Studies in Systems, Decision and Control

Volume 360

The series "Studies in Systems, Decision and Control" (SSDC) covers both new developments and advances, as well as the state of the art, in the various areas of broadly perceived systems, decision making and control–quickly, up to date and with a high quality. The intent is to cover the theory, applications, and perspectives on the state of the art and future developments relevant to systems, decision making, control, complex processes and related areas, as embedded in the fields of engineering, computer science, physics, economics, social and life sciences, as well as the paradigms and methodologies behind them. The series contains monographs, textbooks, lecture notes and edited volumes in systems, decision making and control spanning the areas of Cyber-Physical Systems, Autonomous Systems, Sensor Networks, Control Systems, Energy Systems, Automotive Systems, Biological Systems, Vehicular Networking and Connected Vehicles, Aerospace Systems, Automation, Manufacturing, Smart Grids, Nonlinear Systems, Power Systems, Robotics, Social Systems, Economic Systems and other. Of particular value to both the contributors and the readership are the short publication timeframe and the world-wide distribution and exposure which enable both a wide and rapid dissemination of research output.

Indexed by SCOPUS, DBLP, WTI Frankfurt eG, zbMATH, SCImago.

All books published in the series are submitted for consideration in Web of Science.

More information about this series at http://www.springer.com/series/13304

Vitaliy P. Babak · Serhii V. Babak ·
Volodymyr S. Eremenko · Yurii V. Kuts ·
Mykhailo V. Myslovych · Leonid M. Scherbak ·
Artur O. Zaporozhets

Models and Measures in Measurements and Monitoring

Springer

Vitaliy P. Babak
Institute of Engineering Thermophysics
National Academy of Sciences of Ukraine
Kyiv, Ukraine

Volodymyr S. Eremenko
Igor Sikorsky Kyiv Polytechnic Institute
National Technical University of Ukraine
Kyiv, Ukraine

Mykhailo V. Myslovych
Institute of Electrodynamics
National Academy of Sciences of Ukraine
Kyiv, Ukraine

Artur O. Zaporozhets
Institute of Engineering Thermophysics
National Academy of Sciences of Ukraine
Kyiv, Ukraine

Serhii V. Babak
Verkhovna Rada of Ukraine
Kyiv, Ukraine

Yurii V. Kuts
Igor Sikorsky Kyiv Polytechnic Institute
National Technical University of Ukraine
Kyiv, Ukraine

Leonid M. Scherbak
Kyiv International University
Kyiv, Ukraine

ISSN 2198-4182 ISSN 2198-4190 (electronic)
Studies in Systems, Decision and Control
ISBN 978-3-030-70782-8 ISBN 978-3-030-70783-5 (eBook)
https://doi.org/10.1007/978-3-030-70783-5

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Introduction

Nowadays, measurements are an integral component in all spheres of the life of modern society—from everyday life to high-tech industries, energy, aviation, astronautics, various branches of the scientific and industrial complex. Ensuring comfortable living conditions for a person at home ("smart home"), production of electric and thermal energy, management of complex technological processes, monitoring the dynamics in space and time of climatic and ecological environmental conditions, control of transport objects on earth, water, air and space diagnostics of technical and other objects of varying complexity, product quality control and management—all these processes require high-precision measurements of a significant number of physical quantities, which develop in space and time, and processing of constantly growing volumes of measurement information.

Measurement is almost the only source of obtaining objective quantitative information about the surrounding material world, the level and quality of society. Expanding the dynamic range of measurements in studies of the micro- and macroworld, increasing the requirements for accuracy and reliability of measurement results, increasing the range of measured electrical and non-electrical physical quantities—all this requires an in-depth understanding of the synthesis and analysis of measurement procedures and operations, the development of an appropriate theoretical basis, information and hardware providing.

The cornerstone of measurement theory and practice has always been and remains the fundamental concepts of model and measure. It is known that models and measures have always reflected and served as a kind of indicator of the achievements of science and technology at a certain historical stage of their development. On their basis, measuring instruments were developed, the use of which in practice contributed to the acquisition of new knowledge. In practice, the hypothesis of the famous English physicist A. Michelson (middle of nineteenth century) about new discoveries in physics, when the relative measurement accuracy reaches the level of 10^{-n} ($n \geq 6$), was confirmed.

It is precisely the probability models of the measured quantities, processes, signals as information carriers, as well as physical and probabilistic measures that determine the measurement result, provide it with the properties of objectivity and reliability. Therefore, the issues of improving and developing models and measures in

the measurement methodology play an increasingly important role in finding ways to achieve high accuracy of measurements and expanding their areas of application. This monograph is devoted to questions of generalization and research of features and the application of constructive models and measures in the modern measurement methodology.

The monograph consists of 8 chapters.

Chapter 1 discusses general issues of measurement problems, including the main provisions and definitions of measurements, proposes a system of postulates on which the theory and practice of measurements are based, and the concept of a mathematical model of measurement uncertainty, and briefly describes measurements as the inverse problem of the theory of signals and systems. The concept of measure and its development from a philosophical category to objects of study and use in mathematics and metrology are studied in detail. The authors proposed and reviewed the concept of matching physical and probabilistic measures in measurements and proposed a classification of physical and probabilistic measures for measurements, and the use of various measures in the structure of information-measuring systems.

Chapter 2 systematizes mathematical models of measuring signals and fields, considers the main spatiotemporal models of quasi-determined signals and provides the necessary information about the spaces of signals, in particular linear, metric, normalized and Hilbert. Separately, the use of orthogonal bases in the study of deterministic signals is considered, and theoretical information about the model of random signals and fields is presented.

Chapter 3 discusses models and measures for measuring random angular quantities and provides basic concepts, terms, definitions and characteristics that are used in the statistical analysis of angular data. The most characteristic probability distributions of random angles (von Mises and wrapped normal distribution) are analyzed. A comparative analysis of the numerical characteristics of random variables and random angles is performed. The basic information about the models developed by the authors and measures of random phase shifts of cyclic signals for phase measurements is presented.

Chapter 4 gives an example of the construction and use of models and measures in the diagnosis of electric power facilities, describes in detail the processes of generating diagnostic signals and models of the formation of training sets (measures) for diagnosing the state of electric power equipment and offers the option of constructing diagnostic spaces based on the measurement of information signals, as well as constructing decisive rules for the diagnosis and classification of certain types of defects in the nodes of electro-energy objects.

Chapter 5 shows examples of the use of models and measures on a circle for solving problems of precision ultrasonic thickness measurement of products from materials with significant attenuation, processing the results of bag scale-free phase measurements based on numerical systems of residual classes in phase range finders and direction finders. The features of statistical data processing in environmental monitoring systems based on unmanned aerial vehicles (UAVs) are considered.

Chapter 6 discusses the features of using models and measures for standardless measurements of the characteristics of composite materials and substantiates the

possibility of using neural networks in computerized diagnostic systems to classify defects and build appropriate naming scales.

Chapter 7 discusses air pollution monitoring using UAVs. The specifics and content of the information support of the measuring system using UAVs are described. A model of the vector random field is proposed for the case of the formation of a local pollution field, the characteristics of which are estimated in the framework of the correlation theory. The structure of the multifunctional measuring system using UAVs for remote monitoring of air pollution is analyzed, and the results of experimental studies of monitoring air pollution by radionuclides near the Chernobyl Nuclear Power Plant are presented.

Chapter 8 considers the features of monitoring atmospheric air pollution and proposes a promising direction for the development of an extensive network of monitoring systems. A method for localizing the source of pollution according to monitoring data in the polar coordinate system is proposed. The methods of statistical processing of monitoring data within the framework of the correlation theory are substantiated. The structure of a spatially branched air pollution monitoring network using modern information technologies is described. The measuring modules of the network are developed, and the results of their experimental studies are presented. A method for assessing the level of air pollution based on monitoring results and statistical characteristics of local atmospheric pollution fields is proposed.

A number of formulated provisions and statements are debatable. The authors will be grateful to all readers who will send feedback, comments and suggestions on the material presented in the monograph.

Vitaliy P. Babak
Serhii V. Babak
Volodymyr S. Eremenko
Yurii V. Kuts
Mykhailo V. Myslovych
Leonid M. Scherbak
Artur O. Zaporozhets

Contents

Abbreviations

ADC	Analog-to-digital signal conversion
AFCS	Automatic flight control system
APCS	Automatic process control system
DC	Direct current
ECM	Electronic countermeasure
EDR	Exposure dose rate
EE	Electric power equipment
EM	Electrical machine
EPF	Electric power facility
FID	Filter-injection device
FPM	Frequency–pulse modulation
GPS	Global Positioning System
GCE	Ground control equipment
IMS	Information-measuring system
IRPU	Information receiving and processing unit
ISO	International Organization for Standardization
LRP	Linear random process
MC	Magnetic circuit
MPC	Maximum permissible concentration
NPP	Nuclear power plant
OCE	Onboard control equipment
PCRP	Periodically correlated random process
PDF	Probability density function
PWM	Pulse width modulation
RMS	Root mean square
RO	Research object
RP	Radio pulse
SAR	Synthetic-aperture radar
SCA	Sample circular average
SD	Standard deviation
SM	Steering mechanism
SRC	System of residual class

SRL	Selective resulting length
SRNS	Satellite radio navigation system
TPP	Thermal power plant
UAS	Unmanned aerial system
UAV	Unmanned aerial vehicle
UTM	Ultrasonic thickness measurement
WEU	Wind electric unit