

# Preface to the Third Edition

The purpose of this book is to present methods for estimating the accuracy of real measurements, that is, measurements performed in industry, trade, scientific research – wherever the production process, quality control decision, or the interpretation of an experiment depends on measurement accuracy. The necessity for this book arises from the fact that the existing theory of measurement accuracy (the “classical theory”) contains significant gaps. In particular, the current theory focuses exclusively on multiple measurements and overlooks single measurements. Meanwhile, single measurements are the ones most commonly used in practice. Moreover, the current theory is incomplete even within the scope of multiple measurements. For example, it does not provide answers to such fundamental questions as how to translate the inaccuracy of a measuring instrument into the inaccuracy of a measurement utilizing this instrument, or how to find the full uncertainty of a measurement result, that is, the uncertainty that reflects both systematic and random errors.

I devoted many years of research filling these gaps. This book generalizes and puts into a coherent whole the results of this effort. It presents methods of estimating the accuracy of both single and multiple measurements. Moreover, it formulates these methods in a systematic and unified way by formulating and utilizing a new perspective that single measurements are the basic type of measurements and multiple measurements represent a series of repeated single measurements. This new approach, besides being logical and intuitive, makes accounting for the measuring instruments inaccuracy an inherent part of the calculations of the inaccuracy of the measurement. This book offers well-grounded and practical methods to combine the limits of elementary systematic errors and estimate the overall measurement uncertainty accounting for both the systematic and random errors.

As part of the general theory of measurements, this book develops the theory of indirect measurements. For indirect measurements with dependent arguments, this book proposes the method of reduction in place of the traditional method based on the Taylor series. This method is more accurate, simpler, and most importantly

allows one to calculate the confidence limits of the inaccuracy of these measurements, rather than just standard deviation of the measurement result as in the traditional methods. At the same time, it removes the need to account for the correlation coefficient, which had been a thorny issue in this area. This book further includes a discussion of the applicability of the Bayes' theorem and Monte Carlo methods in measurement data processing, the topics that are being actively discussed now in the metrological research community.

This book can serve as a comprehensive reference for data processing of all types of measurements, including single and multiple measurements, dependent and independent indirect measurements, and combined and simultaneous measurements. It includes many concrete examples that illustrate typical problems encountered in measurement practice. Thus, this book encompasses the entire area of measurement data processing, from general theory to practical applications.

This book is intended for anyone who is concerned with measurements in any field of science or technology, who design technological processes and choose instruments with appropriate accuracy as part of their design, and who design and test new measuring devices. It should also be useful to university students pursuing science and engineering degrees. Indeed, measurements are of such fundamental importance for modern science and engineering that everyone in these fields must know the basics of the theory of measurements and especially how to evaluate their accuracy.

This monograph first appeared in 2010. The emergence of the method of enumeration, which provides a solution for measurement data processing in indirect multiple measurements with independent arguments, was the impetus for the second edition, published in 2013. A number of further additions and corrections developed afterwards have led to the present third edition. The most important changes include the following:

- A new chapter *Step-by-Step Guide to Evaluating Measurement Accuracy* has been added. It is a practical guide that distills solutions to most common measurement data processing tasks into easy-to-follow step-by-step instructions. This guide can be used as a stand-alone reference by those who want to apply proper data processing methods but may not want to study all the theory behind them. It can also serve as the basis for a revision to *Guide to the Expression of Uncertainty in Measurement* (GUM) [2]; the need for such a revision has been widely recognized and planned for almost 10 years, but there has been little progress so far. We discuss the drawbacks and indeed mistakes in the GUM, as well as the related document, VIM [1], in detail in this book (Chap. 9).
- A variant of the method of enumeration, which I newly developed, has been added. This variant retains all advantages of the method of enumeration (removing the need for linearization of the measurement equation, requiring no assumptions about the distribution functions of the experimental data, and utilizing all information that these data contain), but it is more intuitive and does not rely on the central limit theorem to ensure that the sample mean is normally distributed.

- The method for evaluating accuracy of single indirect measurement has been further developed.
- The systematic error in multiple measurements is described with new details; the calculations of such errors in different types of multiple measurements are shown.
- The chapters devoted to the accuracy of multiple direct and indirect measurements (Chaps. 4 and 5) are fully rewritten.
- The addition made to the method of reduction now allows the use of this method for measurements having several measurands instead of only one.
- The method of transformation has been eliminated because the method of numeration is better and simpler.
- The section devoted to the accuracy of measurements performed with a chain of measuring instruments has been rewritten.
- The structure of this book has been improved.
- Besides these changes, this edition also corrects a number of typographical and other errors throughout this book.

In conclusion, I would like to express my special gratitude to my son, Dr. Michael Rabinovich, Professor at Case Western Reserve University. He provided support and assistance throughout my work on this book including editing the proposal for publication, discussing new results and the presentation, and editing the whole book. This book would not be possible without his help.

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A Practical Approach

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