring of Non Stationary Systems Using Dynamic Pattern Recognition" (L. Hartert, M. Sayed-Mouchaweh and P. Billaudel)

In this chapter, the classification method "Incremental Fuzzy Pattern Matching" (IFPM) is proposed to be applied in the case of dynamic classes and to be used for the monitoring of evolving systems. IFPM gives good results for static classes, however, with non stationary systems, the classifier parameters must be adapted in order to take into account the temporal changes of classes' characteristics. These temporal changes can be represented for example by a displacement, a rotation, a splitting, or a fusion of classes. Therefore, the classification method must be able to forget the information which is no more representative of classes and it must adapt its parameters based only on the recent and useful information. This development is based on the use of an incremental algorithm allowing to follow the accumulated gradual changes of classes' characteristics after the classification of each new pattern. When these changes reach a suitable predefined threshold, the classifier parameters are adapted online using the recent and useful patterns. The chapter presents simulation results on the application of the proposed classification method on the two-tank benchmark problem. The chapter's results are of interest for industrial systems researchers since the monitoring of non stationary systems permits to follow online the evolutions and changes which occur in the system's functioning modes in the course of time.

Chapter 16 "Component Models Based Approach for Failure Diagnosis of Discrete Event Systems" (A. Philippot, M. Sayed-Mouchaweh and V. Carré-Ménétrier)

This chapter addresses the problem of diagnosing Discrete Event Systems (DESs), and specifically manufacturing systems with sensors and actuators operating in discrete-event mode. The main concept of the paper is that manufacturing systems are generally composed of several components which can evolve with the course of time. Their diagnosis requires the computation of a global model of the system; however this is not feasible due to the great number of components. To overcome this, the chapter proposes to perform the diagnosis based on component models. Each component model is constructed using different information sources represented by sensor-actuator spatial structure (plant model), controller specifications (desired behaviour) and temporal information about the actuators reactivity. In addition, the components' functioning constraints and characteristics are considered for this component model. The chapter shows that for each model, a local diagnoser can be computed. Its complexity is polynomial because the diagnosis is computed only for the faults which it can diagnose. Limited information about the global system functioning is required to synchronize the functioning of local diagnosers. This synchronisation is considered using a set of expert rules representing the symbolic information about the global desired behavior. Finally the chapter proposes to use the local diagnosers for performing online diagnosis. It is shown that local diagnosers validate, in the case of normal functioning, the transmission of control signals and incoming sensor data between the controller and the plant.

Chapter 17 "Quaternion Based Machine Condition Monitoring System" (W.K. Wong, C.K. Loo and W.S. Lim)

In this chapter, a new and effective quaternion-based machine condition monitoring system is analyzed. The proposed monitoring system uses log-polar mapper; quaternion based thermal image correlator and max-product fuzzy neural network classifier. Two classification characteristics are applied: (i) peak to

sidelobe ratio (PSR) and (ii) real to complex ratio of the discrete quaternion correlation output (ρ-*value*). Large PSR and ρ-*value* are observed in case of a good match among correlation of the input thermal image with a particular reference image, while small PSR and ρ-*value* are observed in case of a bad/ not match among correlation of the input thermal image with a particular reference image. Simulation results show that log-polar mapping actually helps solving rotation and scaling invariant problems in quaternion based thermal image correlation Log-polar mapping helps in smoothing the output correlation plane, hence it provides a better way for measuring PSR and ρ-*value*s. The simulation tests contained in this chapter show that the quaternion-based machine condition monitoring system is an efficient fault diagnosis tool with accuracy more than 98%.