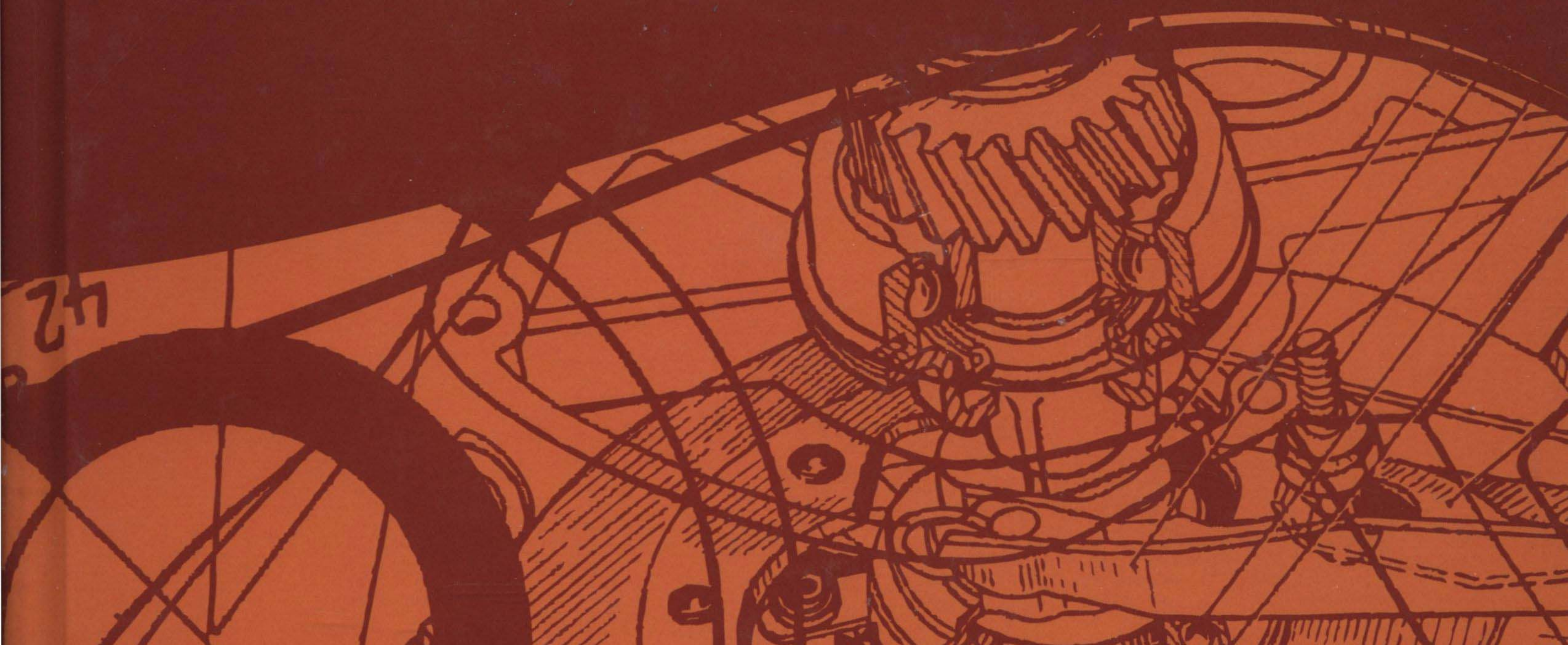
Handbook of Research on Computational Simulation and Modeling in Engineering



Francisco Miranda and Carlos Abreu

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Handbook of Research on Computational Simulation and Modeling in Engineering

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Preface

Computational simulation and modeling applied to engineering is a field that brings together the power of computers and the physical sciences. Computer-based simulations and graphical visualization now play a key role in mathematical models, scientific investigations and engineering design. This interdisciplinary field uses the power of sophisticated computational systems to analyze problems that would be too expensive, dangerous, or even impossible to study by direct experimentation. Virtual prototyping, using modeling and software technologies, is now a key process in reducing the overall cost of designing and manufacturing new products. The growth in the number of organizations developing and accessing these technologies has led to a dramatic increase in the requirement for skilled people and better research in this exciting field.

Computer simulation is a scientific tool that had its peak for the first time during the World War II, and since then has become very important in a growing number of fields, among them, the engineering. At this time, computer simulations were made using analog computers. Analog computers are able to compute mathematical, physical and thecnical problems by abstracting it to a physical system following the same mathematical laws. The new technologies developed for military purposes led to the development of the digital computer. The digital computer is a class of devices that is able to solve the information-processing problems in discrete form. It operates on data, including magnitude, letters and symbols expressed in binary form. By manipulating these digits and their combinations accordingly with an instruction set executed in his memory, a digital computer can perform important tasks in engineering.

To solve different problems in engineering using computer simulation, it is necessary firstly model the problem. This shows the importance of the modeling in the engineering problems and this is a process of representing a real-world object or phenomenon as a set of mathematical equations. As we know, most of the phenomena involved in physical systems are governed by scientific laws. These laws have different properties and provide knowledge about the states and processes that a system undergoes. Therefore, mathematical models can be derived based on these laws, allowing scientists and engineers can to explain what happened or predict what will happen.

Usually, a mathematical model is too complicated to solve, than a computer is required. Thus, we should construct a computer model that approximates the solution using numerical algorithms. Computational models, often called numerical algorithms, are increasingly more important parts in the resolution problems assisted by computer, which are almost a toolbox for all engineers whose work involves research and development.

The modeling and computational simulation are very powerful prediction tools used to solve different engineering problems that we can find in various real world processes.

PURPOSE OF THE BOOK

The main purpose of this book is to give to students, researchers and technicians broad coverage of the technological and scientific subjects in the modeling and simulation field required to underpin the success of engineering structures in a range of scientific and technical fields, providing in-depth study and training encompassing the principles and techniques in modeling and computational simulation. The book aims to equip the young researchers and technicians with the skills developed in this field, and provides an insight into engineering modeling and numerical software used. The purpose is also to demonstrate how these technologies can be used effectively in solving real-world problems.

TARGET AUDIENCE

The target audience of this book will be composed of academicians, researchers, advanced-level students, technology developers, and engineers. This book can potentially be used in any undergraduate or graduate course in the field of modeling and computational simulation in engineering.

ORGANIZATION OF THE BOOK

The book is organized into twenty four chapters. A brief description of each of the chapters follows:

Chapter 1 presents a computational modeling and simulation to assist the improvement of thermal performance and energy efficiency in industrial engineering systems applied to cold stores. This chapter describes three distinct computational tools with different mathematical and numerical models. The computational tools are used with the purpose of improving the thermal and energy performance of cold stores. All tools are applied to the same agrifood company. First, Computational Fluid Dynamics is used to optimize velocity and temperature fields in the interior of a cold room. Afterwards, an energy analysis and thermal load simulation are performed in the cold store facility to reduce its thermal loads. Finally, a statistical prediction model based on empirical correlations is used to predict the energy performance of the cold store and compare it to an average behavior. The numerical results indicate the improvement of the thermal performance and consequently of food safety, as well as considerable energy savings that can be achieved in cold stores by the combined use of different modeling techniques.

Chapter 2 introduces different approaches for studying interruptible industrial processes with application of two different simulation techniques. This chapter presents the issue of complex systems simulation through Discrete Event Simulation (DES) and System Dynamics (SD) techniques. The Authors original approach stands in the combined employ of the two SD and DES simulation techniques to solve real logistic problems. In the course of the chapter, examples of real world issues regarding logistics are explained. In particular, the following case studies are provided: a production environment, a waste collection scheme, a hub base, a harbor including container terminal, bulk terminal and navigation channel.

Chapter 3 presents the energy conservation law for the turbulent motion in the free atmosphere. It is studied the convergent-divergent flow in the free atmosphere which is governed by the three dimensional Navier-Stokes equations and deals with the fundamental problem of fluid dynamics. Considering air movement under influence divergence and rotation are found the true dependencies between the velocity vector and the pressure distribution. Following the classical procedure by using rotor operator and a well-known formula of vector analysis are obtained the second kind nonlinear Volterra-Fredholm integral equations in a matrix form which contained only three components of the velocity vector. According to the theory of the matrix operators are defined the velocity components by the successive approximation method. According to the obtained balance equation for the pressure distribution are defined significant properties of the transient convergent-divergent flow which provide a description of the constitutive relationships between three physical quantities: the velocity vector, the external and internal forces, and the pressure distribution.

Chapter 4 shows us a multi-objective optimization of two-stage thermo-electric cooler (TEC) using differential evolution. First, the technical issues of two-stage TEC are discussed. After that, a new method of optimizing the dimension of TECs using differential evolution to maximize the cooling rate and coefficient of performance is proposed. A input current to hot side and cold side of and the number ratio between the hot stage and cold stage are searched the optima solutions. Thermal resistance is taken into consideration. The results of optimization obtained by using differential evolution are validated by comparing with those obtained by using genetic algorithm and show better performance in terms of stability, computational efficiency, and robustness. This chapter reveals that differential evolution is more stable than genetic algorithm and the Pareto front obtained from multi-objective optimization balances the important role between cooling rate and coefficient of performance.

Chapter 5 presents a work about simulation performance of feedforward and nonlinear autoregressive moving average with exogenous inputs (NARX) networks under different numerical training algorithms. This chapter focuses on comparing the forecasting ability of the backpropagation neural network (BPNN) and the NARX network trained with different algorithms; namely the quasi-Newton (Broyden-Fletcher-Goldfarb-Shanno, BFGS), conjugate gradient (Fletcher-Reeves update, Polak-Ribiére update, Powell-Beale restart), and Levenberg-Marquardt (LM) algorithm. Three synthetic signals are generated to conduct experiments. The simulation results show that in general the NARX which is a dynamic system outperforms the popular BPNN. In addition, conjugate gradient algorithms provide better prediction accuracy than the LM algorithm widely used in the literature in modeling exponential signal. However, the LM performed the best when used for forecasting the Moroccan and South African stock price indices under both the BPNN and NARX systems.

Chapter 6 is a work about the use of stochastic activity networks for an energy-aware simulation of automatic weather stations (AWSs). AWSs are embedded systems equipped with a number of sensors used to monitor harsh environments: glaciers and deserts. AWSs may also be equipped with some communication interfaces in order to enable remote access to data. These systems are generally far from power sources, and thus they are equipped with energy harvesting devices, wind turbines and solar panels, and storage devices, batteries. The design of an AWS represents a challenge, since designers have to maximize the sampled and transmitted data while considering the energy needs. Here is designed and implemented an energy-aware simulator of AWSs to support designers in the definition of the configuration of the system. The simulator relies on the Stochastic Activity Networks (SANs) formalism and has been developed using the Möbius tool. In this chapter first is shown how we use SANs to model the components of an AWS, then are reported the results from validation experiments carried out by comparing the results of the simulator against a real-world AWS and finally are shown examples of its usage.

Chapter 7 makes a reliability analysis of slope using Minimax Probability Machine Regression (MPMR), Generalized Regression Neural Network (GRNN) and Gaussian Process Regression (GPR). First Order Second Moment Method (FOSM) is generally for determination of the reliability of the slope. This chapter adopts MPMR, GRNN and GPR for reliability analysis of slope by using FOSM. In this study, an example of soil slope is given regarding how the proposed GPR-based FOSM, MPMR-based FOSM and GRNN-based FOSM analysis can be carried out. GPR, GRNN and MPMR have been used as regression techniques. A comparative study is carried out between the developed GPR, MPMR and GRNN models. The results show that MPMR gives better performance than the other models.

Chapter 8 designs a fuzzy logic based hydraulic turbine governing system. The chapter describes the design of the speed governing system of 150 MW Francis turbines at a power station. The turbine governing system is vital for the safety and availability of a power plant. The dynamic characteristics of the turbine system are nonlinear and difficult to predict. The identification, development and implementation of the hydraulic system for the power plant are done via literature survey and computer based simulations and also analyzed by comparing different controllers through simulation. The governor system parameters are simulated with the actual data available in the power plant. Traditional Proportional Integral Differential (PID) controller parameters are difficult to tune when used in control systems and a fuzzy PID which can tune the parameters on-line is introduced to be appropriate in the turbine governing control system. In MATLAB/SIMULINK simulation environment, the simulation results show that fuzzy logic PID control strategy has better performances than a traditional PID controller.

Chapter 9 characterizes the enterprise application integration solutions as discrete-event systems. It is not difficult to find an enterprise which has a software ecosystem composed of applications that were built using different technologies, data models, operating systems, and most often were not designed to exchange data and share functionalities. Enterprise application integration provides methodologies and tools to design and implement integration solutions. The state-of-the-art integration technologies provide a domain-specific language that enables the design of conceptual models for integration solutions. The analysis of integration solutions to predict their behavior and find possible performance bottlenecks is an important activity that contributes to increase the quality of the delivered solutions, however, software engineers follow a costly, risky, and time-consuming approach. Integration solutions shall be understood as a discrete-event system. This chapter introduces a new approach based on simulation to take advantage of well-established techniques and tools for discrete-event simulation, cutting down cost, risk, and time to deliver better integration solutions.

Chapter 10 compares methods to display principal component analysis, focusing on biplots and the selection of biplot axes. Principal Components Analysis (PCA) is probably the most important multivariate statistical technique, being used to model complex problems or just for data mining, in almost all areas of science. Despite being well known by researchers and available in most statistical packages, it is often misunderstood and poses problems when applied by inexperienced users. A biplot is a way of concentrating all information related to sample units and variables in a single display, in an attempt to help interpretations and avoid overestimations. This chapter covers the main mathematical aspects of PCA, as well as the form and covariance biplots developed by Gabriel and the predictive and interpolative biplots devised by Gower and coworkers. New developments are also presented, involving techniques to automate the production of biplots, with a controlled output in terms of axes predictivities and interpolative accuracies, supported by the AutoBiplot. PCA function developed in R. A practical case is used for illustrations and discussions.

Chapter 11 introduces an educational software based on Matlab GUIs for neural networks courses. Neural Networks (NN) are one of the most used machine learning techniques in different areas of knowledge. This has led to the emergence of a large number of courses of Neural Networks around the world and in areas where the users of this technique do not have a lot of programming skills. Current software that implements these elements, such as Matlab®, has a number of important limitations in teaching field. In some cases, the implementation of an MLP requires a thorough knowledge of the software and of the instructions that train and validate these systems. In other cases, the architecture of the model is fixed and they do not allow an automatic sweep of the parameters that determine the architecture of the network. This chapter presents a teaching tool for the its use in courses about neural models that solves some of the above-mentioned limitations. This tool is based on Matlab® software.

Chapter 12 presents a survey on human motion analysis and simulation tools. Computational systems to identify objects represented in image sequences and tracking their motion in a fully automatic manner, enabling a detailed analysis of the involved motion and its simulation are extremely relevant in several fields of our society. In particular, the analysis and simulation of the human motion have a wide spectrum of relevant applications with a manifest social and economic impact. In fact, usage of human motion data is fundamental in a broad number of domains (e.g., sports, rehabilitation, robotics, surveillance, gesture-based user interfaces, etc.). Consequently, many relevant engineering software applications have been developed with the purpose of analyzing and/or simulating the human motion. This chapter presents a detailed, broad and up to date survey on motion simulation and/or analysis software packages that have been developed either by the scientific community or commercial entities. Moreover, a main contribution of this chapter is an effective framework to classify and compare the motion simulation and analysis tools.

Chapter 13 introduces methods for assessing still image compression efficiency. Assessing the computational efficiency of an image compression technique plays an important part in evaluations used to estimate the overall quality of the compression. In this chapter, different methods for assessing the computational efficiency will be explored as a part of the evaluations used to determine still image compression usability in image storage/communication systems such as a Picture Archiving and Communication System. Efficiency describes how well the image compression makes use of the available computing resources. It is not an obligatory part of the evaluation and there is no unique method for assessing compression efficiency. The results of compression efficiency assessment are usually interpreted in the context of the hardware and software platform used in the evaluation. This dependence is addressed and different ways for its amelioration are discussed in the chapter. This is the groundwork for research in developing a platform-independent method for assessing compression efficiency.

Chapter 14 emphasizes the role of modeling, prototyping, and simulation in software design. The chapter introduces the principles of software design issues and challenges. Modeling techniques used in procedural and object oriented methodologies are presented along with the Unified Modeling Language (UML). The suitability of prototyping, as a design artifact and a simulation method is briefly discussed. Software processes such as Rapid Application Development (RAD), Rational Unified Process (RUP) and Agile methodologies which influence the design process have been discussed and recommended. The chapter then deals with Design Metrics for Quality Analysis, Software Risk Analysis and Threat Modeling for the design of secure software. Finally, some of the recent research topics such as Model Driven Architecture (MDA), Model Driven Development (MDD), Meta Object Facility (MOF), and Model Driven Testing (MDT) are covered.

Chapter 15 presents a numerical modeling of reinforced concrete (RC) bridges for seismic risk analysis. The main purpose of this chapter is to present numerical methodologies with different complexities in order to simulate the seismic response of bridges and then use the results of the safety assessment with one probabilistic approach. The numerical simulations are carried out using three different methodologies: (i) plastic hinge model, (ii) fiber model and (iii) damage model. Seismic response of bridges is based on a simplified plane model, with easy practical application and involving reduced calculation efforts while maintaining adequate accuracy. The evaluation of seismic vulnerability is carried out through the failure probability quantification involving a nonlinear transformation of the seismic activity in its structural effects. The applicability of the proposed methodologies is then illustrated in the seismic analysis of two reinforced concrete bridges, involving a series of experimental tests and numerical analysis, providing an excellent set of results for comparison and global calibration.

Chapter 16 gives us an overview on the state-of-the-art of the simulation based construction project schedule optimization. Construction projects require a multitude of procedures and resources for the high diversity of building concepts. Most of such projects are unique in their design and need individual schedule planning to be realized. In order to develop the required schedules, several complex decisions need to be made and several different factors need to be taken into account, including cost, make span, safety, resource sparsity, delivery schedules and geometric constraints. The problem of scheduling the involved processes in an optimal way is called the resource constrained project scheduling problem (RCPSP) and several solution algorithms are available. In addition, simulation based techniques can be used to address more complex constraints and objectives. This chapter presents an overview of traditional optimization procedures for the RCPSP and bridge the gap to simulation based techniques, which are described in detail.

Chapter 17 introduces a stochastic drought forecasting exploration for water resources management in the upper Tana River basin in Kenya. Precisely, this chapter presents trend of drought as a stochastic natural disaster influenced by the climate variability for the upper Tana River basin. Drought frequency, duration and intensity in the upper Tana River basin have been increasing over the years. To develop measures for mitigating impacts of drought, the influencing hydro-meteorological parameters and their interaction are necessary. Drought definitions, fundamental concepts of droughts, classification of droughts, types of drought indices, historical droughts and application of artificial neural networks in analyzing impacts of drought on water resources with the special focus of a Kenyan river basin is presented. Gaps for more focused research are identified. Drought prediction in Kenya is limited and yet very vital in numerous sectors such as water, agriculture and hydro-power generation. There is need to develop an effective drought forecasting tool for onset detection and drought classification and drought forecasting, for decision making on matters of drought preparedness and proper water resources management.

Chapter 18 considers structural non-linear models and simulation techniques for safety verification of reinforced concrete (RC) structures. Advances in computer technology allow nowadays the use of powerful computational models to describe the non-linear structural behavior of RC structures. However, their utilization for structural analysis and design is not so easy to be combined with the partial safety factors criteria presented in civil engineering international codes. Trying to minimize this type of difficulties, it proposed a method for safety verification of RC structures based on a probabilistic approach. This method consists in the application of nonlinear structural numerical models and simulation methods. In order to reduce computational time consuming the Latin Hypercube sampling method is adopted, providing a constrained sampling scheme instead of general random sampling like Monte Carlo method. The proposed methodology permits to calculate the probability of failure of RC structures, to evaluate the accuracy of any design criteria and, in particular, the accuracy of simplified structural design rules, like those proposed in civil engineering codes.

Chapter 19 presents modeling for self-optimization in laser cutting. Laser based cutting processes comprise a significant part of industrial manufacturing. To ensure a high level of cutting quality the process parameters have to be kept at the right values and within defined tolerances. In this context, the position of the laser beam focus is one of the most important parameters. However, due to thermal heating of optical elements the focal position shows a transient behavior. The handling of this focus shift is aggravated by the fact that the focal position is not directly detectable during processing. In this chapter an introduction on the topic of laser cutting is given. Subsequently, a closed mathematical formulation of laser fusion cutting is presented before a reduced model is developed that allows the determination of a focus shift by an experimentally accessible surrogate criterion. The theoretical predictions are finally validated by experimental results.

Chapter 20 analyzes the sensitivity of laser cutting based on metamodeling approach. The utility of a metamodel in gaining valuable information relating to the optimization of a laser cutting process using a continuous wave (CW) laser source is analyzed. The simulation itself is characterized by a high dimensional input parameter set. Each parameter has its own range, and thus the complete parameter sets with their ranges from the full parameter domain space. The quality criteria are analyzed and used as objective function to optimize the process. Simulation results can only help in the build-up of process understanding, if they can be presented in their entirety and together with their origin in the parameter domain. For this purpose a metamodeling concept is presented, which takes the results from simulations and generates a process map that clearly indicates the process domains. For gaining insights, the Elementary Effect method is applied to screen the important parameters that exhibit the greater impact on the process.

Chapter 21 presents simulations and modeling of Tunnel Field-Effect Transistor (TFET) for low power design. In Complementary Metal-Oxide-Semiconductor (CMOS) technology, scaling has been a main key for continuous progress in silicon-based semiconductor industry over the past four decades. However, as the technology advancement on a nanometer scale regime for the purpose of building ultra-high density integrated electronic computers and extending performance, CMOS devices are facing fundamental problems such as increased leakage currents, large process parameter variations, short channel effects, increase in manufacturing cost, etc. The new technology must be energy efficient, dense, and enable more device function per unit area and time. There are many novel nano-scale semiconductor devices, this chapter introduces and summarizes progress in the development of the TFETs for low power design. Tunnel FETs are interesting devices for ultra-low power applications due to their steep sub-threshold swing (SS) and very low OFF-current. Tunnel FETs avoid the limit 60mv/decade by using quantum-mechanical Band-to-Band Tunneling (BTBT).

Chapter 22 uses theoretical and computational models to understand how metals function as temperature sensors. Electrical conductivity is a basic property of materials that determines how well the material conducts electricity. However, models are needed that help explain how conductors function as their size and temperature changes. This chapter demonstrates and explains how important atomic motion is in understanding electrical conductivity of conductors (and thus the ability of metals to function as temperature sensors). A derivation is performed (on an atomic level) that provides a theoretical relationship between electrical resistivity, temperature, and material thickness. Subsequently, computational models are used to determine the optimal parameters for the theoretical models as well as the conditions under which they are accurate. Comparisons are performed using experimental data showing that the models are valid and accurate.

Chapter 23 studies the quality of service and radio management in biomedical wireless sensor networks. Biomedical wireless sensor networks enable the development of real time patient monitoring systems, either to monitor chronically ill persons in their homes or to monitor patients in step-down hospital units. However, due to the critical nature of medical data, these networks have to meet demanding quality of service requirements, ensuring high levels of confidence to their users. These goals depend on several factors, such as the characteristics of the network deployment area or the network topology. In such context, this chapter surveys the main applications of biomedical wireless sensor networks, taking into account the key quality of service requirements of each one of them. Finally, it presents an analytic method, and its experimental validation, to help engineers managing the radio power of the network nodes in order to improve the communications and the quality of service provided by the network while minimizing the energy consumption and, thus, maximizing the network lifetime.

Chapter 24 presents a simulation framework to reduce Wireless Sensor Network (WSN) simulation runtime by using multiple simultaneous instances. WSNs can be deployed using widely available hardware and software solutions. The Contiki is an open source operating system compatible with a wide range of supported WSN hardware. A Contiki development environment named InstantContiki is also available and includes the Cooja simulation tool, useful for the simulation of WSN scenarios, prior to their deployment. This simulation tool can provide realistic results since it uses the full Contiki's source code and some motes can be emulated at the hardware level. However, this implies the extension of simulation runtime, which is heightened since the Cooja is single threaded, i.e, it makes use of a single core per instant of time, not taking full advantage of the current multi-core processors. In this chapter is presented a framework to automate the configuration and execution of simulations of multiple scenarios in Cooja. When a multi-core processor is available, this framework can run multiple simultaneous Cooja instances to reduce simulation runtime in exchange of higher CPU load and RAM usage.

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Section 1

Intelligent Systems and Control Engineering