Modern Approaches to the Evaluation of Measurement Uncertainty - Evolution from Error Analysis to Bayesian Uncertainty

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Abstract

The ISO-GUM is a de facto international standard for evaluating uncertainty in measurement. However, many users neither recognize the Bayesian concept that underlies the ISO-GUM nor take advantage of the practical benefits associated with their application. The ISO-GUM propagates estimates and uncertainties through a linear approximation of the measurement equation. In this sense the ISO-GUM is a robust general purpose approach. A draft supplement to the ISO-GUM propagates probability density functions (pdfs) through a numerical simulation of the measurement equation. It supplements the ISO-GUM by providing a way to check the estimates and uncertainties for various pdfs for the input quantities.

The paper demonstrates the need and consistency of the ongoing developments in measurement data analysis and evaluation of uncertainties. A generalized measuring process is employed to illustrate and point out the basic concepts, practical procedures, merits and limitations of classical error analysis, propagation of uncertainties according to the ISO-GUM procedure, and propagation of pdfs according to the draft supplement to the ISO-GUM.

Error analysis considers the measurement error as relevant carrier of information about a measuring process, a sub-process or an individual effect of an influence. It overemphasises the statistical evaluation of observed data and it treats non-statistical information unsatisfactorily. The ISO-GUM refers to non-statistical evaluation of information as Type-B, which are consistent with the Bayesian view of pdfs as representing the state of knowledge using the principle of maximum information entropy. The ISO-GUM utilizes the Gaussian uncertainty propagation through linearization of the measurement equation by first-order Taylor series expansion. Probability statements for evaluations according to the ISO-GUM require approximation based on the central limit theorem, if applicable.

The general approach represented by the draft supplement to the ISO-GUM accomodates almost every measurement model since it interprets any measuring process as knowledge-based Bayesian inference. The ISO-GUM procedure can be derived as a special case from this general approach.

The Bayesian concept provides consistent and powerful tools for uncertainty evaluation and, therefore, supports the further development of measurement techniques and metrology.