Preface

Aim of the Book

Control loops are the most important components in automation systems. Product quality, operation safety, material and energy consumption, and thus the financial performance, are directly or indirectly linked to the performance of control systems. To achieve, restore and sustain top performance of control loops is thus a vital interest for any company. Since process control systems are very complex, usually comprising different hierarchical levels, it is hopeless to maintain them on regular basis by plant personal. This is also the main reason why a large portion of industrial control loops has significant performance problems, as found out by audits carried out regularly since the 1990s. All these factors have contributed to the growth of the control performance monitoring (CPM) technology and applications in the last decade. CPM provides a framework for automatically and systematically assessing the performance of control loops, detecting and diagnosing root-causes of poor performance, as well as suggesting measures to improve control performance or avoid performance degradation. At this point, it is stressed that any CPM technique should be *non-invasive* to be accepted in industrial practice. That is, the analysis should always be carried out *based on only routine operating data with limited or no additional process knowledge and without the need for any experimentation with the plant, not even in closed loop*.

Since the key research by Harris (1989), the control community has developed numerous methods that focus on the performance assessment of control loops. At the centre of these approaches is the concept of minimum variance benchmarking and different modifications or extensions, which have attracted much attention. Meanwhile, there is a large number of techniques for basic and advanced performance assessment, detection and diagnosis of different sources of poor performance (bad controller tuning, process nonlinearities, oscillations, etc.). Usually, emphasis is placed on single techniques to detect special performance problems or plant faults.

This is the first monograph that deals with the *complete CPM technology*, from *controller assessment* (minimum-variance-control-based and advanced methods), over *detection and diagnosis of control loop problems* (process nonlinearities, oscillations, actuator faults), to the *improvement of control performance* (maintenance, re-design of loop components, automatic controller re-tuning). It provides a contribution towards the development and application of completely *self-contained and automatic* methodologies in the field. Moreover, within this work, many CPM tools have been developed that go far beyond available CPM packages. Industrial data from a large number of control loops in different industrial fields (building, chemicals, mining, mineral and metal processing) have been used to demonstrate the presented strategies and methods. Systematic procedures for automatic and continuous control performance monitoring, maintenance and optimisation have been recommended, combining different control performance metrics and assessment, diagnosis and improvement methods. The main objective is to sustain top control performance during the whole life cycle of the control system, despite different and changing operational conditions.

Contributions of the Book

In the light of the *control-system life-cycle management* introduced above, the first contribution of our work is to provide strategies and methods for establishing a new practice of *integrated control design and performance supervision* of technical processes, as illustrated in Fig. 1.

The focus of this book is only on the last three stages, i.e., performance monitoring, condition monitoring and diagnosis, and CPM-based controller re-tuning. The book is however NOT on control system design or implementation, which is the topic of many standard texts. To the knowledge of the author, all major aspects of CPM, from *controller assessment* (minimum-variance-control-based and advanced methods), over *detection and diagnosis of control loop problems* (process non-linearities, oscillations, actuator faults), to the *improvement of control performance* (maintenance, re-design of loop components, automatic controller re-tuning) are treated for the first time in this work from a common viewpoint.

More specifically, the contributions and messages of the present book are stated as follows:

1. *Review, Evaluation and Industrial Application of Available Methods and Systems*. A comprehensive and critical review of the current status in the complete CPM technology, including techniques for performance assessment, diagnosis and improvement. Standard methods and advanced new methods are presented as well. This provides an insight into the assumptions and fundamental limitations of each control performance assessment method, since each of the various techniques signifies specific information about the nature of the process. Most CPM algorithms presented in the book have been implemented and tested by the author in MATLAB/Simulink.

   An evaluation of publications during the 15 years after the key work by Harris (1989) shows some trends in the application of a number of control performance metrics and methods in different process industries. Also included is an

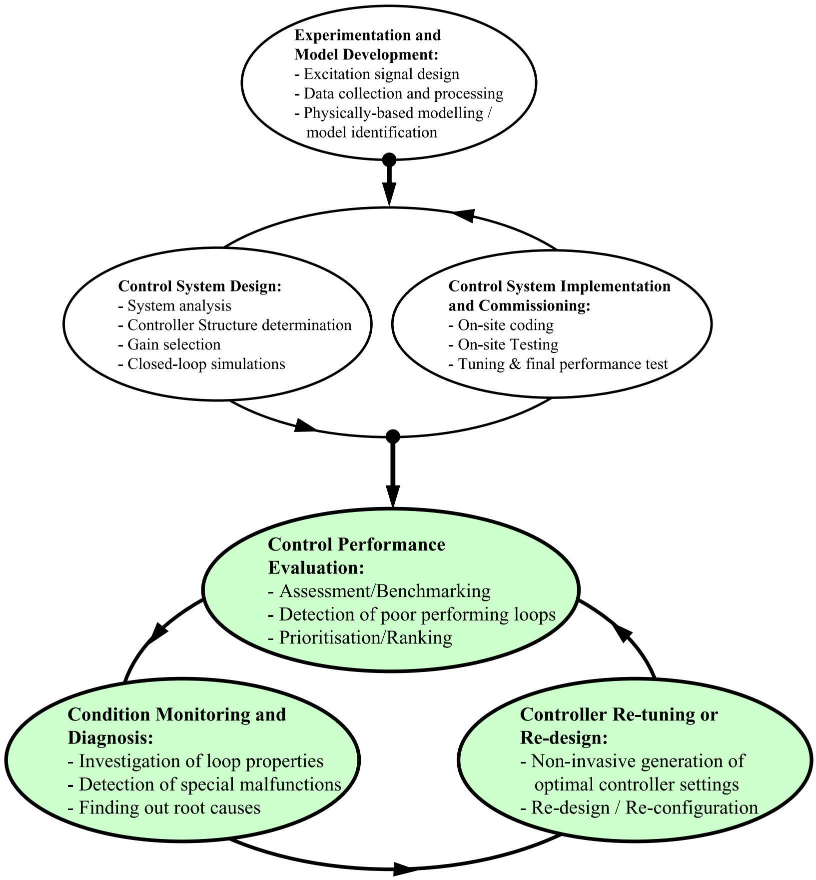

Fig. 1 Flow diagram of the process control design and supervision procedure

overview of CPM packages that have been developed and/or which are commercially available. Merits and drawbacks of the methods are also highlighted. Some control benchmarking techniques are compared in terms of parameters/data requirements and performance to draw guidelines for the choice of the most suitable technique or combination of techniques.
The majority of the methods presented are illustrated with real data from industrial control loops from different industrial fields, including chemicals, petrochemicals, pulp & paper plants, commercial buildings, power plants, mineral processing, mining and metal processing. Some information about these loops is given in Appendix C.

2. *Improved and New Methods for Control Performance Assessment and Diagnosis*. It is not sufficient and often dangerous to rely on a single index, or a single performance analysis method, by itself for performance monitoring and diagnosis, as each criterion has its merits and limitations. The best results are often

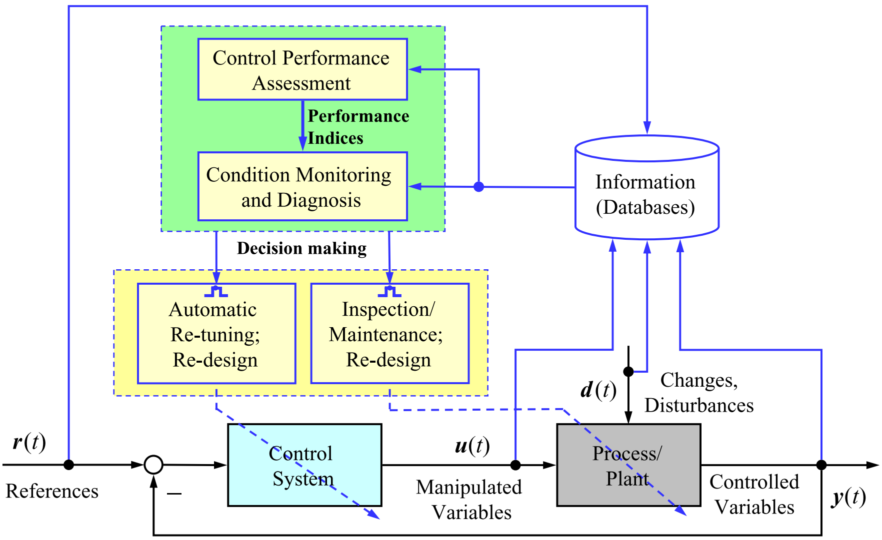

Fig. 2 Proposed framework for control-performance-monitoring-based optimisation of control loops

obtained by the collective application of several methods that reflect control performance measures from different aspects. Based on our experience from application of different assessment methods to control systems in the steel processing field, *systematic procedures for automatic and continuous control performance monitoring, maintenance and optimisation* will be recommended, combining different control performance metrics and assessment methods. Guidelines for how to select or determine the specific parameters, e.g., model orders and time delay, are worked out. Many improved and new CPM techniques developed by the author are presented. For instance, a new framework and method for detection and quantification of stiction in control valves is developed based on Hammerstein modelling and estimation using global search algorithms. Moreover, the method is extended for comprehensive oscillation diagnosis, i.e., discriminating between different causes generating the oscillation, even in the case of multiple faults.

3. *Introducing Anticipatory Control Maintenance Practices*. Bridging the fields "*Condition Monitoring and Diagnosis*", "*Control Performance Assessment and Monitoring*" and "*Automatic Controller Tuning and Adaptation*" is a core objective of this monograph; see Fig. 2. Loop condition monitoring and diagnosis is needed to investigate the properties of control loop components in terms of signal levels, noise levels, nonlinearities and equipment conditions. This particularly includes the detection of oscillations possibly generated by aggressive controller tuning, the presence of nonlinearities (e.g., static friction, dead-zone, hysteresis), or (internal and external) disturbances. Performance assessment is used to supervise the control loops during operation and ensure that they meet the performance specifications. Failure to meet the specifications should give an alert. It is

then decided to inspect/maintain a control loop component or to re-tune the controller. Methods and procedures for how to assist or partly automate this decision are presented.

4. *Automatic CPM-based Controller Re-tuning or Re-design*. When controller tuning is suggested, the control performance assessment results, i.e., indices, are used to generate new controller parameters, which can be downloaded to the controller on demand of the user or of a supervision mechanism. The main aim is to sustain top control performance despite different operational issues. For this purpose, new methods and procedures for CPM-based controller re-tuning are developed.
5. *Transfer the CPM Technology to Metal Processing Industry*. The comprehensive CPM review by Jelali (2006c) revealed a remarkable number of industrial applications to date, with a solid foundation in refining, petrochemical, chemical sectors and pulp & paper plants. However, only a few applications appeared in other industrial sectors. A substantial contribution of this book is thus to *transfer the CPM technology into a new industrial area, the metal processing*, where not much work has been done before. It is shown that the CPM algorithms can still perform well in *this more computationally demanding environment, where the speed is much faster and the time constants much smaller than in the traditional refining and chemicals applications*. Thus many special aspects have to be considered.

As stated by Shah et al. (2005), the challenges are primarily not related to whether the CPM technology itself is effective, but rather related to the human factors surrounding the use of CPM applications. The critical success factor is how an application integrates with existing work practices and maintenance procedures. A substantial part of this work *illustrates the monitoring methods in successful applications and tailored CPM tools integrated into maintenance procedures in rolling mills*, developed within research projects initiated or managed by the author.

Readership

The book is aimed primarily at researchers and engineers in process control and industrial practitioners in process automation, but it is also accessible to postgraduate students and final-year students in process-control engineering.

Most of the methods and algorithms presented in this book are the state-of-the-art and are demonstrated on industrial case studies from different industrial fields (building, chemicals and petrochemicals, mining, mineral and metal processing). The book will thus serve academic and industrial staff working in all these industries on control systems design, maintenance or optimisation.

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was carried out within the EU research project AUTOCHECK (Jelali et al. 2008). Not only the writing of this book, but also the thinking and implementing most of CPM routines took a big portion of my free time, at weekends and long nights.

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