This exciting programme of the IX AMCTM Conference covers a broad range of subjects of interest to metrology and testing, and reflects the activities of IMEKO TC21. The programme consists of plenary sessions, two strands of oral parallel sessions, poster and round table sessions, and includes invited presentations delivered by recognised authorities in their field from world-leading Institutions. The oral sessions feature talks by established and younger scientists from 30 countries around the world. The mix of plenary, parallel and poster sessions will allow attendees to learn about the latest developments and discuss their ideas with the conference participants in a friendly and stimulating environment.

It presents a broad range of subject matters of interest for both fields of metrology and of testing, including 12 plenary presentations delivered by recognised authorities in each field coming from world leading Institutions. The parallel sessions account for 50 oral presentations, leaving a wide opportunity to appreciate fully the Conference programme in addition to plenary talks and from about 20 poster presentations that can be amply discussed in a dedicated Session and throughout the conference. A feature of this conference is a Round Table discussion on New trends in mathematics, statistics and measurement software, of interest to both metrology and testing, and conducted by a panel of experienced scientists who will introduce the themes to facilitate the debate.

http://www.chalmerskonferens.se/en/Contact-us/Find-us-Johanneberg
### Monday, June 20 2011

#### 9:00 CONFERENCE OPENING (location: Chalmers Conference Centre)

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<tr>
<th>Session Plenary (room: RUNAN)</th>
<th>Chairs: Pavese, Forbes, Bär, Pendrill</th>
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<tr>
<td>9:20 K. Shirono, H. Tanaka, K. Ehara, THEORY AND COMPUTATIONAL PROGRAM FOR THE DETERMINATION OF REFERENCE VALUE IN KEY COMPARISON BASED ON BAYESIAN STATISTICS</td>
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<tr>
<td>9:50 A.B. Forbes, A TWO-STAGE MCMC/MCMC ALGORITHM FOR UNCERTAINTY EVALUATION</td>
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**Session Plenary - continued (room: RUNAN)**

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<tr>
<th>Chairs: Benoit, Forbes</th>
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<tr>
<td>10:50 C. Elster, B. Toman, BAYESIAN ANALYSIS VERSUS APPLICATION OF THE GUM-S1 FOR UNCERTAINTY EVALUATION IN LINEAR AND NONLINEAR REGRESSION</td>
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<tr>
<td>11:20 A. Allard, N. Fischer, RECOMMENDED TOOLS FOR SENSITIVITY ANALYSIS ASSOCIATED TO THE EVALUATION OF MEASUREMENT UNCERTAINTY</td>
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<td>11:50 F. Crenna, G.B. Rossi, L.Bovio, PROBABILISTIC CHARACTERIZATION OF FACE MEASUREMENT</td>
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<td>12:20 L.R. Pendrill, UNCERTAINTY &amp; RISKS IN DECISION-MAKING IN QUALITATIVE MEASUREMENT</td>
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**Tuesday, June 21 2011**

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<tr>
<td>11:50 S. Eichstädt, C. Elster, UNCERTAINTY EVALUATION FOR CONTINUOUS-TIME MEASUREMENTS</td>
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**Session Plenary (room: RUNAN)**

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<tr>
<td>13:50 F. Pavese, ON THE DIFFERENCE OF MEANINGS OF &quot;ZERO CORRECTION&quot;: ZERO VALUE vs. NO CORRECTION, AND OF THE ASSOCIATED UNCERTAINTIES</td>
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#### 16:40–18:30 ROUND TABLE (room: RUNAN)

**Projects in metrological research: new trends of interest for mathematics, statistics and measurement software (provisional title)**

**Moderators:** Pavese, Forbes, Bär, Pendrill, Vicario, Shirono, Kyriakis, Kacker

**Presentations:**

**a) Energy:** K-D. Sommer, U. Hanebeck, MODEL-BASED RECONSTRUCTION IN MEASURING SYSTEMS FOR RECKONING AND CONTROLLING OF ENERGY DISTRIBUTION GRIDS

**b) Health:** K. Klauenberg, B. Ebert, J. Voigt, M. Wanzel, J.E. Noble, A.E. Knight, C. Elster, BAYESIAN ANALYSIS OF AN INTERNATIONAL ELISA COMPARABILITY STUDY

**c) Environment:** U. Maniscalco, G. Pilato, MULTI-SENSOR DATA FUSION IN SPATIAL FORECASTING OF ENVIRONMENT PARAMETERS

**d) EMRP and other EURAMET region activities:** M. Bär & L. R. Pendrill

**Floor questions to previous presentations and general discussion**
Monday, June 20 2011

**POSTER SESSION**  (rooms: Foyer/VALDEMAR, posters (dimensions W 1 x H 2 m) displayed until Wednesday) **15 posters** Chair: Pavese

**List of accepted posters**

1) B. Arendacka, A SIMPLE CONFIDENCE INTERVAL FOR THE COMMON MEAN
2) Fang Hong, Bian Xin, Liu Ke, Zhou Xin, Zhao Haining, MEASUREMENT UNCERTAINTY ESTIMATION OF VIRTUAL INSTRUMENT BASED ON MONTE CARLO METHOD
3) P. Fexa, J. Vedral, MEASUREMENT SYSTEM, TESTING AND SIGNAL PROCESSING USING LABVIEW
4) A.B. Forbes, H.D. Minh, GENERATION OF NUMERICAL ARTEFACTS FOR GENERALISED REGRESSION
5) R. Furutani, M. Ozaki, MEASUREMENT UNCERTAINTY FOR CALIBRATED
6) C. Hernandez Zavala, R. Tutsch, INFLUENCE OF THE LOOK-UP WINDOW SIZE WHEN APPLYING A FORWARDLOOKING CONTROLLER
7) S. Parkinson, A. Longstaff, A. Crampton, G. Allen. S. Fletcher, A. Myers, THE USE OF CRYPTOGRAPHIC PRINCIPLES WITHIN METROLOGY SOFTWARE
8) F. Pavese, NEED FOR CONSISTENCY OF TERMINOLOGY IN INTERNATIONAL STANDARDS AND GUIDELINES: SOME CASE STUDIES AND CONCEPT DIAGRAMS
9) C. Perkins, A. Longstaff, S. Fletcher, P. Willoughby, RATE-OF-CHANGE ANALYSIS APPLIED TO MACHINE TOOL MONITORING AND MAINTENANCE SCHEDULES
10) Yan RongXin, Wang Yong, A COMPARISON METHOD USED FOR CALIBRATING LEAKAGE RATE OF HELIUM VACUUM REFERENCE LEAK AND COMBINED STANDARD UNCERTAINTY EVALUATION
11) D. Sporea, C. Dragomirescu, F-D. Frumosu, VIBRATION DAMPING USING LASER VIBROMETRY INVESTIGATED WITH THE ANOVA METHOD
13) A. Valcu, S. Baicu, EXCEL TOOLS FOR ANALYSIS RESULTS IN CALIBRATION / VERIFICATION OF ELECTRONIC BALANCES
14) Wang Yong, Yan RongXin, Sun LiChen, APPLICATION OF THE UNCERTAINTY THEORY IN THE LEAK TESTING OF THE SPACECRAFT
15) C. Yardin, TOOLS TO IMPROVE THE ESTIMATION OF THE CALIBRATION OF THE CALIBRATION LINE AND THE CALCULATION OF FORECASTS
Session 1 (room: RUNAN)

Industrial statistics – 1

Chairs: Bremser, Vicario

15:30 A. Barari, Estimation of detailed deviation zone of inspected surfaces

15:50 G. Barbato, G.D. Panciani, F. Ricci, S. Ruffa, G. Vicario, Form tolerance verification: a sequential approach of the inspected design

Session 1 (cont) (room: RUNAN)

Industrial statistics – 2

Chairs: Bremser, Vicario

16:40 L. Carli, M. Galetto, G. Genta, Uncertainty modelling in 3D SEM stereophotogrammetry

17:00 Ben-Shung Chow, Calibration of MTF for outdoor cameras with polluted lens

17:20 F. Ezedine, J.M. Linares, W. Mansor, J. Othman, Uncertainty calculation of a multicamera tracking system in a cave

Tuesday, June 21 2011

Session 1 (cont) (room: RUNAN)

Industrial statistics – 3

Chairs: Bremser, Vicario

08:40 F. Moschas, P. Psimoulis, S. Stiros, Quality assessment and filtering algorithms of high-frequency measurements of GPS and robotic theodolites using supervised learning techniques

09:00 E. Reetz, A. Schlegel, M. Schumann, G. Linß, Application of spline surface profile filters to subpixel contour decomposition problems

09:20 G.L. Samuel, S. Denis Ashok, Measurement and evaluation of asynchronous radial error of a high speed spindle

09:40 D. Vetturi, A. Delli Carri, I Bodini, M. Lancini, Mathematical method for the definition of a non linear multi input–one output calibration diagram of laser positioning sensor

10:00 P. Werner, A. Schlegel, M. Schumann, Jorg Bargenda, M. Rosenberger, Gerhard Linß, A novel method for an automated analysis of a measurement scene
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<td>15:30</td>
<td>A. Bariska, R. Burgin, Case study of likelihood and Bayes approaches for measurement based on non-linear regression</td>
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<td>O. Bodnar, G. Wöbbeler, C. Elster, Comparison of different choices for a prior under partial information in a Bayesian analysis</td>
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<th>Time</th>
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<td>16:40</td>
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<td>17:00</td>
<td>G.A. Kyriazis, Bayesian inference in waveform metrology</td>
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<td>17:20</td>
<td>I. Lira, D. Gientschnig, A formalism for expressing the probability distributions of interrelated quantities</td>
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<td>Speaker(s)</td>
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<td>08:40</td>
<td>R. Kessel, R. Kacker</td>
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<tr>
<td>09:00</td>
<td>G. Wübbeler, P.M. Harris, M.G. Cox, C. Elster</td>
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<td>09:20</td>
<td>R. Willink</td>
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<td>09:40</td>
<td>R. Kacker, R. Kessel, K-D. Sommer</td>
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<tr>
<td>10:00</td>
<td>Z.L. Warsza, M.J. Korczynski</td>
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<tr>
<td>10:50</td>
<td>R. Kessel, G. Wübbeler, R. Kacker</td>
<td>Improved adaptive procedure to determine the necessary number of Monte Carlo trials to achieve the required numerical tolerance</td>
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<td>11:10</td>
<td>Bin Xin, Zhou Xin, Fan Hong, Liu Ke</td>
<td>Visualization-assisted analytical method for evaluating propagation of uncertainty</td>
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<td>11:30</td>
<td>E. Buzac</td>
<td>Analysis of systematic effects in order to improve the expanded measurement uncertainty</td>
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<td>M.G. Cox, P.M. Harris, I.M. Smith</td>
<td>Software to support the use of the GUM Supplement 2 – Extension to any number of output quantities</td>
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<td>M. Cundeva-Blajer, L. Arsov, R. Malaric</td>
<td>Prediction of resistance standards time behaviours by stochastic determination of Lagrange polynomials</td>
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<td>14:20</td>
<td>M. Galetto, M. Luca</td>
<td>Mathematical model for error correction in MScMS-II (Mobile Spatial coordinate Measurement System)</td>
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<td>M. Galovska, R. Tutsch, O Jusko</td>
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<td>P. Klason, A. Andersson, M. Holmsten, P. Lau, G. Kok</td>
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<td>G.M. Rocha, R.P. Landim</td>
<td>A software for the evaluation of the stability and drift of measuring standards</td>
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<td>Measuring edges on pivot-mounted objects during rotation</td>
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<td>14:20</td>
<td>W. Bremser</td>
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<td>S. Demeyer, N. Fischer</td>
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<td>15:00</td>
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<td>Differences in recording of collocated, identical sensors</td>
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<td>15:20</td>
<td>Z. L. Warsza, V. Ezhela</td>
<td>Evaluation and numerical presentation of the results of multidimensional indirect measurements – Outline of the theoretical backgrounds</td>
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<td>15:40</td>
<td>V.A. Granovsky, T.N. Siraya</td>
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<tr>
<td>08:40</td>
<td>H-P. Beck, J zum Hingst, G. Gewiß, Nodal load observer with imperfect measurement infrastructure for (smart) electrical grids</td>
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<td>09:00</td>
<td>P. Dupuis, N. Van Overstraeten, J-P Raskin, L.A. Francis, D. Flandre, Some mitigations for unequal data variance in linear regression</td>
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<td>09:20</td>
<td>A. Silva Ribeiro, C. Oliveira, M.G. Cox, J Alves e Sousa, L. Lages Martins, J. Cardoso, P. Limede, Modelling and uncertainty evaluation for the radiation quality parameters used in metrological management of diagnostic</td>
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<tr>
<td>11:10</td>
<td>M. Reginatto, Resolving power and superresolution for spectrometers used in radiation detection</td>
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<td>11:30</td>
<td>J. Mailhé, J.M. Linares, J.M. Spraul, Coordinate generator for the TKA navigator testing after reference frame displacement</td>
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<td>08:40</td>
<td>E. Bashkansky, T. Gadrich</td>
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<td>M-A. Henn, H. Gross, C. Elster, M. Bär, Maximum likelihood estimation for profile reconstructions in scatterometry</td>
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<td>10:50</td>
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<td>Continuous modelling and inverse problems –2</td>
<td>H. Gross, M-A. Henn, A. Rathsfeld, M. Bär, Stochastic modelling aspects for an improved solution of the inverse problem in scatterometry</td>
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<td>R. Model, S. Schmeiter, G. Lindner, M. Bär, Numerical simulations and turbulent modelling for applications in flow metrology</td>
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<td>T. J. Eward, P. M. Harris, C.E. Matthews, L. Wright, X-S. Yang, Metrology and design with continuous models: tools for optimisation, sensitivity and uncertainty evaluation</td>
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Sensitivity analysis is an important part of metrology, particularly for the evaluation of measurement uncertainties. It gives additional information on the measurement process under study, in order to have a better knowledge on the contributions of the different input quantities to the variability of the output quantity. According to the Guide to the evaluation of Uncertainty in Measurement (GUM)[1], the natural sensitivity indices are the partial derivatives, which are an inherent part of the law of propagation of uncertainty.

The supplement 1 to the GUM [2] provides an alternative method to evaluate the uncertainty of measurement : the propagation of distributions using a Monte Carlo Method (MCM). As a sensitivity tool, this supplement suggests to perform the Monte Carlo simulation by varying the input quantities One At a Time (OAT), in order to determine which input quantities are the most contributive to the variance associated with the output quantity. Such a method presents two main drawbacks. First, it doesn’t deal with interaction effects. As the input quantities are varied one at a time, holding the others fixed at their best value, the interaction effect can’t show up. Second, it implies a higher computational cost in the sense that more Monte Carlo trials are needed to estimate the contributions.

We propose some other methods to evaluate sensitivity indices, whether the measurement function is approximately linear or strongly non-linear. In the linear case, the suitable sensitivity indices are the partial derivatives, known as “sensitivity coefficients” if the law of propagation of uncertainty is used. With a Monte-Carlo simulation, we propose to compute Spearman correlation coefficient or the Standardized Rank Regression Coefficient (SRRC) [3]. These two sensitivity methods are easy to compute, don’t need extra Monte Carlo trials and provide a good estimation of the sensitivity indices in the linear case.

If the non-linearity of the measurement model is significant, we propose to characterize the sensitivity through the variance of the conditional expectation. That quantity may be estimated by different methods, often known as importance measures. First, the Sobol'
method [4] is quite satisfying, but needs many evaluations of the measurement model in order to reach a good level of convergence. Second, the regression based on local polynomials [5] provide a good estimation of the sensitivity indices, at a much lower computational cost than the Sobol’ method.

The principle of importance measures is to decompose the variance of the output quantity into terms of increasing dimension. All these methods will be able to deal with sensitivity indices whatever the properties of the measurement model are, and also to provide an estimation for higher-order sensitivity indices if needed. They are also called global sensitivity indices in the sense that they yield a measure of sensitivity all over the region covered by the input quantities, whereas both the partial derivatives and the OAT sensitivity indices evaluate the sensitivity at the best value of the input quantities : the last two are called local sensitivity indices.

The advantages and drawbacks of the different sensitivity indices are then discussed through a practical application case. Care should be taken to provide a sensitivity method that is consistent with the measurement model considered and also that minimizes the computational cost [6].

References
6. A. Allard, N. Fischer, F. Didieux, E. Guillaume and B. Iooss, Evaluation of the most influence input variables on quantities of interest in fire simulation, Journal de la Société Française de Statistique, accepted
A SIMPLE CONFIDENCE INTERVAL FOR THE COMMON MEAN

B. ARENDACKÁ

Institute of Measurement Science, Slovak Academy of Sciences,
Dúbravská cesta 9, 841 04 Bratislava, Slovakia
E-mail: barendacka@gmail.com

When certifying standard reference materials, estimation of the common mean (or the consensus value) and construction of a confidence interval for it arise naturally and a number of papers, both in statistical and metrological literature, has been devoted to suggesting and studying applicable procedures. For an overview of these see e.g. Witkovský et al. (Discussiones Mathematicae Probability and Statistics 23(2), 2003, 123-145), Iyer et al. (JASA 99, 2004, 1060-1071), Rukhin (Metrologia 46, 2009, 323-331).

The underlying statistical model often used for describing measurements of essentially the same quantity coming from different laboratories is the one-way heteroscedastic (allowing for different within-laboratory variances) random-effects model in combination with normal distribution assumed for random errors and random laboratory effects. Procedures for obtaining a confidence interval for the unknown common mean under this setting range from computationally relatively easy methods, like the Mandel-Paule or the DerSimonian-Laird intervals (see e.g. Rukhin, Metrologia 46, 2009, 323-331), to computationally intensive solutions, like e.g. the maximum likelihood interval (Vangel, Rukhin, Biometrics 55, 1999, 129-136), intervals based on likelihood ratio test statistics (Sharma, Mathew, Biometrical Journal 53, 2011, 128-136), the Kenward-Roger interval (Witkovský et al., Discussiones Mathematicae Probab. and Stat. 23(2), 2003, 123-145), the fiducial interval (Iyer et al., JASA 99, 2004, 1060-1071). The most important feature of a confidence interval is always the probability of coverage, which should be close to the desired confidence level (usually 95%) in general. Once this is obtained, one can consider the length or computational demands to select a preferred method. However, despite extensive studies, neither of the mentioned confidence intervals has been generally accepted for use.

The purpose of this contribution is to bring to attention a simple confidence interval for the common mean, which apparently has not been studied in the literature, but which seems to maintain the desired confidence level very well across a wide range of settings (as considered in our simulation study). The interval is of the form \( \bar{y} \pm t_{0.975,k-1} \sqrt{\frac{\sum (\bar{y}_i - \bar{y})^2}{k(k-1)}} \), where \( \bar{y}_i \)s denote the \( k \) individual laboratory means, \( \bar{y} = \sum \bar{y}_i / k \), and \( t_{0.975,k-1} \) is the 97.5th quantile of the Student distribution with \( k - 1 \) degrees of freedom. The
expression under the square root is an unbiased estimator of the variance of $\bar{y}$ and its distribution may be approximated by a multiple of the $\chi^2$ distribution with $k - 1$ degrees of freedom as shown by Wimmer, Witkovský (Journal of Stat. Comp. and Simul. 73(5), 2003, 333-346), but independence of $\bar{y}$ would be necessary to fully justify the use of the Student quantile. However, the interval can be viewed as based on a weighted means statistic with weights equal to $1/k$ and thus being of the form suggested by Rukhin (Stat. & Prob. Letters 77, 2007, 853-861) for weighted means in general. It can be also viewed as the limiting case of an exact confidence interval for the common mean when the between-laboratory variance in the model is large. Besides pointing out the nice features of this interval, we will also discuss the price paid for the simplicity and good overall coverage.

Acknowledgement. This work was supported by the Slovak Research and Development Agency under the contract No. LPP-0388-09, and further by grants VEGA 2/0019/10 and VEGA 1/0077/09.
Estimation of Detailed Deviation Zone of Inspected Surfaces

Ahmad Barari
Faculty of Engineering & Applied Science, University of Ontario Institute of Technology, Oshawa, Ontario, L1H 7K4, Canada

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Summary A procedure to estimate Distribution of Geometric Deviations (DGD) of an inspected surface is presented. The methodology is developed based on estimation of parametric proximity of the surface points to the actual measured points. Utilizing a Voronoi Diagram and its corresponding Delaunay Triangulation the procedure to develop DGD is developed. The resulting DGD model can be employed to estimate the deviation values at any unmeasured point of the inspected surface. This estimation of the deviation values is very important when a detailed understanding of the surface geometric deviations is required. Implementation of the developed methodology is described and case studies for typical industrial parts are presented. This methodology can be used for closed-loop of inspection and manufacturing processes when a compensation scheme is available to compensate the manufacturing errors based on the DGD model.

Keyword: Coordinate Measurement, Surface Inspection, Metrology, Geometric Deviations.
DEVELOPMENT OF THE IMPROVED METHOD OF GRIDS

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Virumaa College of Tallinn University of Technology, Järveküla tee 75
Kohila-Järve, 30328, Estonia

GENNADY ARIASSOV
Tallinn University of Technology, Ehitajate tee 5
Tallinn, 19086, Estonia

The purpose of this paper is to develop and generalize the improved method of grids (method of finite differences) described in [1]. For obtaining of interpolation polynomials are used the matrixes and method of uncertain factors. The essential simplification of the calculation formulae is received. The question of accuracy of the obtained solution is examined. The numerical results are presented. The use of overlapping of interpolation intervals allows increasing an accuracy of the solution. The calculation results show that it is possible to adjust the accuracy of the solution either by changing the degree of the interpolation polynomial or with the help of overlapping of intervals.

1. Two dimensional problem

The theory of the method of grids is based on the theory of the approximation functions, for which the magnitudes are given in discrete or separate points. For this purpose interpolation polynomials obtained with the help of a method of uncertain coefficients are applied. Thus such approximation is possible to execute not using difference schemes. Such approach is fit for the improved methods of grids. The method of grids allows reducing a task of continuous analysis to a problem of solution of system of the algebraic equations. The accuracy of used interpolation polynomials is estimated with the uncertainty. Approximation by a method of uncertain coefficients and Interpolation of derived function [2] can be extended to calculation a partial derivative. Let's describe one possible variant. Let's accept additional notations and consider with the purpose of simplification a two-dimensional problem only. We assume that a function $U$ of two variable is transformed using the dimensionless abscissa $\xi$ and ordinate $\eta$. The integer variables $\xi$ and $\eta$ form a square grid. Nodes of the grid are defined by two indexes. The first index corresponds to integer abscissa $\xi$,
second–to ordinate η. It is expedient to join points laying on the same horizontal or vertical, that means having one and same abscissa or ordinate. Such association of points we shall name a vector–abscissa or vector–ordinate. The generalized matrix is applied [2], but two indexes to it are added. They are written in specify coordinates of a point or vector–abscissa or a vector–ordinate, along which the partial derivative are calculated. The essential simplification of the calculation formulae is received with the help of matrix notable symbolic. The used matrix symbolic gives the convenient tool for realization of calculations with the help of computers.

References

FORM TOLERANCE VERIFICATION: A SEQUENTIAL APPROACH OF THE INSPECTION DESIGN

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Abstract
Manufactured parts are necessarily affected by form and size errors, assessed against dimensional and geometrical tolerances. Such errors have to be estimated in order to test and verify compliance with tolerances. Different methods and devices may be used to inspect manufactured parts. Coordinate Measuring Machines (CMM) are among the most widely used devices because of their flexibility and versatility, catering for verification of a broad range of characteristics. Currently, the ISO Technical Committee (ISO/TC) 213 is working on standards concerning Geometrical Product Specification and

†
Verification (GPS) in modern industry, aimed at providing a comprehensive set of operations to control most characteristics.

In the paper, we deal with a flatness tolerance problem, one of the simplest and among the most widely used form tolerances, quite representative of other types of tolerances for the task of analyzing verification methods. It defines a zone between two parallel planes within which a surface must lie [ISO 1101]. As a consequence, only few points, outer and inner ones, are relevant in verifying flatness. In order to detect the relevant points, an inspection of the whole surface is virtually required, therefore ISO/TS 12781 prescribes, in addition to the traditional flatness symbol, the clear statement of cut-off wavelength, in order to define the amount of information theoretically needed. Nevertheless sampling density required in ISO standards is quite high, ways too expensive to be applied in industrial practice. To overcome these difficulties, development of intelligent algorithms is aimed at obtaining a fairly “good” inspection plane, that links a reasonable number of points to be probed together with an efficient estimate of the flatness tolerance value.

The algorithm we suggest in the paper is based upon the use of Kriging models, and on a sequential selection of the points to be probed by the CMM. Kriging models were extensively used to predict spatial data in geostatistics (Krige D.G., 1951); recently, their use is strongly suggested to approximate the output of Computer Experiments (Sachs et al., 1989a; 1989b). Once more, Kriging models have been adopted in industrial metrology to drive the online construction of sequential designs for inspecting industrial parts on CMM (Pedone et al., 2009). Following this approach, the Kriging modelisation is adopted in the experimental estimation of a feature flatness error.

The paper discusses, on the basis of experiments performed in a case-study, different approaches in using the Kriging models.

References
CASE STUDY OF LIKELIHOOD AND BAYES APPROACHES FOR MEASUREMENT BASED ON NON-LINEAR REGRESSION

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We consider measurements where the measurands are parameters in a non-linear regression model. Defining and computing point and interval estimates for such parameters in agreement with the data, the model and additional available information are frequent problems in science and engineering. The usual frame works for solving these problems are Maximum Likelihood and Bayes inference.

The Maximum Likelihood approach in our case leads to a non-linear Least-Squares problem. On the other hand, the Bayes approach leaves several possibilities for inference. Without claiming completeness, standard theoretical results and computational methods for point and interval estimates under the respective frame works are reviewed and presented. Their performance is investigated in a simulation study on a test problem from material science. The problem size is chosen to be small (with three identifiable parameters), nevertheless the problem displays typical intricacies associated with non-linear regression: parameter dependent correlations, break-down of linear approximations and global optimization difficulties.

We give practical tips and tricks for getting satisfactory results using either of the frame works and touch on some further topics for future research.

Keywords: Non-Linear Regression, Least-Squares, Covariance Matrix, Maximum-Likelihood, Profile Likelihood, Bayes, MCMC.
SOME METROLOGICAL AND MATHEMATICAL ASPECTS OF ORDINAL DATA TREATMENT

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Abstract

Although some measurements can be made on any scale (including a continual scale), cost and speed considerations sometimes tip the scales toward using ordinal measurements. This lecture presents a way to evaluate classical metrological characteristics, such as error, uncertainty and precision of single and repeated measurements, based on the legitimate basic mathematical operations for ordinal data. The only valid measurement operations among ordinal variables are equal to or greater than/less than; the usual assessment measures such as average and standard deviation cannot be applied. Consequently, in order to receive reliable results and draw applicable conclusions from ordinal measurements it is essential to develop and use the appropriate mathematical methods. We discuss these methods, and note how they are also essential for many applications that require the comparison of two measurement systems. An on-line calculator developed by the authors, and based on their algorithm [1], will also be presented to the conference participants.


Key Words: ordinal scale; error; uncertainty; repeatability; reproducibility; agreement; calibration; kappa measure
Nodal load observer
with imperfect measurement infrastructure
for (smart) electrical grids

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Keywords: nodal load observer; Luenberger observer; low voltage; smart electrical grids, system state reconstruction, control theory

1. Extended Abstract

High voltage grids are known to be well measured and mostly over-determined systems, so that by classic state estimation techniques validity checks and even error determination are possible like with method of least squares (1,2). Whereas, medium and especially low voltage grids show an imperfect measurement infrastructure (due to high investment costs) so they represent under-determined systems. For the upcoming low voltage grids with not only consumers but also a significant proportion of prosumers, so-called smart grids, this situation becomes even more severe (3). To operate these grids soundly the system state has to be known which today is actually not.

Based on the idea of a nodal load observer with imperfect measurement infrastructure for gas grids (NLO-Gas) (4) a nodal load observer for medium voltage grids (NLO-MV) was developed at the University of Technology Clausthal (5) in order to reconstruct the system state online (in contrast to other traditional state estimation that is done offline).
To represent the inner system states both NLO-Gas and NLO-MV rely on a Luenberger-observer (6). For the NLO-Gas this is realized in a classic way by using state space notation which is possible since the gas system as time-variant volume/mass-flows can be modeled as a system of 1st-order PDEs. In contrast the electric system is described by a system of complex algebraic equations (due to phasor arithmetic) that doesn’t offer a direct transfer to state space notation. So the observer is implemented by a novel algorithm using an adapted feedback for the input quantities via a multivariable l-controller that satisfies stability for the PT1-approximated-control path.

Up to date the issue of imperfect measurement infrastructure is covered generally by the NLO-Gas only, using a “disturbance observer”. This one is a system in state space notation similar to the Luenberger-observer and it works in feedback operation to the Luenberger-observer for covering the unmeasured inputs. Implementing the disturbance observer for the NLO-MV is current work of research: one way is to describe the disturbance observer by adapted methods like for the Luenberger-observer itself before where the other way could be to transfer phasor arithmetic to state space notation by returning to general differential calculus of electricity theory.

References

The purpose of this paper is to present a calibration approach for ordinal metrical scales.

*Keywords*: representational theory of measurement; scale; calibration

1. Introduction

The representational theory of measurement gives a central role to scales in the definition of measurement process. It identifies four main families classified from the weakest to the strongest: nominal scales, ordinal scales, interval scales and ratio scales. The two last scale families are well known in hard sciences. Actually, in hard sciences like Physics, most uni-dimensional quantities can be measured with a scale leading to one of these two families. The measurability throw nominal scales of quantities stays controversial. Ordinal scales are considered as the weaker scales that can be used for measurement. This scale family is historically used by the behavioural sciences and psychophysics and unconsidered in hard sciences.\(^1\) Actually the use of this scale family focuses the historical division between hard sciences and behavioural sciences. In a previous paper we presented that nominal and ordinal scale on one hand, and interval and ratio scales on the other hand differ on the number of subgroups that can be defined on each family. This difference acts on the complexity of the calibration process and it is legitimate to consider that the calibration capability in various scale families is the main source of the division between these communities. Now, psychophysics plays a crucial role in the society, and the hard sciences needs to measure new quantities that cannot be measured with strong scale. As a simple example, just consider a quantity that can be represented only by
a multi-dimensional value. The calibration of weak scales is an important issue studied in this paper. For interval and ratio scales the calibration concerns few parameters. But for nominal and ordinal scales the calibration is performed by the definition of a partition.

2. proposal

Between nominal and ordinal scales, Coombs proposed the set of metrical scales based on the existence of a distance between the manifestations of quantities. Actually, within this set, only ordinal metrical scales make sense. Ordinal metrical scales are defined by a nominal scale on quantities, and by an ordinal scale on the distances between the manifestations of quantities. In previous studies we proposed the concept of fuzzy nominal scale$^3$ and we built a metrical scale on such fuzzy nominal scale$^2$. The calibration of this scale is performed through the definition of 3 items: the fuzzy equivalence family, the distance, and the fuzzy partition. If the equivalence family and the distance are defined by consensus, the fuzzy partition is empirically defined with experiments or expertise. At this step, we propose a comparison procedure between metrical scales. It first supposes a unique quantity measured with the two scales. Then the distances of metrical scales are used to compute a distance histogram between the measurement results. The produced histogram is the elementary information used to compare the scales and to analyse their variability. The full paper will present the approach first with metrical scales on non-fuzzy nominal scales and then with metrical scales on fuzzy nominal scales. An example comparing scales issued from knowledge of various experts will illustrate the concept with an application to color measurement.

References

Comparison of different Choices for a Prior under Partial Information in a Bayesian Analysis

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We consider a Bayesian inference on a quantity $\theta$ from $n$ observations $x_1, \ldots, x_n$

$$x_1, \ldots, x_n \overset{iid}{\sim} N(g(\theta, \psi), \sigma^2).$$ (1)

We assume that a prior $p(\psi)$ on $\psi = (\psi_1, \ldots, \psi_p)$ is available but not on $\theta$ and $\sigma$. We compare three different choices of assigning a 'non-informative' conditional prior $p(\theta, \sigma|\psi)$ in terms of the resulting posteriors.

Supplement 1 to the GUM (GUM-S1) assigns a probability density function (PDF) for $\theta$ in the above situation when $\theta$ can be expressed (uniquely) in terms of $g$ and $\psi$, $\theta = f(g, \psi)$, which we assume. It has been shown that in this case the GUM-S1 PDF is equivalent to a Bayesian posterior under a specific choice of prior, see. 2–5 GUM-S1 intends to provide a Bayesian PDF, and it is therefore relevant to consider the question if, or when, its implicit choice of prior is adequate and can be recommended.

Assignment of 'non-informative' priors has long been discussed in the literature, 6 and several different approaches are available. Among these, the Berger Bernardo reference prior 7 may be viewed as being currently favored. The extension 8 of this concept to the case of partial prior information has recently been proposed 3 in metrology to the above problem when the function $g(\theta, \psi)$ is a polynomial in $\theta$.

We compare this conditional reference prior with the GUM-S1 prior and a 'hybrid' prior $p(\theta, \sigma|\psi) \propto 1/\sigma$ that results by using the 'standard' $1/\sigma$ prior for the scale parameter $\sigma$ and a constant for the quantity of interest. 10

We first give conditions when the three priors yield the same posteriors. For a comparison in other cases, we consider propriety of the posterior (clearly the most important criterion 7) and coverage probabilities of credible inter-
vals for $\theta$ (i.e. long-run properties).

We show that the ‘hybrid’ prior can lead to an improper posterior. The GUM-S1 prior, on the other hand, always yields a proper posterior. Interestingly, and while experience shows that the reference prior produces proper posteriors, the conditional reference prior considered here does not work out in some cases as the posterior is improper.

Finally, we present results on the long-run behavior implied by the three different conditional priors for examples where all priors yield proper posteriors. In order to account for the conditionality of the priors this requires to also vary the underlying problem with respect to $p(\psi)$. To this end, $\psi$ are drawn from their prior distribution, and for each selected $\psi$ (and fixed chosen $\theta$ and $\sigma$), data are drawn according to (1) and analyzed. The average success rates of credible intervals covering the underlying $\theta$ are then compared. For the examples we observed that 95% credible intervals obtained by the hybrid and GUM-S1 prior covered the underlying $\theta$ in at least 95% of the cases, while for the conditional reference prior this coverage probabilities fell below 95% in some of the examples.

In conclusion we can generally recommend the use of the GUM-S1 conditional prior for the addressed problem. The fact that the conditional reference prior often does not work out is interesting, and we present some possible explanation in this direction which accounts for the particular problem structure, and which may stipulate further future work.

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Self-Consistent Reference Value Estimation

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Although much has been published over the last years on finding the best (consensus) reference value for a given set of laboratory data attained in inter- or key comparisons (the latter with a specific view to the CIPM MRA), the discussion is ongoing. Except cases where real reference values are available from other sources, the quality of the consensus value is of major importance in proficiency testing, method validation, or reference material certification.

Several pragmatic and a number of statistical approaches including robust and Bayesian statistics have been proposed. It is, however, often forgotten that quality attributes require a scale, i.e. whether a particular approach deserves the attribute "best" fully depends on the criteria according to which the quality is assessed. Criteria are derived from an a priori belief (scenario) on how different methods and laboratories are likely to perform in the intercomparison. Several frequently used scenarios will be discussed, and the corresponding criteria and "best" RV estimation approaches given.

A distribution-free, self-consistent RV estimation approach has been developed which is based on the single criterion of participant's compatibility, at the cost of adjusted uncertainties. For an initial guess of the RV, uncertainties for all results in the data set are adjusted in a way that any value is made compatible with the RV ($E_n \leq 1$ criterion for the expanded uncertainties). Some values will already obey the criterion within the uncertainty stated. In these cases, the stated uncertainty remains unchanged. The sum of variances of all participants is calculated. In an iterative procedure, the RV is found which minimises the sum (or average) uncertainty of the intercomparison. In a second iteration loop, the (unknown before) uncertainty of the RV is accounted for in the $E_n$ criterion. The final result is a fully compatible data set with minimum overall variance.

Any outlier discussion becomes obsolete, including considerations concerning different degrees of robustness of the various location and dispersion estimators available. The penalty for "badly" performing laboratories is a large attributed uncertainty which forces them to either improve the measurement or adjust (i.e. reduce) their performance claims.

The paper will describe the evaluation algorithm. Examples from CCQM comparisons will be given, and consequences for the performance claims of the participants discussed.
ANALYSIS OF SYSTEMATIC EFFECTS
IN ORDER TO IMPROVE THE EXPANDED MEASUREMENT UNCERTAINTY
(Abstract)

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Keywords: Measurement uncertainty, traceability, accuracy

1. INTRODUCTION

In the introduction is a brief overview of metrology, the science of measurement. They make some considerations about the importance of performing accurate measurements in a modern society where the focus is on promoting and ensuring the quality of labor, environmental or life. In particular, metrology seeks ways to achieve uniformity of measurements, accuracy and compatibility of measurements, the measurements correlate with accepted reference standards.

2. ACCURACY, TRACEABILITY AND MEASUREMENT UNCERTAINTY

The paper refers to the concepts of accuracy, traceability and uncertainty of measurement and do an analysis on the influence of random and systematic effects on expanded measurement uncertainty components. It also examines the possibility to improve the expanded measurement uncertainty leaving from the uncertainty components associated systematic effects. It will also make a presentation of electronic measuring instruments used at present in the electrical measurements and refers briefly to the technical and metrological characteristics of these apparatus.

3. ANALYSIS OF SYSTEMATIC EFFECTS TO IMPROVE THE MEASUREMENT UNCERTAINTY

Measurement uncertainty comprises, in general, more components. Some of these components can be evaluated from the statistical distribution of results of measurements and can be characterized by experimental standard deviations. The other components, which can also be characterized by standard deviations, are evaluated based on experience or other information from the field measurements, with the admission of certain probability distributions. The paper refers to the influence they have systematic effects on the expanded measurement uncertainty. It analyzes the temporal behavior of the standard, used in a chain of calibration to obtain a history on its behavior over time, in order to improve the extended measurement uncertainty, which contributes to the result of measurement.

The result of a measurement is the best estimate of the measurand value. Therefore, all components of uncertainty or variance, $u_j^2$ ($y$), including those determined by the systematic effects, such as components associated to values of quantities supplied of the standards, contribute to dispersal of the measurements results. This paper presents a chain of traceability and graphical representation of results that were obtained in time, after calibration reference standard used in the measurement chain in order to analyze the possibility of improving the expanded measurement uncertainty.

4. CONCLUSIONS

After considering the observations made, in time, on the behavior of the reference standard used to calibrate an instrument, we can draw some conclusions about the way in which we can reduce the expanded measurement uncertainty, which means, finally, obtaining better results in the measurement process.
UNCERTAINTY MODELING IN 3D SEM STEREOPHOTOGRAMMETRY

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Abstract

Scanning Electron Microscopes (SEM) are widely used to acquire high resolution images. Although SEM images, obtained by detecting secondary electrons, have a striking 3D appearance, they are still inherently 2D. No height information can be extracted directly from the images, and measurements in x- and y-dimensions are only correct in the image plane. In order to reconstruct the third dimension of surface features, photogrammetry methods can be adopted [1,2]. To produce a stereoscopic reconstruction, a specimen is imaged in the SEM acquiring two images, the stereo-pair, by scanning the same area under two different perspectives, achieved by eucentric tilt of the sample. Surface features of different heights on the specimen surface differ in their lateral displacement in the two images. The image-matching problem mainly encompasses automatic identification in the stereo-pair of homologous points, representative of corresponding features [1]. Nowadays, this procedure is performed using commercial software where the stereo-matching is done using an area-based or a feature-
based method. Basing on photogrammetry collinearity equations [1], Piazzesi provided a model for deriving surface topography from eucentric stereo-pairs, exploiting the physical point coordinates \((z, \xi, \eta)\) [2]. Subsequently, Bariani et al. simplified this model and carried out a preliminary uncertainty assessment [3]. A thorough uncertainty evaluation of \(z\)-coordinate has been later on performed in [4], according to GUM [5]. The aim of this work is to extend the uncertainty evaluation to the vector \((z, \xi, \eta)\), exploiting covariance matrix. In particular, the proposed approach is based on the Multivariate Law of Propagation of Uncertainty (MLPU) applied to collinearity equations [5,6]. Some preliminary results of model practical implementation are presented and discussed as well.

References

USING STATISTICAL CONFIDENCE BOUNDARY OF A D.O.E.
RESPONSE SURFACE TO ESTIMATE OPTIMAL FACTORS

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This paper deals with the use of uncertainty propagation in a Design Of Experiments. The Guide to expression of Uncertainty in Measurement is applied to compute the Statistical Confidence Boundary of the response surface. Next, the uncertainties of the model are used to estimate the probability density function of the estimated optimal factors. After, a maximum likelihood criterion is employed to optimize the solution for a set of factors.

1. Introduction
A Design Of Experiments (D.O.E.) is commonly employed to control processes and optimize the input parameters. The aim of this paper is to apply uncertainty computation methods to estimate the covariances of the process control factors of the D.O.E. and analyze their influence to the optimal solution.

2. Proposed method
The proposed method associates the use of a D.O.E. and the propagation of uncertainty as proposed by the Guide to expression of Uncertainty in Measurement (GUM) [1], in order to define the Statistical Confidence Boundary (SCB) [2] of the response surface. This method is presented in the flowchart of Figure 1. First, the experimental results of the D.O.E. are collected and expressed in a matrix form as presented in Equation 1. In this expression \( Y \) represents the measurement results of the D.O.E., \( X \) the matrix of experiments and \( B \) the vector of the model coefficients. The model coefficients, \( B \), are then computed through a least squares best fit method.

\[
Y = X \cdot B \quad ; \quad B = (X^T \cdot X)^{-1} \cdot X^T \cdot Y
\]  

(1)

Second, the uncertainty of each parameter of the D.O.E. model is derived from the variance covariance matrix defined by the best linear unbiased
estimator of the least squares optimization. At the same time, the SCB is estimated using the GUM propagation method.

Figure 1. Flowchart of the method proposed to optimize a process using a D.O.E. which includes uncertainty propagation and computation of the SCB.

Third, the reliability of the model is tested using an ANalysis Of VARIance (ANOVA) and experimental validations. If required, additional tests are carried out as long as that model is not regarded as sufficiently accurate. Fourth, the variability induced by the uncertainty of the D.O.E. model parameters onto the optimal solution is studied. Since the computation of the optimum of the response surface leads to a nonlinear expression, a Monte-Carlo simulation is used to determine the probability density function of this optimal position, because the GUM does not apply to such problem. Finally, a maximum likelihood criterion is proposed to find the best compromise of a set of factors.

3. Application to the increase of the surface quality of a knee prosthesis

The presented method is used to optimize the conditions of machining of high quality knee prosthesis free-form friction surfaces. The employed toolpaths use a new five degree polynomial interpolation method. The realized D.O.E. has two factors and one result. The optimal value of the first factor is derived from a maximum likelihood criterion integrating a set of values of the second factor.
References


CALIBRATING THE MTF FOR OUTDOOR CAMERAS WITH A POLLUTED LENS

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Abstract: The modulation transfer function (MTF) is a critical parameter of aberrated optical systems. The present existing methods are not suitable for our outdoor monitoring application because it is not practical to have the conventional reference images as outdoor scenery. Therefore, we propose a new method of MTF calibration using natural image as reference image. Our method is verified by the restoration results.

Motivations:
The typhoon Morakot in August 2009, with its tremendous rainfall, caused the collapse of many quake lakes and finally made the tragedy of landslide disaster of Shau-lin village. To avoid this kind of tragedy, we propose to monitor the quake lakes in the mountain areas by arranging inexpensive video camera sensors. To monitor the quake lakes, we need to calibrate the MTF for sensors above the lakes where the conventional methods can not apply.

Backgrounds:
The modulation transfer function (MTF) is a critical parameter of aberrated optical systems [1]. We can improve the blurring effects of the deteriorated imaging system by calibrating the corresponding MTF. All the present existing methods are not suitable for our monitoring application because it is not practical to have the reference image as random target [2], sharp knife-edge [3], or impulse-type point source [4] as outdoor scenery. Therefore, we propose a new method of MTF calibration using natural image as reference image. This kind of reference was not used before because of a problem of interference patterns. This problem is overcome in this paper by applying the Kalman filtering technique to our MTF calibration.

Strategies: (A more detailed theory is summarized in Appendix)
1. A natural reference image would produce an image dependent pollution MTF and thus cause interference pattern. Therefore, the goal is to find an image independent MTF.
2. Characterizing an image independent pollution MTF by a state transition process because the MTF is theoretically computed from the autocorrelation formulation in Eq. (1) below.
3. Estimating an image independent pollution MTF from the image dependent pollution MTF by Kalman filtering because strategy 2 above implies a good signal model.

Experiments and Results:
Our experiments demonstrated that the raw MTF obtained from the reference image “book” would produce interference patterns in the restored image “people” shown in Fig. 1 (f). This
interference can be fixed if applied by the calibrated MTF using Kalman filtering. It is noted that the calibrated MTF removed the spikes efficiently from the raw MTF in Fig.1 (a).

Figure 1. (a) Comparison for the calibrated MTF with the spiky raw MTF. (b) the clean reference image (c) the polluted reference image (d) the clean test image (e) the polluted test image (f) the restored test image by raw MTF: significant interference (g) the restored test image by calibrated MTF.

Conclusions

It is noted that the natural images have their energies concentrated on their lower band in contrast to the random target with a full band spectra. The calibrated MTF does not provide the full band information but is sufficient for the required band for our monitor applications.

Acknowledgments

This research is supported by the National Science Council of the ROC under the contract NSC 99-2625-M-009-004-003 (the National Disaster Mitigation program for landslide dam)

Appendix: Summary of theory

Goal: The pollution MTF denoted by R below should be image independent to allow the applied image different with the reference natural image.

\[ R(f_x, f_y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} P(x, y) P^*(x - \overline{x}, y - \overline{y}) T(x, y) T^*(x - \overline{x}, y - \overline{y}) dx dy \quad (1) \]

Raw data:

\[ R^c(f_x, f_y) \triangleq \left| H(f_x, f_y)_{\text{polluted}} \right| / \left| H(f_x, f_y)_{\text{clean}} \right| \]

the measured (but not calibrated yet) pollution MTF which is image dependent.

Solution: The calibrated MTF by Kalman filtering denoted by \( \bar{R} \).

Final Solution: The calibrated Imaging MTF

\[ \text{MTF}_{\text{calibrated}}(f_x, f_y) = R^c(m, n) \text{MTF}_{\text{diff}}(f_x, f_y) \]

Signal model for Kalman filtering:

\[ R(f_x, f_y) = c_1 \cdot R(f_x, f_y + 1) + c_2 \cdot R(f_x - 1, f_y) + c_3 \cdot R(f_x - 1, f_y + 1) + c_4 \cdot R(f_x - 2, f_y) + n(f_x - 1, f_y) \]

Measurement model for Kalman filtering:

\[ R^c(f_x, f_y) = R^c(f_x, f_y) + N_1(f_x, f_y) + N_2(f_x, f_y) \]

where \( c_1, c_2, c_3, c_4 \) are set to 0.25, \( n \) is the generating noise, \( N_1 \) and \( N_2 \) are the thermal noise with zero-mean and known variances.

References

SOFTWARE TO SUPPORT THE USE OF GUM SUPPLEMENT 2 – EXTENSION TO ANY NUMBER OF OUTPUT QUANTITIES

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The “Guide to the expression of uncertainty in measurement”\(^1\) (GUM) provides a framework for the evaluation of uncertainty for measurement models having any number of input quantities and a single output quantity.

Working Group 1 (Expression of uncertainty in measurement) of the Joint Committee for Guides in Metrology (JCGM) promotes and extends the application of the GUM through the preparation of supporting documents, including Supplements to the GUM. Supplement 1 to the GUM\(^2\) (GUMS1), published in 2008, describes a Monte Carlo method for the propagation of distributions through a measurement model. As in the GUM, the method is applied to a measurement model having one output quantity.

Supplement 2 to the GUM\(^3\) (GUMS2), due for publication in 2011, is concerned with multivariate measurement models, i.e., models having any number of output quantities. The Supplement describes two approaches: a generalisation of the GUM uncertainty framework, and the use of a Monte Carlo method as an implementation of the propagation of distributions. The concept of coverage intervals for univariate models is extended to that of (hyper-elliptical and hyper-rectangular) coverage regions for multivariate models based on characterising the (vector) output quantity by a multivariate Gaussian distribution. A method for using the results returned by the Monte Carlo method to obtain an approximation to the smallest coverage region, based on the work of Possolo,\(^4\) is provided. GUMS2 also includes an extension of the adaptive Monte Carlo method described in GUMS1.

To help illustrate the concepts and procedures introduced, GUMS2 includes a number of examples. Software that implements two of these examples, the first involving a simple additive model, the second the transforma-
tion of a complex number expressed in Cartesian form to its representation in polar form, has been developed in MATLAB\textsuperscript{5} and will be released, via the NPL and JCGM websites, to coincide with publication of GUMS2. Through running the software, users will be able to become familiar with the concepts and approaches underlying GUMS2 and, in particular, work through the calculations associated with the examples presented in GUMS2.

In this paper, the extension of the GUM uncertainty framework and Monte Carlo method given in the GUM and GUMS1, respectively, to multivariate measurement models is described. Results and figures obtained using the supporting software for the two examples listed above are used to illustrate the hyper-elliptical, hyper-rectangular and (approximation to the) smallest coverage regions.

References

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5. MATLAB \textcopyright The MathWorks, Inc., \url{http://www.mathworks.com/products/matlab/}. 
1. Abstract

Face recognition is rather diffused in security applications, since it offers the possibility to recognize without the collaboration of the subject under investigation, enabling applications based either on existing video surveillance systems, or on specific face recording systems properly placed, for example at the ticket counter.

From a scientific standpoint, face recognition may be considered as a classification on the basis of a face measurement result. The measurement process is applied to both a reference set of face images, constituting the set of known subjects, and a test face image recorded in the field. By comparing the measurement results for the reference and the test faces, the recognition procedures takes a decision regarding the subject identity.

A face, as a measurand, may be seen as a surface in the three dimensional physical space, including an infinite number of points. Measurement methods are based either on the detection of specific, repere, points, such as the mouth or the eye corners, or on obtaining a picture of the overall appearance of the face. In the latter case the face image is represented by a rather large matrix of grayscale values, one for each known subject: by using statistical techniques it is possible to reduce the dimensionality of the problem [1].

In the current literature the recognition procedures are mainly characterized by their recognition efficiency, assessed on the basis of the amount of false (positive or negative) results. As an alternative approach, we propose to regard recognition as a decision based on a measurement result, and we thus focus on the measurement process instead. In particular, we propose a probabilistic approach to the expression of the face measurement results, including compensation for influence quantities [2]. This approach, considered and tested in other fields [3, 4], seems to be new for the face-recognition problem. It allows a probabilistic evaluation of the risk in the decision procedure [5], with the
possibility to determine a probability level for each subject that contributes to the risk, so giving to the user a probabilistic ranking of candidate subjects in the recognition. The compensation of the effects due to influence quantities, such as the “scale”, i.e. the dimension of the face in the image, or the orientation, may improve the quality of face measurement result and facilitate the comparison with the reference faces set.

The proposed methodological approach is very general and can be applied to different face measurement methods. In order to validate our proposal, we have considered the eigenfaces recognition method. This method is based on the Principal Component Analysis (PCA) technique and it has been formerly presented in Refs. [1,6,7].

In the paper we first introduce the basic theory for the probabilistic approach and the eigenfaces method. Then we present some experimental results and compare the new probabilistic approach with the traditional deterministic recognition.

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PREDICTION OF RESISTANCE STANDARDS TIME BEHAVIOR BY STOCHASTIC DETERMINATION OF LAGRANGE POLYNOMIAL

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In the paper a novel method for determination of the time behavior trend line of a resistance standard of 1 Ω by using the stochastic genetic algorithm will be given. For modeling of the trend line a Lagrange polynomial (LP) will be acquired. The coefficients of the LP will be determined from the experimental data from previous calibrations of the resistance standard. The goal function of the optimization process by genetic algorithm will be the minimum difference between the theoretical resistance value, derived by the LP, and the experimental value of the resistance at certain time moment. The uncertainties of the experimental data will be the mapping range of the input data during the stochastic evolution of the LP trend line. A verification of the gained model with known experimental data will be done.

1. Introduction

One of the main problems in the metrological laboratories is to determine the optimal moment for calibration of the standards. These decisions are made on the basis on the empirical experience of the laboratory staff, the behavior history and the conditions of the standard. The metrological laboratories usually extrapolate trend lines to predict the time-behavior of the standards by using the classical least squares method. An example for such procedure is the method of the Primary Electromagnetic Laboratory (PEL) at the University of Zagreb, [1], based on least squares regression of values with exclusion of the oldest values of the reference standard. However, these models do not take into account the random nature of the calibration results and uncertainties. In this paper a new model of the trend line by using the Lagrange polynomial (LP) will be developed, using the time points of the performed calibrations and the gained values of standard resistance. The final model of the trend line using five input experimental values can be reduced to polynomial of fourth order:

\[ R(t)=a_0t^4 + a_1t^3 + a_2t^2 + a_3t + a_4 \]  (1)
where $t$ is the time, $R$ is the resistance and $a_i$, $i=0,...,4$ are the LP coefficients, depending on the values of the resistance at five calibration moments. The mathematical model of the LP and its coefficients will be given in the full paper. The LP model will be derived on the basis of the experimental data of calibrations of 1 $\Omega$ standard in time intervals from 1996 to 2005 year given in Table 1. The determination of the coefficients of the LP will be done by application of the genetic algorithm (GA) implemented in the original software developed at the Faculty of Electrical Engineering-Skopje (FEIT), described by Cvetkovski et. al. in [2]. The number of GA input variables is five, with mapping range equal to the measurement uncertainties as in Table 1.

Table 1. The experimental input data in the GA for determination of the LP model and the experimental data for verification of the model

<table>
<thead>
<tr>
<th>Time moment</th>
<th>$t$ [month]</th>
<th>$R$ [$\Omega$]</th>
<th>Uncert. of $R$ [$\Omega$]</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>26. 09. 1996</td>
<td>9.87</td>
<td>0.999992300</td>
<td>±5.10^{-7}</td>
<td>Input var. No. 1 in GA</td>
</tr>
<tr>
<td>23. 10. 1998</td>
<td>25.74</td>
<td>0.999992450</td>
<td>±3.10^{-7}</td>
<td>Input var. No. 2 in GA</td>
</tr>
<tr>
<td>28. 12. 2000</td>
<td>51.90</td>
<td>0.999992330</td>
<td>±6.10^{-6}</td>
<td>Input var. No. 3 in GA</td>
</tr>
<tr>
<td>08. 04. 2003</td>
<td>79.27</td>
<td>0.9999922506</td>
<td>±6.10^{-6}</td>
<td>Input var. No. 4 in GA</td>
</tr>
<tr>
<td>09. 05. 2005</td>
<td>104.19</td>
<td>0.999992353</td>
<td>±3.10^{-6}</td>
<td>Input var. No. 5 in GA</td>
</tr>
<tr>
<td>20. 04. 2007</td>
<td>127.67</td>
<td>0.999992461</td>
<td>±1.10^{-7}</td>
<td>Value for the goal funct. in GA</td>
</tr>
<tr>
<td>14. 06. 2010</td>
<td>165.47</td>
<td>0.9999916844</td>
<td>±1.10^{-7}</td>
<td>Value for verification of the LP model</td>
</tr>
</tbody>
</table>

2. Results and conclusions

In Figure 1, changes of the goal function throughout 10000 generations are displayed. In the full paper the changes of the input variable as well as the LP coefficient will be given. The theoretical value of the standard resistance gained by the LP trend line is 0.9999916844, with difference of -7.77-10^{-7} $\Omega$, which is the same order of uncertainty as the input variable with highest uncertainty $R$ (1996).

References

MODELLING EXPERT KNOWLEDGE TO ASSIGN
CONSENSUS VALUES IN PROFICIENCY TESTS: A BAYESIAN
APPROACH

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Proficiency tests (PT) can be used routinely for external quality control. To this purpose measurement bias is a tool to evaluate the proficiency of each laboratory. When no reference value is available for the measurand, measurement bias has to be estimated with respect to the consensus value of the comparison. Standard NF ISO 13528 provides a way to compute the consensus value and its associated uncertainty respectively as a robust mean and a robust standard deviation. A major drawback of this, is the strong dependence of bias to results of the other laboratories.

Our proposal to improve the reliability of measurement bias is to introduce auxiliary information from the measurement process (expert modelling of the sources of uncertainty) to improve the reliability of the consensus value and its associated uncertainty. The strength of the approach is that the structure of the auxiliary information can be viewed as the structure of bias in the current state of knowledge.

In this paper a full methodology is described to first model, then estimate the structure of the auxiliary information. This auxiliary information can often be divided into blocks resulting from a decomposition of the measurement process. In this paper relations between blocks are captured in a Structural Equation Model (SEM) where each block is modelled by a latent variable. Each latent variable stands for a component of bias. SEM is estimated in a Bayesian framework using a parameter expanded Gibbs sampler to improve convergence properties.

The inference of SEM provides joint posterior distributions of latent variables used to compute scores for laboratories which represent the quality of the measurement practice. These scores can be viewed as prior information on measurement and are combined with measurement results to compute the marginal posterior distribution of the consensus value.

† The research within this EURAMET joint research project receives funding from the European Community’ Seventh Framework Programme, ERANET Plus, under Grant Agreement No. 217257.
value and measurement bias. The Bayesian framework allows to take into account in the uncertainty budget all the sources of uncertainty occurring in the measurement process as well as the variability in the Markov Chains used to estimate the model. Benefits of such a modelling of bias can extend to the computation of contributions of sources uncertainty to bias, when bias is modelled as a random effect. The work has been applied to environmental PT data with promising results.

Key words: proficiency test, consensus value, measurement bias, expert knowledge, Bayesian analysis, structural equation modelling

References

SOME MITIGATIONS FOR UNEQUAL DATA VARIANCE IN LINEAR REGRESSION

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One of the most overlooked hypothesis in data analysis concerns the homogeneity of variance. In the context of detection of biological substances on interdigitated microsensor, electrical impedance were recorded and processed over a wide frequency range. Those data clearly exhibited heteroscedatic behaviour. Two mitigations in order to evaluate and alleviate in a generic way the influence of the variance inhomogeneity will be presented.

Keywords: IDA sensors; parameter extraction; weighted Least Squares

1. Introduction

The continuous trend in size reduction observed in micro-electronics leads today to deal with capacitance values which, a decade ago, would have been considered as of the order of magnitude of parasitics from interconnection coaxial cables. The concomitant evolution of measuring equipment makes possible to access those values with enough resolution. Yet we need to interpret these measurements and to evaluate their signal-to-noise ratio.

2. Material and Methods

This work context is to map changes in impedance recorded over a frequency range to the electrical parameters of biologic samples in contact with an microelectrode IDA sensor. The substance to be detected is trapped on and between the electrodes surface by an antibody–antigen–antibody reaction, the antigen being linked to a label modifying locally the permittivity.

Starting from the measurement of the electrical parameters over a frequency range, the whole device is modelled as an equivalent lumped circuit made of a small number of series and parallel association of linear elements,
with up to three to four capacitors. To this end, for a chosen model structure, a parameter set has to be obtained minimising a criterion, usually the norm of the absolute error, between predicted and observed values.

3. Mathematical Framework
The observed electrical behaviour with the described setup is dominated by capacitive effects. The impedance norm being proportional to the frequency, a three decades frequency sweep yields data spread on three magnitude ranges. Unweighted regression minimises the \textit{local} error mostly where the data have the maximum amplitude: \textit{i.e.} over the highest frequency decade.

A better fit over the whole data range can be obtained by minimising \textit{f.i.} the norm of the relative error. This criterion is implemented in a method called “Element-Wide Total Least Square”. \textsuperscript{2,3} In the present case, it is too generic as it permits each row of the regression matrix to possess its own variance; and, as expressed, does not possess a closed-form solution, requiring iterative solving.

4. Original contributions
• \textbf{Design of experiment}: the set of test frequencies has been choose in such a way that each frequency is repeated a few times at randomised intervals. Local variance estimates are obtained by pooling all results per frequency decade, reducing the uncertainty of this value.
• \textbf{Data pre-scaling}: in the studied case, the minimisation criterion explained by Markovsky\textsuperscript{3} is equivalent to a pre-scaling of the data by a square root of the inverse of the covariance matrix. Expressed in terms of block of data columns, this covariance matrix is sparse. By a suitable grouping of the data, the sparsity of the pre-scaling matrix is preserved. The presented implementation is thus direct and does not require the storage of a full matrix.

5. Results
Analysis of the unweighted and weighted approaches will be compared, as well as their computational loads. The weighted approach leads to a better fit over the whole data range. Using error propagation techniques, a covariance matrix on the extracted parameters is also computed, yielding an estimate of the parameters uncertainty. The exposed approach takes into account the variance inhomogeneity using a direct method and permits to minimise a criterion which is similar to the \textit{relative} error.
References


Uncertainty evaluation for continuous-time measurements

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The Guide to the Expression of Uncertainty in Measurement (GUM) [1] considers the measurement of physical quantities whose values are constant in time. However, this stringent assumption is not always satisfied. For instance, in the analysis of dynamic measurements [3,4] or atomic clocks [5] the value of the measurand shows a time dependence. This also happens when monitoring a quantity, such as temperature, over time. While for discrete-time function estimation basically the (extended) methods of GUM and GUM-S1 [2] can be applied, this is no longer possible for continuous functions.

GUM and GUM-S1 employ probability calculus suitable for the inference on univariate or multivariate quantities. However, this is no longer possible for the inference on continuous functions which requires assigning a probability measure in infinite-dimensional function spaces, such as the space of continuous functions. In this case, techniques from stochastic calculus [6] can be employed, and we show that in using Kolmogorov’s extension theorem for stochastic processes the GUM and GUM-S1 methodologies can be extended to also cover estimation of continuous-time functions. As a consequence, propagation of (co-)variances (GUM) and propagation of distributions (GUM-S1) naturally carries over to the propagation of covariance functions and stochastic processes, respectively.

We illustrate the approach by means of two examples. The first considers monitoring a time-varying temperature for which the measurement noise is modeled by an Ornstein-Uhlenbeck process. We give an explicit expression for the covariance function and show how it is propagated in linear
functionals such as the average temperature. The second example addresses a particular task in dynamic measurements. Here we illustrate the propagation of the covariance function and of the mean function in terms of a SDE.

References
Bayesian Analysis versus Application of the GUM-S1 for Uncertainty Evaluation in Linear and Nonlinear Regression

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Supplement 1 to the GUM (GUM-S1)\(^1\) provides a Monte Carlo procedure for the (approximate) calculation of a probability density function (PDF) that encodes the state-of-knowledge about the value of a measurand \(Y\). It is assumed that a joint PDF on all input quantities \(X_1, \ldots, X_N\) is given together with the functional relation \(Y = f(X_1, \ldots, X_N)\). Then from the PDF for \(Y\) an estimate and its associated uncertainty can be calculated as the expectation and the standard deviation of this PDF. However, the GUM-S1 also recommends the assignment of PDFs for the input quantities in various situations, and in particular when repeated observations on one or several input quantities are available. It has been shown\(^2\)\(^-\)\(^5\) that such an assignment leads to a PDF for the measurand which is equivalent to a Bayesian posterior when employing Bayes theorem together with certain (noninformative) priors.

Least-squares estimation is an important tool of data analysis for metrology, and it is tempting to employ the GUM-S1 for evaluating the uncertainty of a least-squares estimate. Albeit such a procedure is beyond the specified scope of the GUM-S1, it is easily carried out and (hence frequently) applied. The question arises how such a procedure is related to the calculation of a posterior PDF via the application of Bayes theorem. We address this ques-
tion and mainly refer to the case when no prior knowledge is available. It was shown in 6–8 that when the variance of the sampling distribution is known the same PDFs are reached for linear regression problems, provided that particular noninformative priors are employed. For nonlinear models, generally different PDFs result. We extend these investigations by considering in particular the case of unknown variance of the sampling distribution of the data. In this case, two variants of an application of the GUM-S1 may be possible, one with and one without pooling of the variances. For linear models, a multivariate t-distribution results for the regression model parameters when pooling the variances. The Bayesian posterior (using standard noninformative priors) is also a multivariate t-distribution but its degrees of freedom are in general larger than those obtained by a GUM-S1 application, and different PDFs are produced even in the linear case. For the nonlinear case we show that the two ways of inference are structurally different.

The conclusion is that application of the GUM-S1 to the least-squares estimate does yield a PDF equivalent to a Bayesian posterior only when the regression model is linear in its parameters, when no prior knowledge is available and standard noninformative priors are used, and when the variance of the sampling distribution of the data is known in advance. Different PDFs are generally reached otherwise, and application of Bayes’ theorem is recommended for the calculation of a degree-of-belief PDF in this case.

References
MEASUREMENT OF ACCESSIBILITY TO RAIL TRANSPORT SYSTEMS

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1. Background

Improving accessibility to rail system for persons with disabilities is a governmental assignment to the Swedish Transport Administration. According to Statistics Sweden, SCB [1], a fifth of the Swedish population or 1.3 millions are disabled, including vision- or hearing deficiencies, mobility disorders, severe asthma or allergy. Challenges for this group of travelers can be found at all stages of a journey, from initial planning to make the journey to arriving at the final destination. Various measures can be implemented to improve and increase accessibility for the disabled throughout the rail transport system. Which actions that have the greatest positive impact and are most cost-effective, however, is not obvious. In addition to identifying and developing a variety of measurements to locate areas of concern, the question of how the measurement should be handled in order to be able to draw appropriate conclusions has to be answered. In order to improve accessibility and usability, a first prerequisite is to define the central concepts, especially in relation to rail travel and review how accessibility and usability have been measured previously.

2. Methodology

In this paper, we present a methodology for measuring the extent to which passengers with disabilities can use a rail transport system as part of a whole trip. The measurement methods to be developed, particularly where a human is a key component of the measurement system, importantly provide a basis for an objective evaluation of accessibility for disabled people. The measurements will also be used to target improvements in the areas where they have the greatest positive impact. By using such methods, the measurements will be used for
decision making about what action should be done to make the rail transport system more accessible to the disabled. In this paper we focus on an approach to measuring accessibility. Following Church et al. [2], we can define accessibility as:

\[ A_{ikl} = \sum_j p_{ijkl}d_{ijl} \]

where \( A_{ikl} \) is the accessibility of person \( i \) with regard to activity \( k \) and travel type \( l \), \( p_{ijkl} \) is the probability that a person \( i \) will go to zone \( j \) for activity \( k \) involving travel type \( l \), and \( d_{ijl} \) is the distance, travel time, or other measure of effort for person \( i \) to reach \( j \) of travel type \( l \). Based on a critical incidents technique [3], we can identify significant barriers en route to accessing the goal. Measures of accessibility can either be judged by observing the choice and effort expended (Measuring Man) or by rating the perceived effort (Man as a Measurement Instrument) of each route. Grading the barriers, we can use them as \( d \). Using such an approach, it is important to be aware of the scales that are used to form \( d \) [4]. Using this approach, we can now write the accessibility for a group of travelers as:

\[ A_{kl} = \sum_i f_{ikl} \sum_j p_{ijkl}d_{ijl} \]

where \( f_{ikl} \) is frequency of trips of type \( l \) (e.g., trips per year) for a person \( i \) going for activity \( k \). In this paper, we discuss on how to obtain quality assured accessibility measurements using the described approach.

Acknowledgments

This work is supported by the Swedish Transport Administration.

References

UNCERTAINTY EVALUATION FOR TRACEABLE DYNAMIC MEASUREMENT OF MECHANICAL QUANTITIES: A CASE STUDY IN DYNAMIC PRESSURE CALIBRATION

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Many applications of the measurement of mechanical quantities such as force, torque and pressure are dynamic, that is, the measurand shows a strong variation over time. Measurement uncertainty in dynamic applications may also be time dependent. The transducers employed in such applications are in most cases calibrated by purely static procedures owing to a lack of traceable methods or documentary standards for the dynamic calibration of mechanical sensors. It is well known that mechanical sensors exhibit distinctive dynamic behaviour that shows an increasing deviation from static behaviour as frequency increases. These limitations can lead to inaccurate measurement results, including unreliable evaluation of measurement uncertainty.

To support emerging industrial needs in the UK and elsewhere for calibrated pressure sensors for dynamic applications, the UK’s National Physical Laboratory (NPL) is developing new primary measurement standards that can generate time varying pressure signals of the required bandwidth and dynamic range. Currently NPL is concentrating on the use of shock tubes as a means of developing well controlled wide bandwidth pressure variations that can be employed to calibrate pressure sensors.

The main metrological challenges that are posed by the shock tube
method arise from the fact that the waveform that is created at the sensor as the shock propagates along the tube is step-like in nature. As the sensor is located close to the shock tube end wall, it detects not only the direct step change in pressure but also echoes from the walls of the tube and from within the sensor itself. In addition, acoustic disturbances travel through the metal tube much faster than the shock wave can travel in the gas of the tube so that the sensor detects these prior to the arrival of the shock front. The consequence is that the signal obtained from the pressure sensor has a complicated structure that represents the superposition of many separate effects.

The authors review and demonstrate the challenges that arise from the use of shock tubes as a calibration tool. These include:

- Modelling and predicting the manner in which the shock front develops as it travels along the shock tube;
- Accounting for the effects of diffraction, the non-planar nature of wavefronts, and echoes from the tube wall and end-faces;
- The short time duration of the measurement and the consequences of this for choice of signal processing and data analysis techniques;
- Establishing an uncertainty budget that is appropriate for the shock tube technique;
- How to account for the bandwidth limitations of the sensors employed in the shock tube.

The work described here will be developed further within the European Metrology Research Programme (EMRP) project entitled *Traceable Dynamic Measurement of Mechanical Quantities* that is due to start later in 2011. Lessons learned from the study of dynamic pressure sensors will be applied to the calibration of dynamic force and torque transducers.

A key work package within the EMRP project, which will be led by NPL in close collaboration with colleagues from other leading European National Measurement Institutes, is devoted to mathematical and statistical methods and modelling to support new developments in dynamic mechanical measurement. It will establish dynamic models for the complete calibration measurement chain, develop procedures for uncertainty evaluation in dynamic calibration, and research the design of appropriate deconvolution filters that can be employed in industrial applications to correct measurements for sensor effects.
1. ABSTRACT

The greater availability of cheap computing power has led to an increase in the use of continuous models, and particularly finite element (FE) models, within industry and metrology.

The most common use of FE models is for design purposes. In industry, models are used to develop designs of products and structures that satisfy performance requirements and constraints on manufacturing, and minimise cost. In metrology, models are used to design equipment and experimental set-ups that enable good measurement and minimise the uncertainties associated with the measured data. In both areas, the design process involves adjustment of parameters to obtain a required performance. This type of problem is an inverse problem and is typically solved using optimisation methods, and can benefit from uncertainty evaluation to assess the robustness of the performance of a chosen design to small changes to its parameters.

Another important requirement within metrology is the investigation of the sensitivity of the FE model results (and thus the measured data) to experimental parameters such as temperature, sensor location, and geometric and material parameters. Understanding what are the key parameters allows the experimentalist to control the important experimental aspects without wasting effort on insignificant features. This type of problem requires sensitivity analysis of the model.

An increasingly important problem within metrology is the use of continuous (including FE) models to estimate material properties or other characteristic parameters from measurement data. This type of problem generally involves optimisation to minimise a measure of the difference between measured data and model results, and requires uncertainty evaluation using the model in order that a meaningful uncertainty can be associated with the parameter estimate.

The majority of FE modelling within industry is carried out using commercial packages that do not offer source code access. Whilst in-house packages and freeware are also used, the large development and testing costs and the reliability
and wide application range of commercial packages generally mean that commercial packages are still widely used. Many applications now use models of high complexity and large computational expense. Sensitivity coefficients are usually calculated by evaluating the partial derivatives of the model result with respect to the parameters. Uncertainty evaluation using the methodology of the “Guide to the expression of uncertainty in measurement” (GUM) requires the calculation of such sensitivity coefficients. Many optimisation methods also use derivative information to estimate the best search direction. The use of black box software means that this derivative information is not available to the user directly. The large computational expense of FE models in particular often means that alternative methods (e.g. finite differences for derivative estimation and Monte Carlo sampling for uncertainty evaluation) are not computationally viable.

NPL recently completed a project [1–4] investigating the use of optimisation, sensitivity analysis and uncertainty evaluation applied to computationally expensive black-box models. The work involved algorithm implementation and their application to simple problems with analytical solutions to allow algorithm performance to be investigated, as well as to two real-world case studies. This talk will discuss the results of the project and will outline our plans for future development of a user-friendly toolbox to simplify optimisation, sensitivity analysis and uncertainty evaluation using FE models.

References

1. **Introduction:**

Many applications have been developed for Cave Automatic Virtual Environment (CAVE). In a same time, the technology used of the system put in place strongly influences the quality of the immersion experienced and sensed by the user. So, before loading an application inside a virtual reality system, checking the compatibility between the precision called for this application and the real accuracy delivered by the CAVE is a compulsory step. This paper will deal with the calculations of the accuracy and the uncertainty of a multi-camera tracking system, using linear algebra.

2. **Proposed method:**

A spherical marker \( (S_{X,Y,Z}) \) is virtually located at the center of the CAVE. Its coordinates of the center are known in \( R_w \), the main axis system of the CAVE. The pin-hole model uses intrinsic and extrinsic factors of the camera. It can determine coordinates of the center of the marker \( (M_{th(U,V)}) \) in the 2D image of the camera in function of coordinates in \( R_w \). This is a projection from \( R^3, (O,x_{C_w},y_{C_w},z_{C_w}) \), to \( R^3, (O',u,v) \) (Figure 1).

\[
\begin{bmatrix}
h \cdot u_{jk} \\
h \cdot v_{jk} \\
h
\end{bmatrix} =
\begin{bmatrix}
f_x & \alpha & u_0 & 0 \\
0 & f_y & v_0 & 0 \\
0 & 0 & 1 & 0
\end{bmatrix}
\begin{bmatrix}
x_{jk} \\
y_{jk} \\
z_{jk}
\end{bmatrix}
\]

**Figure 1.** Pin-hole model and its associated matrix

The equation [1] gives these for the marker \( j \), belonging to the item \( i \), and seen by the camera \( k \).
These intrinsic and extrinsic factors are subjected to disturbances, according to data collected. Part of these disturbances refers to temperature variation, deformations… that the structure can undergo. This will cause a variation of the estimated location of the marker \( (M_{P_{UP}}) \) in the 2D image of the camera. This variation is called projection error \( (e) \). It is the distance between the theoretical location and the “disturbed” one. This projection error for each camera is computed. From these previous projection errors, the least square method has been used to calculate the estimated location of the marker in \( Rw \). \( \Delta M \) means the deviation between the theoretical localization of marker and its estimated localization \( (s(x,y,z)) \) in \( Rw \). Thanks to a Monte Carlo simulation, the standard deviation in every direction of the main axis system is computed. The variance covariance matrix of \( \Delta M \) is determined. The error matrix is deduced from the previous variance covariance matrix.

Moreover, this method can also be used to determine a rating of influence of these intrinsic and extrinsic factors, in order to improve the accuracy of the CAVE.

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MEASUREMENT UNCERTAINTY ESTIMATION OF VIRTUAL INSTRUMENT BASED ON MONTE CARLO METHOD

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Abstract

Although there is hitherto no standard definition of virtual instruments (VI) that could be universally accepted, VIs have been extensively applied in the industrial environment and in the test and calibration laboratories. More and more kind of measurements are performed using a general purpose data acquisition board connected to a common personal computer and processing the acquired data by using VI development platforms, such as Labview, Agilent VEE, and so on. VIs are superior to traditional instruments because of their cost effectiveness, flexibility, reusability, as well as friendly interface. However there are also some problems exist. The one of difficulties is evaluating its measurement uncertainty in an economical and acceptable process, and the evaluation method has to be, even if an approximation, easy to apply. In order to solve these problems, many authors have presented various interesting methodologies. Nuccio and Spataro presented two kinds of methods, numerical method based on Monte Carlo and theoretical method applying the “uncertainties propagation law” of GUM, to evaluate the uncertainties of measurement results with a VI, and then compared the results using these two kinds of methods. Jing XD presented the approaches to evaluate the combined measurement uncertainty of a VI with consideration for the main parts of the measurement chain.

In this paper, we handled this topic too. Starting from the measurement chain of the typical configuration of VI, we analysis the measurement uncertainty sources

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of VI. And then discuss the theoretical method and the numerical method to evaluate combined uncertainty of static measurement and dynamic measurement. Then we introduce the software tool designed by ourselves for propagating the uncertainty distributions using Monte Carlo method. Last, with the aim of verifying the application of the method, we show a practical case on estimate measurement uncertainty for the measurement of the AC RMS voltage by data acquisition board.

![Block diagram of measurement uncertainty estimation of virtual instrument based on Monte Carlo](image1)

**Figure 1.** Block diagram of measurement uncertainty estimation of virtual instrument based on Monte Carlo

![Approximations to the PDF for the output quantity Y obtained using the Monte Carlo Method.](image2)

**Figure 2.** Approximations to the PDF for the output quantity Y obtained using the Monte Carlo Method.

**References**

Measurement systems, testing and signal processing using LabView

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Abstract— This paper summarizes 2 years experience with LabView in the field of measurement and instrumentation. It provides us with basic but important literature. History and examples of graphical programming are briefly mentioned. The introduction into graphical development environment LabView is shown. Thereafter the example of application LabView for measurement systems, testing and signal processing will be stated. Last not least the chosen results from DAC testing using band signal will be presented.

Keywords— Graphical programming, measurement systems, signal processing, DAC testing, band signals, damped sinewave, SINC signal

I. INTRODUCTION

Primordial visual data flow system was implemented by W.R. Sutherland - MIT Lincoln Labs in 1966, [1],[2],[3]

Since then graphical programming languages has come a long way. LabView, MatLab Simuling, Agilent Vee, Test Point from Keithley or Siemens Logo Soft Comfort are examples of contemporary GPLs [4], [5]. In [4] a comprehensive set of modeling methods for data and uncertainty analysis, taking readers beyond mainstream methods described in standard texts is provided.

In this paper LabView will be only mentioned bellow, however the principles of other graphical programming languages are similar.

Introduction into LabView will be stated in full paper.

II. EXAMPLE OF LABVIEW IN MEASUREMENT

Will be stated in full paper.

III. TESTING USING BAND SINGAL

A. Sinc dac test

Waveform of the sinc signal is:

$$u(t) = \frac{\sin\left(\frac{2 \cdot \pi \cdot t}{T_2}\right)}{2 \cdot \pi \cdot t}$$

And the crest factor can be computed by this equation or measured directly using our measuring systems. Then correction could be applied.

$$CF = \frac{\text{Max}[u(t)]}{\text{RMS}} = \frac{1}{\sqrt{\frac{1}{T_1} \int_{-T_1/2}^{T_1/2} u^2(t)dt}}$$

B. Damped Sine Wave Fft Test

General but important presumptions for testing ADC or DAC are:

- firstly testing near Full Scale FS - it is necessary to ensure, that Peak-to-Peak value covers FS of DUT;
- secondly condition is, that Slew Rate SR of the signal is slower than Slew Rate of the DUT and generator. It is possible to use standard formula for...
slew rate, because damped sine-wave has same slew-rate.

$$2 \cdot \pi \cdot f_i < SR_{\text{RUL}}, 2 \cdot \pi \cdot f_i < SR_{\text{GENERATOR}}$$ (1)

Solution of harmonic motion of the under damping system [5] can be expressed:

$$u(t) = A e^{-2 \pi d f_i t} \cos(1 - d^2 2 \cdot \pi \cdot f_i \cdot t - \phi)$$ (2)

where $A$ is signal's amplitude $d$ is damping ratio, is undamped frequency, is phase shift of the signal. If damping ratio $d \ll 1$ this formula can be rewritten as:

$$u(t) = e^{-2 \pi d f_i t} \sin(2 \cdot \pi \cdot f_i \cdot t)$$ (3)

in this case signal's amplitude is $A = 1$.

The signal's RMS, which is periodically generated with frequency $f_i$, can be computed using (4):

$$RMS = \sqrt{\frac{1}{T} \int_0^T u^2(t) \, dt}$$ (4)

$$RMS = \sqrt{\frac{f_2}{2} \left( e^{-\frac{4 \pi f_i d}{f_1}} - 1 - d^2 + \sqrt{1 + d^4} \right) \sin \left( \frac{4 \pi f_i}{f_2} \right)}$$ (5)

This formula can be simplified for the ratio of frequencies $f_1/f_2 = 0.5, 1, 2...$, results is shown in (6)

$$RMS = \sqrt{\frac{f_2}{8 \cdot \pi \cdot f_1 \cdot d \cdot (1 + d^2)}}$$ (6)

Amplitude of this signal is the first maximum. After doing some math, it can be expressed as following formula:

$$\text{Amplitude} = \sqrt{\frac{f_2^2}{d^2 + f_1^2} e^{-\frac{4 \pi f_i d}{f_1}}}$$ (7)

Crest Factor $CF$ is Amplitude to RMS ratio:

$$CF = 2 \sqrt{1 + d^2 - \sqrt{1 + d^4}}$$ (8)

This formula can be reduced if $d \ll 1$. Then the $CF$ is given by next formula (9).

$$CF = \frac{2 \cdot e^{-\frac{\pi d}{f_1}}}{\sqrt{1 - e^{-\frac{4 \pi f_i d}{f_1}}}}$$ (9)

Spectra of the damped sine waves signal with different damping ratio are shown in Fig. 2

**IV. EXAMPLES OF GENERATED SIGNALS, METHODS AND RESULTS**

<table>
<thead>
<tr>
<th>Damped Sine Wave FFT Test $f_1 = 5kHz, f_2 = 1kHz$</th>
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<tbody>
<tr>
<td>$C_{\text{Ref}}$</td>
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<td>-----------------</td>
</tr>
<tr>
<td>$1.78$</td>
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<td>$2.09$</td>
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<td>$2.63$</td>
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<tr>
<td>$3.38$</td>
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<td>$4.10$</td>
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</table>

**DACE testing using Single-tone, Multi-Tone, AM, FM, Sinc, Damped sine wave signal will be stated in full paper.**

**REFERENCES**


**Figure 2. Spectrum of damped sine-wave $d = 0.64$, $D = 2000$, $f_1 = 5 kHz$, $f_2 = 1 kHz$.**
A BAYESIAN APPROACH TO THE CONDITIONAL ESTIMATION OF PARAMETERS AND ASSOCIATED UNCERTAINTY: APPLICATION TO MEASUREMENTS OF THERMAL DIFFUSIVITY OF MATERIALS

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The ISO standard 13005, Guide to the Expression of Uncertainty in Measurement (GUM), deals with the evaluation of measurement uncertainty. It is easily implemented when the measurand is the observed quantity, that is the outcome of the measurement process, or when it is the analytic prediction of a mathematical (measurement) model.

More complex situations for uncertainty evaluation arise when the measurand is a non-measured (hidden) variable, whose impact on the actual observations is obtained from a numerical solver. In such cases, the measurand should be evaluated by parameter identification (inverse) methods. Identifying a mathematical model, also referred to as model calibration, consists in comparing the model prediction to experimental data of the same quantity, and to estimate the model parameters through a resolution or inference method (e.g. using an optimization or regularization technique). In the context of uncertainty, the Bayesian framework appears to be very much suited to address model calibration problems. Indeed, the Bayesian paradigm provides a generic and flexible approach to inverse problems, particularly interesting when dealing with complex, hierarchical and non-linear systems. In addition, the posterior distribution of the
parameters provides a measure of the measurand’s uncertainty, in compliance with the GUM supplement 1 framework. Finally, it offers a principle way to incorporate prior information, coming from previous results or expert’s knowledge. We thus propose a Bayesian model for the conditional estimation of statistical model’s parameters. The ensuing inference is based on a Metropolis-Hastings algorithm.

We evaluated this Bayesian approach for the estimation of the thermal diffusivity of various materials. The physical principle of measuring thermal diffusivity is to irradiate with a pulse of energy one side of a material sample and to measure the transient temperature rise (thermogram) on its opposite side. This experimental thermogram is compared with a theoretical one obtained by solving the heat equation and accounting for radiation and conduction effects.

Namely, we investigated the impact of different prior densities on model parameters, as well as of different model structure, depending on available information about the experimental setting and the material to be studied.

The developed models were first tested on simulated thermograms to assess their ability to recognize the simulated parameters and their robustness to noise and model error. These models were then applied and compared on real data (experimental thermograms obtained with a sample of Fer Armco). The conditional estimates of the thermal diffusivity obtained proved accurate and reproducible across repeated experimental measures.

Keywords: uncertainty evaluation, inverse problem, parameter identification, Bayesian, dynamic measurement

References

A TWO-STAGE MCM/MCMC ALGORITHM FOR UNCERTAINTY EVALUATION

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A number of recent papers, e.g., 1–4, have considered the relationship between the propagation of distributions, as described in Supplement 15 to the GUM,6 and Bayesian inference in the context of uncertainty evaluation. The analysis shows that from the point of view of Bayesian inference, propagating distributions through a measurement model imposes a particular type of prior distribution for the measurand and other influence factors. For some models, the assigned prior distribution might not be plausible as it can imply the prior dependence of the measurand on the influence factors.3 If an alternative prior distribution is adopted, then other approaches have to be employed.

Markov chain Monte Carlo7,8 (MCMC) methods are widely-used algorithms for providing a sample \( \{a_q\} \) from a target distribution \( p(\alpha) \). However, their implementation is sometimes not straightforward as the user has to design the chain in such a way that it a) converges quickly to the target distribution and b) provides a sample that can be used efficiently to determine estimates of the distribution parameters such as its mean and standard deviation: if the chain has a high auto-correlation, then a large sample is required in order to determine useful estimates of the distribution parameters. For Metropolis-Hastings algorithms, designing an efficient sampling scheme means choosing an appropriate transition distribution \( q(a_q, a^*) \) to generate the next candidate sample \( a^* \) from the target distribution. This candidate is accepted with a probability determined according to a simple rule involving the target distribution and the transition distribution. If the candidate is accepted, then \( a_{q+1} = a^* \), otherwise \( a_{q+1} = a_q \).

In this paper, we show that for many practical problems a sample produced using a Monte Carlo method (MCM), as an implementation of the
propagation of distributions, can be used to define candidate steps in a particular type of Metropolis-Hastings algorithm, sometimes called an independence chain. For many classes of measurement model, the Metropolis-Hastings implementation is a simple post-processing step and converts an MCM sample to a sample from the desired posterior distribution. The approach can be implemented in a few lines of software and we describe a short Matlab implementation that can be used, without change, for a wide class of models. The acceptance percentage gives a measure of how close the MCM distribution is to the posterior distribution derived using the preferred prior distribution and, for many practical problems, the acceptance rate is close to 100%. For high acceptance rates, the auto-correlation in the chain is low so that sample statistics converge to their distribution counterparts at rates similar to those achieved using MCM.

References
The term numerical artefact relates to a reference data set used to test metrology software. Given a computational task, a numerical artefact will define input data and an associated reference solution. The input data can be supplied to software under test and the solution values output by the software can be compared with the reference solution. There are basically two approaches to generating numerical artefacts. The first is to construct an appropriate set of input data and apply reference software to determine the reference solution. This approach depends on having reference software available and also on the validity of the reference software. The second approach is to use the conditions for a set of parameter values to be a solution for the chosen computational task and then construct the input data and output solution simultaneously. For least squares regression problems, this approach is sometimes known as the nullspace approach as the input data is constructed from a vector in the nullspace of the observation matrix. In general, the nullspace approach requires a much smaller number of computational components and provides an effective shortcut to generating numerical artefacts without the need to develop and validate reference software.

In this paper, we describe how the nullspace approach can be applied to assess the performance of software for a wide class of regression problems involving data subject to correlating systematic effects. In practice, the regression problem is often replaced by a simpler one, e.g., one ignoring the correlation. Numerical artefacts can be used to assess the impact of the approximating assumptions and allow the user to decide if the simpler implementation is fit for purpose. The regression problems under consideration are associated with observation matrices that have specific structure...
such as block-angular, bordered bi-diagonal, or the more general bordered banded. In order to apply the nullspace approach effectively, it is necessary to exploit this structure in generating the numerical artefacts.

We illustrate the approach for generating numerical artefacts associated with determining calibration functions, free form surface fitting\(^4\) and other generalised distance regression problems\(^5\) and large scale coordinate metrology involving multiple measuring stations.\(^6\)

References

MEASUREMENT UNCERTAINTY FOR CALIBRATED INSTRUMENT

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Some measuring instruments are calibrated by comparing with the standard material size to keep traceability. When the length is measured by the calibrated instrument, the uncertainty of calibration, e.g. the uncertainty of standard material of size, the uncertainty of probing and so on., should be considered to estimate the uncertainty of measurement. The uncertainty of calibration is affected by probing strategy and distribution of standard material of size. In this paper, both processes of calibration and measurement are considered. A dial gauge is dealt as an example of these processes and models. At first, the dial gauge is calibrated using some gauge blocks and interpolated. At second, the uncertainty of measurement is estimated based on the calibration result. Fig.1 shows the relationship between the length and uncertainty based on the calibration result. The dot in Fig.1 shows the deviation from the standard material size. The line in Fig.1 shows the estimated uncertainty in length measurement.

![Fig.1 Uncertainty and Deviation at Reference Point](image-url)
MATHEMATICAL MODELS FOR ERROR CORRECTION IN MScMS-II (MOBILE SPATIAL COORDINATE MEASUREMENT SYSTEM)*

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Abstract

Nowadays, one of the most challenging issues for coordinate metrology instruments is to ensure consistent performance throughout the whole working volume. This goal is even more tough in the field of Large Scale Dimensional Metrology (LSDM) when the dimensions of the working volumes are of the order of several meters. Distributed measurement systems, which are characterized by a distributed hardware architecture based on a network of metrology stations spread in a well defined working volume, seem to particularly suffer this problem. With particular regards to this typology of systems, several corrective models have been proposed in order to partially address this issue. Some of them are already integrated into the onboard firmware and software applications [1]. This paper deals with the mathematical models for error correction implemented into a new prototype system developed at Politecnico di Torino, the Mobile Spatial coordinate Measurement System (MScMS-II) [2]. The prototype is characterized by a distributed modular architecture, consisting of a network of wireless sensing devices, a remote portable and armless probe, and a centralized data processing unit. The network is composed by a set of

* This work and the whole research program “Large-scale coordinate metrology: study and realization of an innovative system based on a network of distributed and cooperative wireless sensors” (PRIN 2008) have been financially supported by the Italian Ministry of University and Scientific and Technological Research (MIUR).
low-cost IR cameras, able to wirelessly communicate with the data processing unit. Relying on the principles of close-range Photogrammetry, the system is able to define the position of the armless probe and, as a consequence, to reconstruct the measured geometries [3]. Because of its architecture and its working principle, the system is affected by several error sources that impact differently on system performance [4]. The distortion of each camera lens, as well as the physical size of the probe that can approach the measurand with different trajectories, but also the kinematics of the probe are just some of the factors that can cause bias and variability during the measurement [3,5]. This paper aims at analyzing the different error factors verifying their impacts by proposing some correction models addressed at the improvement of the global metrological performance of the system. For each of the models presented in the paper, a theoretical treatment is given along with a discussion of its practical implementation and results in terms of performance improvement.

References

High precision surface measurements can be performed by means of combining different procedures, measurement strategies and instruments. The combination of straightness-, roundness-, or helically scanned form profiles and two-point diameter measurements can be used to generate 3D topographies of piston-cylinder assemblies. The procedure to fuse these measurement results is proposed.

Cylindrical measurements can be performed using different techniques and instruments. Precise measurements of cylindrical surfaces are required for many applications involving high-precision cylinders like high-precision machine or engine parts, piston-cylinder assemblies or cylindrical standards [1]. Nowadays, data fusion, being widely applied in measurement techniques, provides the opportunity to improve the measurement process. The current work considers the fusion of the cylindrical measurement data by using different instruments and measurement strategies.

The choice of the probing strategy defines the number, location and distribution of the measured points. Some of the methods for cylindrical measurements are: radial section method, generatrix method, helical line method and bird-cage method.

In the case of point clouds fusion, the crucial point of the conjoint data processing is the data registration. Given that each point cloud is obtained from its own coordinate system, the purpose of the registration process is to transform the measured points to the same coordinate system. The transformation in the Cartesian coordinate system is defined by the transformation matrix \( R \) (3x3) and the translation vector of the origin \([x_0, y_0, z_0] \), estimated by solving the optimization task. Different criteria can be used to perform this task with respect to the second point cloud. Two general criteria can be distinguished: (i) minimization of the function \( d \), which characterizes the distances between the elements of both point clouds (least square method), (ii) maximization of the cross correlation coefficient \( k_{corr} \) between the elements of both point clouds.

For matching the radial section and the generatrix measurements in a cylinder-piston assembly [3], the criterion of minimum least squares of distances
in the intersection points is used. The task becomes more complicated if the strategies of helical scan (Fig. 1a) and radial sections need to be combined.

The advantage of representing the point clouds in cylindrical coordinate system \((\theta, z, \rho)\), as shown in Fig. 1b, is the univocal dependence between the coordinates: \(\rho = \sqrt{x^2 + y^2}, \ \theta = \arcsin(y/\rho) = \arccos(x/\rho)\). The use of 2D interpolations algorithms and cylindrical coordinate system allows generating interpolated points on rectangular grids from the set of measured points. Interpolated representations of surfaces have the same number of points according to the chosen rectangular grid and are represented by images. This makes the registration process visible and allows the use of advanced image processing techniques in the next steps of data processing.

![Cylindrical surface interpolation and image representation](image)

Fig 1. Cylindrical surface interpolation and image representation: (a) – helical scan of the cylindrical surface, (b) – its representation in cylindrical coordinate system, (c) – image representation of the interpolated data cloud. The grey tones represent local form deviations.

Three different procedures of data fusion are available, but the weighted procedure is recommendable. Data fusion of measured and interpolated points in the case where the sampling condition was satisfied gave better results.

The precise diameter measurements have been matched to the roundness measurements by applying the criterion of maximum correlation. In respect to the much higher precision of diameter measurement, a weighted procedure for data fusion was interpreted as a special correction algorithm of the helical scan data.

References
METROLOGICAL TRACEABILITY AND QUALITY OF INDUSTRIAL TESTS MEASUREMENTS

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Quality of industrial product is due to the correctness of the dimension chains, that is based on consistency of the tolerances for parameters of workpieces and assembled components, which is an integral part for division of labour. Confirmation of the workpiece quality is based on the testing that actual parameters are within tolerable limits. This testing is usually performed by measuring parameters and comparing measurement results with stated requirements (tolerable limits). Thus, the measurement quality is the conditioning factor for the workpiece quality. From the practical standpoint, the measurement quality means, firstly, the comparability of measurement results (that involves expression of measurement results in accepted units and estimation of measurement errors according comparable methods) and secondly, limitations for errors, consistent with the tolerable limits for parameters.

Modern system of metrological notions encloses the only concept for the measurement quality designation, namely, traceability. This notion is defined in [1] as follows: “a property of measurement result whereby it can be related to a measurement unit or standard through a chain of calibrations”.

Primarily, traceability realization does not and could not ensure the required level of accuracy of the measurement result, as this task is unsolvable by purely metrological methods (see Note 5 to the VIM-definition). Moreover, traceability does not really ensure all the practically significant “metrological” aspects of the measurement quality. It is discovered while structuring the measurement errors, and analysis, based on metrological traceability chain, of the errors components and estimates. The main steps of this procedure are as follows.

1 While taking into account full metrological traceability chain of calibrations, one can estimate the basic instrument error, which is the error of measuring instrument under calibration conditions:

\[ \delta_0 = \delta \{ Q \mid \text{chain of calibrations} \} \]

2 While taking into account also construction of measuring instrument (metrological characteristics) and measurement conditions, one can estimate the total instrumental error, which is the error of measuring instrument under measurement (operating) conditions:

\[ \delta_I = \delta \{ Q \mid \text{measuring instrument characteristics & measurement conditions} \} \].

3 For obtaining the total error of measurement result, one has to consider not only instrumental errors, but also properties of the measurand and the procedure of its comparing with the unit, which is

\[ \delta_R = \delta \{ Q \mid \text{measuring instrument & measurement model} \} \].

Obviously, even the widest treatment of the traceability concept embraces only the stages 1 and 2, therefore it ensures only estimation of the instrumental component of measurement error.

For obtaining the total error of measurement result (stage 3) one has to use
the model elements of the measurement procedure. In other words, it is necessary either to expand the concept of traceability, or to introduce the concept of measurement quality, which embraces the content of the stage 3. The latter has to contain the structure of the measurement procedure model and estimating of the corresponding “model” component of the measurement result error. Analysis of the related modeling procedure is presented in papers [2 - 4].

Consideration of the “model” aspect of measurement quality allows revealing the reasons for the lack of comparability of the measurement results, which occurs in manufacturing.

As a simple example, the control of the workpiece manufacturing (production) may be considered. The tolerable limits for parameters are supposed to be stated in advance, and the control encloses the measurements of parameters. If there is any mismatch at the next stage of manufacturing (in assemblage), then the arbitral measurements are executed. However, the error estimation procedures for these two measurements (under traceability condition) will differ, as these are performed under different measurement procedure models. At the first case, while workpiece manufacturing, the error estimation is based on the “technological” model of the workpiece and its parameters. This model may be simplified or optimistic, as it is based on the previous assumption; so it brings to the simplified control procedures. For instance, in the model of the turned work the faceted structure may be neglected. It is usually taken for granted, that the workpiece section is a circle, so all the distortions are just the deviations of the diameter from the specified value. Under this assumption it is impossible to detect the real form of the workpiece. At the second case, the workpiece model for arbitral measurements (while controlling in assemblage) may be a refined model, or it may be quite different from the first one.

The stated above may be summarized as follows.

1 Now the measurement result is presented by two numbers, these are measurand estimate and error estimate. The measurement models are neglected, so the different measurements of the same quantity could not be compared.

2 It is necessary to include the information on the measurement models into the measurement result presentation. Then the comparability of measurement results will be ensured.

3 It is necessary to expand the concept of traceability, or to introduce the concept of measurement quality as stated above.

References


IN-ORBIT MAGNETOMETER CALIBRATION BASED ON LINEAR KALMAN FILTERING

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Abstract

Magnetometers are widely used for small satellites attitude determination and control system. These sensors are useful for attitude determination, since they provide both the direction and magnitude of magnetic field. In addition, they are small and low power consuming sensors, which can easily meet strict size and power requirements for small satellites. For these reasons, most LEO small satellites have magnetometers as part of their basic sensor package. In order to estimate satellite dynamics and control attitude accurately, scale factor and bias of magnetometer must be estimated.

In last decade, popularity of small satellites with low cost and weight has increased significantly. That brought about a search for lighter but more accurate sensors. Under these circumstances, three-axis magnetometer (TAM) has become so attractive because of its advantages such as providing a continuously available two-axis attitude measurements; relative low cost and almost insignificant power demand.

Operating magnetometers as primary sensor in small satellite missions is a common method for achieving attitude information. However, these sensors are not error free because of the biases, scaling errors and misalignments (nonorthogonality). These terms inhibit the filter efficiency and so attitude data accuracy and even they may bring about the filter divergence in long terms. The attitude accuracy requirements demand compensation for the magnetometer errors such as misalignments and biases. Estimating magnetometer biases and scale factors as well as the attitude of the satellite is a proposed technique to solve such problems and increase on-board accuracy.

In initial phase of the satellite mission, measurement of magnetometers are indispensable for attitude determination and control system. In order to obtain accurate geomagnetic field measurements, the sensor should be calibrated precisely. In literature there are several methods for estimating the magnetometer bias. Extended Kalman Filter (EKF) is used as a part of the estimation scheme. Via an Unscented Kalman Filter (UKF) based estimation algorithm, which has advantages over EKF such as absence of Jacobian calculations etc., its accuracy may be surmounted. As a disadvantage, this approach requires a high computational effort because of UKF and it may be not suitable for pico satellites where the processing capacity of the attitude computer is limited.

In this study a Linear Kalman filter based algorithm is proposed for magnetometer calibration. Proposed algorithms are simulated through attitude dynamics of a small satellite. Comparison of the calibrated and uncalibrated magnetometers results shows that (See Figs.1-2) the calibrated magnetometer results nearly coincide with their true values, in contrary the uncalibrated results are significantly biased.

For the operation of the proposed method, the attitude transformation matrix is needed to transform the orbit modeled geomagnetic vector to body coordinates. Measurements from other attitude sensors (for example, gyroscopes) are thus essential for the accuracy of this calibration algorithm. Simulation results show that, it is possible to estimate both magnetometer bias and scale factor via the linear Kalman filter. The computation burden of the proposed calibration algorithm is not significant. This algorithm is suitable for pico satellites which has three magnetometers as measurement sensors and the processing capacity of the attitude computer is limited.

Since magnetometer utilization has significance especially for pico satellite missions, proposed algorithm may affect the mission performance and reliability in a considerable degree.
Fig. 1. X-axis Geomagnetic Field Magnitude in Body Frame of the Calibrated and Uncalibrated Magnetometers

Fig. 2. Y-axis Geomagnetic Field Magnitude in Body Frame of the Calibrated and Uncalibrated Magnetometers
ABNORMAL MEASUREMENT DETECTION METHOD ROBUST TO SYSTEMATIC UNCERTAINTIES

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Abstract

Practice of statistical measurement information processing shows that among multiple measurement results there are some values (abnormal measurement results) that differ drastically from the rest. Appearance of such measurement is concerned with a sharp disturbance of the operating conditions of information-measurement equipment. In most cases, abnormal measurements arise in the process of measurement transformation. However, they can be a result of computer faults in measurement preprocessing and as a consequence of faults in data transfer through communication lines. Statistical investigations show [1] that very different scientific, industrial, and other data contain as a rule 5-10% abnormal measurements, and in the case of radio technical measurements some sessions can contain more than 10% abnormal measurements [2] that reduce dramatically the application efficiency of many classical statistical procedures. Hence, abnormal measurements disturbing the statistical character of information on the process under investigation should be timely detected and eliminated from subsequent processing.

The existing abnormal measurement rejection algorithms do not consider the systematic measurement uncertainties and their effect on the decision procedure. In real condition, solution of the problem of abnormal measurement rejection has to be done in most cases in the presence of systematic uncertainties whose average value is not zero. The systematic uncertainty is a result of unaccounted for constant or slowly varying factors such as conditions of radio wave propagation, change in reference frequency of oscillators, errors of geodesic survey of measurement device, etc.

The presence of systematic uncertainties lowers reliability of the foregoing methods of abnormal measurement detection. The unaccounted systematic uncertainty may lead to such a situation that as a result of processing the normal measurements can be rejected as abnormal ones whereas the abnormal measurements can be taken as normal ones. Thus, the systematic components of measurement uncertainties may lead to a considerably reduced efficiency of the process of abnormal measurement rejection, therefore, their consideration is of great practical significance. In what follows, a new approach to designing the abnormal measurement rejection algorithms, which is robust to systematic measurement uncertainties is proposed in this study. To detect abnormal measurements, this approach uses differences (mismatch) of two sequential measurements and calculated values of the output coordinates of the model system. As a result, the systematic measurement uncertainties are mutually exclusive. Statistical characteristics of the mismatch are investigated and prompt method for abnormal measurement rejection is developed.

The proposed abnormal measurement rejection method does not require any information on the value and sign of the systematic error and also on the statistical characteristics of abnormal measurements. The algorithm is quite simple and easily implemented on a microprocessor. This algorithm can be widely used in various technical branches for measurement data processing, i.e., in radio inertial navigation systems, computer-aided technological process control systems, data processing devices in radio radar systems, in piloting flying vehicles, etc.

References

GENETIC ALGORITHM BASED CALIBRATION OF MEASUREMENT APPARATUS

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Abstract

Accurate measurement is the basis of almost all engineering applications, since uncertainty inherently exists in the nature of any measuring apparatus. On the other hand, the cost of a measuring apparatus increases with its accuracy. Therefore, low cost accurate measurement devices are one of the main goal of metrology engineers. One way for decreasing the sensor uncertainties is the calibration process [1]. Therefore, this paper deals with the calibration of a low cost sensor using the corresponding values obtained by reference standards. From the practical point of view, the calibration characteristics should be in a polynomial form. The accuracy of this polynomial depends on the noise-free data which is used to obtain the characteristics [2]. To reduce the effect of the noise, excessive number of data should be used.

The calibration of sensors, or in general, the measurement apparatus, can be considered as a typical problem of “model searching” from experimental data and then, it should be approached by applying Experimental Design techniques. In this case, the calibration design should drive the operator in the choice of [3]:
- the experimental plan (e.g. the number and the location of the calibration points, the number of the repetitions);
- the main influence quantities;
- the regression curve;
- the regression technique;
- the standard references and their uncertainties.

In this study a Genetic Algorithm (GA) is used for the measurement apparatus calibration purpose. Consider calibrating a measurement instrument by means of standard setting devices. The calibration characteristic of the measurement instrument is described adequately by an \(m\)-order polynomial

\[
y = a_0 + a_1 p + a_2 p^2 + \ldots + a_m p^m
\]  

(1)

The measurement equation is written as

\[
z_k = a_0 + a_1 p(k) + a_2 p^2(k) + \ldots + a_m p^m(k) + v(k), \quad k = 1, \ldots, n,
\]  

(2)

where \(v(k)\) is the Gaussian random measurement errors with zero mean and variance \(\sigma^2\). It was assumed that values of arguments \(p(k), k = 1, \ldots, n\) (values generated by standard setting devices) were known with errors. It is required to design algorithm for the calibration curve (1) coefficients identification via GA.

The simple GA, which we are using in the present research, works as follows:

Firstly, the initial population of individuals (chromosomes) is created by GA. Each chromosome represents the possible solution of the problem. The chromosome in a binary representation is the vector, consisting the sequence of bits: zeros and unities. Each bit is called a gen. The chromosomes set generates the population. The number of chromosomes in the population determines the population size (ps).
For applying reproduction operator and carrying out selection, firstly the following operations are implemented.

1) For each chromosome \( v_i \), \( i = 1, p_s \) the fitness value is calculated:

\[
J_i = \frac{1}{1 + e_i^2}
\]

Where \( e_i^2 \) is the mean-square error.

2) The total population fitness is found:

\[
J = \sum_{i=1}^{p_s} J_i
\]

3) For each chromosome \( v_i \), \( i = 1, p_s \), the probability of a selection \( p_i \) is calculated:

\[
P_i = \frac{J_i}{J}
\]

4) For each chromosome \( v_i \), \( i = 1, p_s \), the cumulative probability \( q_i \) is calculated:

\[
q_i = \sum_{j=1}^{i} p_j
\]

It is a must that the next to be noted: Among all fitness values, GA founds the maximal fitness value, which is reached by minimal mean-square error [4]. These two values are stored at the memory of computer. The calibration coefficients values, by which the minimal mean-square error is reached, are also stored in computers memory.

The best chromosomes are reproduced more than one time, the average – one time, the worst are not reproduced in a new population. Now a crossover operator must be applied. Then next recombination operator–mutation is applied to newly generated population. In contrast to crossover, the mutation is accomplished on bits. Following selection, crossover and mutation the new population is ready for the next evaluation. Achievement of definite number of generations is the condition of termination of GA’s work. After this the smallest one among all the minimum errors stored in memory is found. The calibration coefficients values, by which the smallest mean square error is obtained, are selected.

As an example, the problem of calibration of a differential pressure gauge using standard pressure setting devices (piston gauges) is examined. The calibration characteristic of the differential pressure gauge is described adequately by the polynomial. It is shown that the proposed GA based calibration algorithm provides the required calibration accuracy. This approach can be easily realized and widely used in metrological support to measuring instruments in various branches of industry.

References

Stochastic modelling aspects for an improved solution of the inverse problem in scatterometry

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In wafer metrology scatterometry is an established method to determine the critical dimensions (CD) of periodic surface structures from the measured light diffraction pattern. These CDs include line widths, heights and side-wall angles in the sub-micrometer range. In extreme ultraviolet (EUV) scatterometry the incident light has wavelengths in a small range around 13.5 nm and the measured light diffraction pattern consists of many plane wave modes, the so-called orders. The intensity distribution over these modes characterizes the profile geometry and the optical properties of the illuminated surface structure.

The rigorous numerical simulation of the diffraction process for periodic 2D structures can be realized by the finite element solution (FEM) of the two-dimensional Helmholtz equation. The inverse problem is formulated as a non-linear operator equation and can be solved by iterative methods, i.e., by an iterative variation of the model parameters to minimize the deviation of the measured efficiency or phase shift values from the calculated ones.

Clearly, the uncertainties of the reconstructed geometric parameters depend on the uncertainties of the input data and can be estimated by various methods like Monte Carlo or approximative covariance methods. Furthermore, aperiodic perturbations in the examined line structures affect the uncertainties. In order to clear the impact of line edge and line width roughness, we present an FEM based method to simulate diffraction patterns for structures with aperiodic random perturbations. We apply this for a typical EUV mask composed of TaN absorber lines of about 80 nm height and 93.33 nm width, a period of 280 nm, and with an underlying MoSi-multilayer stack of 300 nm thickness. A systematic decrease of the mean intensities for higher diffraction orders along with increasing variances is observed and established for different degrees of roughness. As a consequence this systematic bias has to be included in the reconstruction model to provide accurate values for the reconstructed profile parameters.

Keywords: inverse problem, uncertainties, scatterometry, roughness
Maximum likelihood estimation for profile reconstructions in scatterometry

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Abstract: The maximum likelihood method (MLE) has been employed as an alternative to common procedures for solving the inverse problem of scatterometry. In contrast to previous approaches [1, 2], where the variance of measurement errors is assumed to be known, MLE can be applied also when such information is not available. This is important because the variance of measurement errors has a strong influence on the profile reconstruction in scatterometry, and an inadequate choice can lead to poor reconstruction results. In addition uncertainties of profile reconstructions can turn out unreliable. We illustrate the advantages of our approach in a first step by simulated data.

In a second step we demonstrate the reliability of our approach by applying it to different datasets obtained using two different scatterometric setups. In the first experiment an EUV photo mask consisting of a TaN absorber structure on an MoSi-multilayer stack has been measured using EUV radiation with a wavelength of about 13 nm. In the second experiment an absorbing structure made of MoSi placed on a glass substrate has been measured with a DUV scatterometer operating at a wavelength of 193 nm. Application of our approach to these datasets obtained from different experimental setups yields consistent results for the profile reconstructions.

OCIS codes: (050.1950) Diffraction gratings; (120.3940) Metrology

References and links
INFLUENCE OF THE LOOK-UP WINDOW SIZE WHEN APPLYING A FORWARD-LOOKING CONTROLLER

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The Forward-Looking Control Model (FLCM) relies on statistical methods to determine the adjustments needed to keep a process under control. A Look-up Window (LuW) delimits the interval in which the process’ inner variables will be observed before attempting any adjustments to its parameters. As manufacturing processes are influenced by a number of sources of variation that present different patterns the size the LuW is a key factor in the success of FLCM.

1. Look-up Window (LuW)

As many of the variations affecting a manufacturing process describe a characteristic patterns that can only be revealed by observing the variables of interest during a certain interval. Such interval is delimited by the LuW size.

The estimation of an adequate LuW size will be the result of trading-off effort and benefit. Defining a small LuW size will imply an increment in the adjustments made through the time. Thereby, defining an exaggerated LuW size will make harder to identify patterns.

The relevance of the LuW size strives in the fact that it will determine the number of adjustments required to control a process.

2. Measured Samples

Once the LuW size has been defined according to the characteristics of the process under control, it is necessary to determine the number of samples to be measured.

Intuitively one might think that taking as many samples as possible would be the easiest way to get a representative value of the behavior of the variables during the interval of the LuW. In spite of being true this approach could
possibly be not realizable. Instead, the efforts should to be better focused in optimizing the number of samples as to make them costly reasonable.

Let us consider the simulation of the production of a micro-assembly whose length specification is 30.00 ± 1.00 [mm]. The values of the mean and standard deviation obtained before applying FLCM were \( \mu = 29.55 \) and \( \sigma = 0.29 \) respectively. The Table 1 summarizes the results obtained after applying FLCM. Whereas the size of the LuW was set to different values, the number of measured samples per LuW remained the same. It was set to twenty samples per LuW.

<table>
<thead>
<tr>
<th>Size of LuW</th>
<th>( \mu_{\text{assy,ctrl}} )</th>
<th>( \sigma_{\text{assy,ctrl}} )</th>
<th>( % \text{ shift reduction} )</th>
<th>( % \text{ reduction} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>29.9467</td>
<td>0.2781</td>
<td>13.44 %</td>
<td>4.10 %</td>
</tr>
<tr>
<td>400</td>
<td>29.9458</td>
<td>0.2613</td>
<td>13.70 %</td>
<td>9.89 %</td>
</tr>
<tr>
<td>300</td>
<td>29.9510</td>
<td>0.2621</td>
<td>12.22 %</td>
<td>9.62 %</td>
</tr>
<tr>
<td>200</td>
<td>29.9522</td>
<td>0.2563</td>
<td>11.88 %</td>
<td>11.61 %</td>
</tr>
<tr>
<td>100</td>
<td>29.9441</td>
<td>0.2568</td>
<td>14.19 %</td>
<td>11.46 %</td>
</tr>
<tr>
<td>50</td>
<td>29.9531</td>
<td>0.2554</td>
<td>11.63 %</td>
<td>11.94 %</td>
</tr>
<tr>
<td>40</td>
<td>29.9394</td>
<td>0.2552</td>
<td>15.55 %</td>
<td>11.99 %</td>
</tr>
<tr>
<td>25</td>
<td>29.9494</td>
<td>0.2532</td>
<td>12.67 %</td>
<td>12.68 %</td>
</tr>
</tbody>
</table>

The data above reveals that the size of the LuW size has an impact in the output of the process. Whereas in all cases there is almost constant reduction of the mean shift, the standard deviation decreases only up to certain point after which not significant improvement can be achieved by means of modifying the LuW size.

References

SOFTWARE VALIDATION OF IN SITU WEATHER STATIONS FOR METROLOGICAL SUPPORT TO METEOROLOGY

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On different levels, considerate scientific attention has been risen recently to metrological support for meteorology due to enormous social, environmental and financial impact. One of the important aspects that are going to be investigated by a recently initiated European metrology research programme (EMRP) project, named MeteoMet, is also ensuring measurement methods and protocols, which would be traceable to the national standards for ground-based meteorological observations and climate data.

In order to meet the challenges, one of the important step that needs to been taken is the validation of automatic weather stations (AWS) data-logging software. In many occasions, in situ weather stations use data-logging software to calculate the indirect measured value from the direct measurements. The equations used to calculate indirect value can be simplified due to limitations in hardware used, which could lead to non-negligible measurement errors.

The paper intends to presents an assessment of the need for validation of data-logging software according to the World Meteorological Organization (WMO) requirements. Based on this assessment, software validation is to be performed on controllable sub-models using reference software and reference data sets together with implemented measurement software. The results shall report on validation tests, the need for using...
sniffing and decrypting techniques, self check and software quality assessment using error trapping and redundancy scheme.
ONLY NON-INFORMATIVE BAYESIAN PRIOR DISTRIBUTIONS AGREE WITH THE GUM TYPE A EVALUATIONS OF INPUT QUANTITIES

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1. Abstract

The Guide to the Expression of Uncertainty in Measurement (GUM) is self-consistent when Bayesian statistics is used for the Type A evaluations and the standard deviation of posterior distribution is used as the Bayesian Type A standard uncertainty. We present the case that there are limitations on the kind of Bayesian statistics that can be used for the Type A evaluations of input quantities of the measurement function. The GUM recommends that the (central) measured value should be an unbiased estimate of the corresponding (true) quantity value. Also, the GUM uses the expected value of state-of-knowledge probability distributions as the (central) measured value for both the Type A and the Type B evaluations of input quantities. It turns out that the expected value of a Bayesian posterior distribution used as a Type A (central) measured value for an input quantity can be unbiased only when a non-informative prior distribution is used for that input quantity. Metrologically, this means that only the current observations without any additional information should be used to determine a Type A (central) measured value for an input quantity of the measurement function.
RAPID MONTE CARLO SIMULATIONS USING PARALLEL COMPUTING AND A CLIENT-SERVER MODEL

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With the publication of Supplement 1 to the Guide to the Expression of Uncertainty in measurement (GUM), an alternative calculation method is available in metrology to evaluate measurement results and their uncertainties. The calculation method is based on Monte Carlo simulation techniques and it employs a large number of repeated numerical calculations. Depending on the measurement model, the computational effort can be large and time consuming. Processors with multiple CPU cores become widely available. Therefore it is useful to implement and test concepts to parallelize the Monte Carlo simulation process in the context of metrology. The development of an Open Monte Carlo Engine (OMCE) for metrology in Python offers the possibility to implement some parallel computing concepts in practice. Different approaches for parallel computing including Monte Carlo simulations are available and have been studied. We choose an approach which is based on a client-server model and which allows the use of remote computing resources if they are available. The communication between clients and servers is socket based using a high level remote procedure call protocol which integrates different system architectures (e.g. Windows and Linux) in an overall simulation “network”. The user can access the simulation network via a lightweight client which delegates all calculations to his network entry server. The network entry server handles the job and employs other servers or CPU cores as far as they are available. The results are communicated back to the client when the simulation task is finished. The system is optimized to limit the communication between client and server to a minimum and it is buffered to allow the calculation processes to continue, even if communication might be slow. The concept is flexible enough to be used by computers with multiple CPU cores or by multiple computers connected by a fast local network (LAN) or any combination of both. The key element for the quality of the Monte Carlo simulation is the use of uncorrelated parallel random number generators in the cooperating servers. We analyze different techniques and implement different seeding methods. We share some preliminary results about practical measurements of the simulation speed that can be achieved with a 16 CPU core system under Linux and we analyze how well our concepts will scale with increasing number of CPUs included in the network.

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The evaluation of uncertainty according to the Guide to the Expression of Uncertainty in measurement (GUM) is the internationally agreed procedure to evaluate complete result statements in measurement including measurement uncertainty. An alternative calculation method is described in the Supplement 1 to the GUM. It uses a Monte Carlo simulation technique to evaluate the distribution of possible results by drawing samples from different random distributions and re-evaluating the result for the measurement using a sufficiently large number of trials. A key element of applying this method correctly is a proper choice of the number of simulation trials. A possible adaptive procedure which is based on an early estimation of the sample variance is published in GUM Supplement 1. It is known that in general this procedure guarantees sufficient runs for the required performance only for a large number of repeated Monte Carlo simulations but in many cases not for every single simulation. For a given fixed simulation problem, the number of runs determined by the existing procedure can vary dramatically. We propose here a new adaptive procedure which does not require an estimate of the variance in the first stage. As a result the number of Monte Carlo trials determined by our procedure is essentially independent of the variance and the method can therefore guarantee that the required numerical tolerance for the result value has been achieved with a stated probability for every single simulation. We will analyze in detail the established method given in GUM Supplement 1 to specify the numerical tolerance. We discuss how the adaptive procedure is affected by this method and how this could be improved. Finally, we put the new adaptive procedure to test and by repeated simulations we demonstrate the effectiveness of the new procedure for some representative cases often used in metrology.
and some special cases which show the limits of the procedure. The results were compared to the standard GUM Supplement 1 procedure and another procedure proposed earlier by Wübbeler et. al. Our simulations show that the new procedure can be more effective and reliable compared to these existing methods.
Modern and carefully calibrated process flow meters show measurement uncertainties typically in the range 0.5 % to 0.2% if perfectly installed. In power plants or heat distribution networks measurement uncertainties are rather in the range of 2 % and higher. A second limitation for measuring thermal energy accurately is due to inhomogeneous or changing temperature distribution in the flow. Especially in power plants these highly dynamic (spatial and in time) “streaming effects” are rarely investigated at all.

In this report we propose to use a multi-sensor device for measuring the temperature distribution in pipe flow. A multi-sensor was fabricated using 9 Pt-100 sensors placed inside a pipe in a cross-pattern. The multi-sensor can be used to measure a temperature distribution and to calculate the average flow temperature based on the 9 measurement points. The multi-sensor was tested under various mixing conditions of two water flows of different temperature to obtain an estimate of its measurement uncertainty and reliability. Two different methods for calculating the average water temperature were applied. Our results show that the uncertainty of the average water temperature depends on which method is used for calculating the average temperature. This knowledge can be used to develop a smart multi-sensor that can identify an existing temperature pattern in a pipe and choose an appropriate weighing method to calculate the average flow temperature.
Bayesian Variance Separation Under Heteroscedasticity – Pressure Measurement as Case Study

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Let us analyse a measurement problem, where \( n_i \) different, unknown measurands are each measured by (the same set of) \( n_j \) devices or laboratories. The aim is to characterize the device variability uncoupled from the variability of the measurand. The developed method is to be applied to pressure measurement devices tested at the Physikalisch-Technische Bundesanstalt (PTB).

A standard set-up of this measurement problem corresponds to the following (balanced) linear mixed model

\[
Y_{ij} = \mu_j + \epsilon_{ij} + u_i,
\]

where we assume, that the measurements \( Y_{ij} \) of device \( j = 1, \ldots, n_j \) are for all measurands \( i = 1, \ldots, n_i \) independently, identically and normally distributed according to \( N(\mu_j, \sigma^2_j + \sigma^2_P) \). The measurands are independently, identically and normally distributed with variance \( \sigma^2_P \) and unknown mean, which is incorporated in the fixed effect \( \mu_j \) together with the appliance bias. These two components of the fixed effect cannot be separated and are not of primary interest here. We want to estimate the variability of the appliance measurements \((\sigma^2_1, \ldots, \sigma^2_{n_j})\) and of the measurand \(\sigma^2_P\), captured by the random errors \(\epsilon_{ij}\) and the random effects \(u_i\) respectively in the above model.

This is a standard statistical model which has been extensively treated for known variances \((\sigma^2_P, \sigma^2_1, \ldots, \sigma^2_{n_j})\) as well as for unknown but equal variances \(\sigma^2_1 = \sigma^2_2 = \ldots = \sigma^2_{n_j}\). For an overview on classical as well as Bayesian solutions, see for example Ref. 1. However, different devices (or labs) rarely exhibit the same variability. We are therefore bound to consider the full heteroscedastic model.

Reformulated, the measurements \(Y_{ij}\) can simply be viewed as \(n_i\) identical replications originating from an \(n_j\)-variate normal distribution with mean \((\mu_1, \ldots, \mu_{n_j})\) and full covariance matrix of known structure \(\Sigma = \text{diag}(\sigma^2_1, \ldots, \sigma^2_{n_j}) + \sigma^2_P 1_{n_j}1_{n_j}^T\). Fitting a multivariate normal distribution to data has been discussed frequently. For an (objective) Bayesian point of view generally accounting for the full covariance matrix, see for example Ref. 2. However, for the specific (parametric) covariance structure above, no Bayesian approach appears to be available.

We research a Bayesian approach using the non-informative Jeffreys prior
to learn about the full distribution of the variance parameters \((\sigma_P^2, \sigma_1^2, \ldots, \sigma_n^2)\) in a heteroscedastic linear mixed model. By way of simulation, we show that the Bayesian estimates reproduce underlying parameters well, better than Maximum Likelihood Estimates do. Our results are insensitive to small changes in prior assumptions; while assuming a uniform prior distribution on each variance parameter gives more conservative estimates. Moderate violations of the normality assumption for the measurand have no effect on the estimation of the variability of the appliance measurements. We will additionally demonstrate the effect of investments into resources, i.e. how accuracy and precision improve with an increasing number of participating devices or labs \(n_j\).

We will present results of fitting the above model to measurements of \(n_i = 16\) pressures by \(n_j = 4\) appliances each, performed at the PTB. The estimated variability for some devices is substantially smaller than the observed variance of their measurements. This case study demonstrates the full potential of variance separation under heteroscedasticity.

**Keywords**: linear mixed model, multivariate normal distribution, Bayesian Approach, Jeffreys prior

**References**

Bayesian Analysis of an International ELISA Comparability Study

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Immunassays are biochemical tests applied to measure even very small amounts of substance using the highly specific bindings between an antibody and its antigen. Immunassays thus have a wide range of applications, e.g. to detect the presence of an infection, of hormones or drugs. This work focuses on an Enzyme-Linked ImmunoSorbent Assay, called sandwich ELISA, which allows detection of antigens by sandwiching them between two antibodies and labelling one type of antibody with an enzyme to generate a detectable signal (e.g. fluorescence).1

ELISAs typically involve a high number of protocol steps, each susceptible to perturbations. A recent publication2 has highlighted the variability in concentration estimates in the scope of an international comparability study. Some laboratories estimated an average concentration twice as high as other laboratories. But little is published on the uncertainties of individual laboratory estimates.

Decisions which are based on plausible ranges of measurements (such as credible intervals), are generally superior to those solely based on point estimates (such as the mean). Reliable uncertainties are thus vital – and not only in metrology.

We have developed a Bayesian framework to rigorously quantify the uncertainty in ELISA concentration estimates. This framework encompasses simultaneous calibration of a nonlinear model and estimation of the unknown concentration from a set of fluorescence measurements. The resulting Bayesian uncertainties of individual ELISAs and laboratory estimates are considerably larger than previously reported uncertainties in Ref. 2. The average concentrations we estimate differ from the ones estimated by each study participant. In general, this leads to different conclusions about the comparability study. In particular, the inter- and intra-laboratory consistency is increased, and repeatability problems occur for fewer laboratories.

For ELISA concentration estimates, applying the standard international
guideline to express measurement uncertainty in metrology (the GUM\textsuperscript{3}) will inevitably lead to inadequate uncertainties and possibly misleading mean estimates due to the inherent nonlinearity of the calibration curve. For the same token standard frequentist approaches (using asymptotic normal approximations) will give inadequate uncertainties. For nonstandard (e.g. nonlinear) models, metrologists would implement a Monte Carlo based approach according to a recent supplement, called GUM S1.\textsuperscript{4} However, especially at low concentrations this approach leads to deviations in uncertainties as well as mean estimates compared to the Bayesian approach, because substantive prior knowledge (such as nonnegativity of concentrations) is disregarded.

Keywords: Bayesian Inference, CCQM, Fluorescent ELISA, Uncertainty

References
COMPUTATIONAL OPTIMIZATION OF CO2 CONTROL BY METHOD OF LASER SPECTROMETRY AND PRESENTING RESULTS ON SERVER

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ABSTRACT

Optimization and results of calculation and are examined for method to control CO2 content in atmosphere by tuned diode laser.

Area under curve is computated by the trapezoidal rule and by the Lagrange rule for approximate integration of line area.

The xml file for calculation can be uploaded: http://www.makeupsystem.com/x1/ and results are presented on server.
COMPUTATIONAL OPTIMIZATION TO REDUCE EFFECT OF INTERFERING COMPONENTS ON THE MEASUREMENT OF GREENHOUSE GASES BY METHODS OF NON-DISPERSIVE SPECTROMETRY

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ABSTRACT

Method of spectral compensation is examined for the purposes of remote control of CO2, CH4, CO, and SO2 in atmosphere.

Results of calculations on basis of HITRAN database are presented.

It is shown that for NDIR and NDUV instruments an effect of different interfering species including H2O on the measurement of CO2, CH4, CO, and SO2 in atmosphere at open optical paths can be reduced very strongly.

Besides the effects of light source instabilities, changes in the spectral transfer function of the optics, and changes in the detector’s spectral responsivity on the measurement also is minimized.

Free software used for computational optimization can be downloaded from: http://www.composesystem.com/study.php
BAYESIAN INFERENCE IN WAVEFORM METROLOGY

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A Bayesian approach to spectrum analysis is here applied to waveform metrology. There is interest in estimating the signal parameters from the sampled data and comparing the estimates with the readings (or settings) of the instruments under calibration. A simple method for obtaining estimates of signal parameters and their associated uncertainties is described. It uses approximations based on the posterior mode which are valid for large sample sizes and/or high signal-to-noise ratios. Several computer simulated examples are presented and discussed in detail.

1. Introduction

Bayesian parameter estimation techniques have been applied to spectrum analysis [1],[2]. The method has been successfully applied to the analysis of acoustic and oceanographic chirped signals and of decaying sinusoidal signals in chemical material analysis employing nuclear magnetic resonance. It has also been applied to astronomy and to audio testing and measurement.

The method is here applied to waveform metrology. The objective is the analysis of deterministic signals contaminated with additive noise that are generated and measured for instrument calibration purposes. There is interest in estimating the signal parameters from the sampled data and comparing the estimates with the readings (or settings) of the instruments under calibration. The parameters are assumed not to vary over the interval of observation. This is reasonable for the stable signal generators used by metrologists.

This problem of inference has many applications in the calibration or performance evaluation of data converters, waveform recorders, phase angle meters, ac voltmeters, ac voltage calibrators, power and energy meters, power calibrators, signal generators, wideband signal analyzers and power quality measuring instruments.

Several techniques based on classical statistics have been applied to this problem, such as maximum likelihood, least squares, and Fourier transform methods. As the metrologist has little prior information beyond the signal

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waveforms, Bayesian estimates of the signal parameters do not differ significantly from the estimates one would obtain from those techniques.

The periodogram has been introduced as an intuitive ad hoc method for detecting a periodicity and estimating its frequency. It remains well defined when the frequency is allowed to vary continuously. As shown in [1], [2], the periodogram will always obtain good answers to the question “What is the evidence of a single stationary harmonic frequency in these data?” However, if the data show evidence for multiple nonharmonically related frequencies or complex behavior, the periodogram can give misleading or incorrect results in the light of more realistic models.

The Bayesian approach to spectrum analysis allows us to derive a ‘sufficient statistic’ that summarizes all the information in the data that is relevant for inference about the frequencies of the signal when a white Gaussian probability distribution is assigned for the noise. As advanced in [2], the proper algorithm to convert that statistic into frequency estimates is a nonlinear operation much like exponentiation.

The main objective here is to summarize and extract the essentials of the work in [2]. Several examples related to waveform metrology are presented. It is assumed that the data can be modeled with trigonometric equations. The method can be easily implemented with those commercial laboratory software packages routinely used by metrologists for controlling instrumentation and reporting measurement results. In order to save time, it does not use or require numerical integration techniques. Numerical derivatives are also not needed except for evaluating the covariance matrix associated with the frequency estimates.

The method uses approximations based on the posterior mode which are valid when the data size is large and/or the signal-to-noise ratio (SNR) is high. Metrologists have cogent prior information about the signal waveform, they can design their experiment and select an arbitrarily large number of samples, and they typically work with high SNRs. For instance, the accurate estimation of ac signals generated by superconducting quantum-based standards is a typical example of increasing interest.

References
CORRECTION OF THE DYNAMIC ERROR OF TEMPERATURE-SENSITIVE GAUGES ON THE BASIS OF THE SIGNAL SPLINE - APPROXIMATIONS

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The method of correction of a dynamic error of inertial measuring converters having linear transfer function with use a parabolic spline - approximations of a signal discrete values, and also its derivative, is considered.

The dynamic error of a temperature-sensitive gauges, that is a converter of the parameter $x(t)$, depends on its time constant, and also speed of change of the measured parameter (measuring temperature) and can be corrected with use of hardware or software.

Let's consider correction of dynamic errors with use of software.

In some cases correction of a dynamic error represents the decision of a return task [1], that is task of an entrance signal $x(t)$ restoration on known transfer function $A$ of the converter.

Most simply such task is solved with realization of operator $A^{-1}$, the opposite to the operator $A$, with use of an software unit correcting converter output signal $y(t)$.

The correct decision of a return task at dynamic measurements can be executed if to provide the certain delay in a signal $z(t)$ formed on an output of the correcting unit.

In the most widespread case the inertial gauge has aperiodic transfer function of the first order

$$ W \left( s \right) = \frac{y(s)}{x(s)} = \frac{K}{Tp + 1}, $$

where $T$ - a time constant of the converter.

At $K=1$ the correcting unit should realize the differential equation

$$ T \frac{dy(t)}{dt} + y(t) = z(t) $$

For the such task decision it is offered to use the digital filter realizing a spline - approximation of a signal $y(t)$ discrete values, and also its derivative.

At use a parabolic spline - approximations on a $n$-th discrete interval the signal is described by parabolic function.
\[
y_n(t) = a_2 n t^2 + a_1 n t + a_0 n,
\]
where \(a_2, a_1, a_0\) - factors of approximation.

For example, factor \(a_0[n]\) of the five-dot parabolic spline function approximating a signal \(y(t)\) on a \(n\)-th discrete interval will be defined by expression [2]:
\[
a_0 \left[\begin{array}{c}
x \\ -2 \\ +4 \\ -1 \\ +10 \\ -x \\ +4 \\ -x \\ +2 \\ .
\end{array}\right] = \frac{1}{16} x - 2 - 4 x - 10 x + 4 x + 1 - x + 2 .
\]
Expressions for factors \(b\) of a spline function approximated a derivative of a signal \(y(t)\) have similar kind [2]:
\[
\frac{dy}{dt} = b_2 n t^2 + b_1 n t + b_0 n .
\]

In this case the signal on an output of an correcting unit on \(n\)-th discrete interval represents a spline - function
\[
z(t) = c_2[n]t^2 + c_1[n]t + c_0[n] .
\]
where \(c\) are defined by factors in expressions (1) and (3), and also by a parameter \(T\).

The correcting signal \(z(t)\) on an output of an correcting unit is formed with a delay in some discrete intervals.

In particular, at a gauges time constant \(T = 1\)c and at the input parameter \(x(t)\) looking like Gauss function in width about 0.8c a dynamic error of the converter is equal 80 %.

The dynamic error of a signal, corrected with use of the described digital filter, for this example does not exceed 5 %.

Use of such approach allows to realize as well the digital filter correcting more complex transfer function of the gauge, in particular representing 2-nd order aperiodic function.

**References**

A FORMALISM FOR EXPRESSING THE PROBABILITY DISTRIBUTIONS OF INTERRELATED QUANTITIES

(Abstract)

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Consider a set of quantities $X = \{X_1, \ldots, X_m\}$ interrelated through a consistent system of equations of the form

$$F_i(X_i) = 0, \quad i = 1, \ldots, n < m,$$

(1)

where the $X_i$ are subsets of $X$, not all pairwise disjoint, such that their union is equal to $X$. It is assumed that none of the quantities is perfectly known and that their true values are unique. The goal is to obtain the state-of-knowledge probability distribution of the measurand or measurands $X_j$, $j \in \{1, \ldots, m\}$, taking into account the existing information $\mathcal{I}$ and the model (1), which is hereafter symbolized by the letter $\mathcal{M}$. In the case of several measurands, sometimes the focus is on their univariate distributions, which follow from marginalizing their joint distribution.

To analyze this problem consider sets $X_p = \{X_{p1}, \ldots, X_{pl}\}$, where $\{p1, \ldots, pl\} \subset \{1, \ldots, m\}$ and $l = m - n$. Such sets constitute parameterizations if the model (1) allows all quantities in their complements to be expressed as explicit or implicit functions of the quantities the sets contain. There can be no more than $m!/n!l!$ parameterizations.

Three situations arise depending on the number of quantities to which the information $\mathcal{I}$ pertains. The first occurs when there is no parameterization for which information on all its quantities is provided. It is then
not possible to obtain the distribution associated with at least one of the quantities for which there is no information.

The second situation is frequently encountered in metrological practice. It occurs when there is information on just the $l$ quantities of a certain parameterization $X_b = \{X_{b1}, \ldots, X_{bl}\}$, henceforth called the base parameterization, such that the distribution $f_b(\xi_b|I)$, where $b = \{b1, \ldots, bl\}$, is either given or can be constructed by duly processing the available information. In this case the distribution of the quantities in any other parameterization $X_p$ is obtained from the change-of-variables theorem

$$f_p(\xi_p|I, M) = |J_{ pb}| \times f_b(G_b(\xi_p)|I),$$

(2)

where $p = \{p1, \ldots, pl\}$, the $l$ functions $G_b$ are defined by

$$X_{bk} = G_{bk}(X_p), \quad k = 1, \ldots, l$$

(3)

and

$$J_{ pb} = \left| \frac{\partial G_b(\xi_p)}{\partial \xi_p} \right|$$

(4)

is the determinant of the Jacobian matrix of the transformation.

Finally, in the third situation information on more than $l$ quantities is provided. It is easily seen that in this case one can use the change-of-variables theorem with different choices of $X_b$, leading to different distributions $f_p(\xi_p|I, M)$ for any fixed parameterization $X_p$. This means that there is excess information. Either some of it must be discarded in order to keep just a single base parameterization or some compromise must be reached if all information is to be retained.

The paper focuses on the second situation. Two examples will be given to illustrate the concepts above.
DESIGN OF THE SYSTEM FOR MEASUREMENT THERMAL CONDUCTIVITY OF SOLID CONDUCTIVE MATERIALS

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We developed a system to measure the thermal conductivity of metals by using a secondary method: the cut bar method. The measurement system operates under a condition steady state heat flow and uses a set of high purity copper metal bars as reference material.

In this system a bar of unknown heat conductivity is placed between two bars of known thermal conductivity value. This way we have a reference-sample-reference ensemble. Reference end of one side is in thermal contact with a heat source while the other end is in a thermal contact with a heat sink.

Temperature difference between heat source and heat sink generates a thermal profile along the bars. This thermal profile depends on the thermal conductivity values of reference and the sample.

We present the design criteria of this system based on the analytic and numerical solution for heat transfer and considering the length and the diameter of both reference and sample bars as well as longitudinal and heat loses.
DESIGN OF A CELL FOR AN ADIABATIC CALORIMETER OF FLUIDS

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CENAM is developing an adiabatic calorimeter to measure heat capacity of fluids with an uncertainty less than 1%.

The main component of the calorimeter is the cell or vessel where the fluid is store.

To get up the uncertainty required, we need to design, build and test the device.

Here are showed design criteria of calorimeter’s cell. Building on to find analytical and numerical solutions to know heat transfer and temperature profile, taking account different parameters like, cylindrical and spherical form, length, diameter, fluid contained and some boundary conditions.

To find numerical results was used a commercial program and were accomplished different simulations to get results near to experimental tests.

We found positions of sensors, as well as some interesting parameters to build the cell.

Finally we present a comparison among analytical and numerical results to evaluate potential that numerical solutions represent to the design from devices with a higher accuracy.
A geometrical model object oriented based on declarative geometry is presented in this paper. This method is used to test measurement algorithms for complex systems as for a human body. Geometrical objects are actually defined by a vector family. This family can be efficiently described by a Gram matrix. This kind of modeling, as can be a metric tensor, provide the advantage to propose a geometrical object invariant to translation, rotation and all symmetric transformation of the affine space. This work will be used to simulate Total Knee Arthroplasty surgery.

1. Introduction

Geometrical models are often used to simulate a measuring machine. Such a model can then be employed for Monte-Carlo Simulation or analytical application. This paper deals with a method to create geometrical models applied to test Computer Aided Orthopedic Surgery (CAOS). Here the method will be applied in the case of Total Knee Arthroplasty. The aim is to detect incoherent information from the navigator and avoid geometrical deviation during the surgery.

1.1. Geometrical modeling in biomechanics:

A Total Knee Arthroplasty (TKA) consists in a replacement of damaged knee link surfaces. A human body is composed by 206 bones, over 600 muscles, over 900 ligaments. To be efficient the geometrical method used for a musculo-skeletal system modeling, should allow reliable modification and collaborative working. To answer to this kind of issue, a declarative model based on Gram matrix has been developed. This is based on geometrical object oriented and topological connection, permitting fast and reliable modification.

1.2. Declarative geometry

The declarative approach has been developed to solve this problem [1][2]. The method consists in a topology declaration and the expression of a set of
geometrical constraints. Then the geometrical object is obtained by solving the geometrical problem [3]. Objects are actually defined by a vector family noted E. This family can be efficiently described by a Gram matrix as shown in the equation 1:

\[ G = E \otimes E^T \]  

(1)

A transformation to a vector family can be directly applied to the Gram matrix representing this vector family. To apply a transformation represented by the linear application associated to the matrix M to a vector family noted E, the equation 2 should be done:

\[ E' = M \cdot E \]
\[ G' = E' \otimes E'^T = M \cdot (E \otimes M \cdot E^T) \]  

(2)

\[ G' = M \cdot E \otimes E^T \cdot M^T = M \cdot G \cdot M^T \]

The matrix G is a bilinear operator which can be used as a scalar product.

2. **Coordinate generator for TKA navigator testing.**

There are six elements to model in the TKA process [4]. The navigator, which is actually a coordinate measuring machine, can be modeled by a reference frame. One ancillary for each bone is used as local reference frame. One probing pen permits to measure bone surfaces. And finally there are the femur and the tibia. Each of these elements are modeled by a geometrical object.

![Figure 1. Total Knee Arthroplasty (TKA) simulation.](image-url)
Figure 1 shows how these six elements are assembled. The assembly is done by the connection operator. The set of coordinate needed to generate the measured set of points is obtained by projection of each studied point on a global reference frame. To do this matrix G is used.

References

MULTI SOFT-SENSORS DATA FUSION IN SPACIAL FORECASTING OF ENVIRONMENTAL PARAMETERS

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Abstract

Soft sensors based on neural networks, constitute an innovative paradigm in the field of measurement techniques. We developed soft sensors for spacial forecast of environmental parameters, using different models and topology of neural networks.

In the last years we focused our attention on measure aspects of soft sensors. The idea is that they should work in place of physical sensors. Therefore their performance should be accurately described, stable throughout the period of working time and suitable for the application.

Thus, several kinds of soft sensors have been developed and several models of neural networks have been considered.\(^1\) A statistical procedure based on specific evaluators has been introduced in order to evaluate and compare soft sensors performance.\(^2\) Several fundamental concepts of measure theory have been adopted and transposed in the field of soft sensors, for which measurement uncertainty is zero.

Using physical devices, the procedure of repeated measurements to average out, as known, enables the uncertainty reduction of a measured value (of course each measurement should be independent of the previous ones as much as possible and in the same environmental conditions). Differently, using a soft sensor, it makes no sense repeating the measurement, as we always obtain the same value, having soft sensors a deterministic characterization. In order to transpose the above-mentioned concept in the field of soft sensors, we substitute "repetition" with "multitude". This means that we use different independent sources of measure and perform an averaging out process on their output. In other words, this means that we can
design several soft sensors based on different neural networks models and
topologies (so, the statistical assumption of no correlation is fully satisfied),
verify that they belong to the same class in terms of comparable mean and
variance and averaging out their output.

In this work, we consider soft sensors based on three different kind of
neural network models: Radial Basis Function, Elman neural Network and
an enhanced Multi Layer Perceptron named E-αNet. We have used and
tested these three kinds of soft sensors in a real world application in
which we realize spatial forecast of air temperature, contact temperature and air
humidity.

With reference to spatial forecast of air temperature, all three kind of
soft sensors work as thermometers belonging at the same class having about
zero mean for all three kinds and 0.924 °C std for Elman, 0.942 °C std for
E-αNet and 0.972 °C std for RBF. Simply by averaging out the output we
can improve the performance by 5% compared to the Elman model and by
10% compared the RBF. As a consequence, we get a new soft sensor for air
temperature spatial forecast, having about zero mean and 0.90 °C std.

Observing the error vectors on the three kind of soft sensors, if we could
always select the best performance among the three measures, we could get
a soft sensor with 0.565 °C std, improving the performance by 90%.

In this work we present a method to select the best value among the
three measurements obtained using the three kind of soft sensors. To this
purpose, we use a gating network that gives three values of conditional
probability. These three values represent, substantially, the accuracy with
which the three soft sensors have supplied the results in similar condition
of input during the training phase.

The outputs of the gating network can be used as input for a selector
working like a multiple input, single output stochastic switch. The proba-
bility that the switch will select the output from a soft sensor is linked to
its conditional probability returned by the gating network.

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150.
Climate change and its consequences require immediate actions in order to safeguard the environment and economy in Europe and in the rest of the world. Safe assessment of climate change crucially depends on the robustness of climate data and on the uncertainties associated with measurements. The need to improve data collection and reduce uncertainties in existing climate and impact modelling is expressed by different climate data users (climatologists, economist, politicians…). A long term analysis of data series across countries, under a metrological perspective, will give the possibility to predict more reliably the consequences of climate changes with a deep impact on social, political and economic life.

At the Italian Istituto Nazionale di Ricerca Metrologica (INRiM), a project is running since 2007: an automatic system of acquisition and collection of climate data (pressure, temperature and humidity) directly traceable to national standard has been developed. Temperature, Pressure and humidity data are measured, corrected by calibration curves and saved together with the evaluated uncertainty budget that also keeps into account the variance and covariance matrixes due to the mutual influence of the quantities to the different sensors.

The data is collected in real time and stored in an archive: daily, monthly and yearly climate trends can then be reconstructed in order to carry out medium and long term analysis or comparisons. The data archives are available online and opened to public access. Ensuring an adequate access to reliable, traceable, and comprehensive information is an important prerogative of the developed system and an essential aspect for long-term climate monitoring. In 2011, in the context of the MeteoMet ENV07 EMRP funded project on the traceability of meteorological measurements, the project has been extended and is now part of a more general scope aiming at generating traceable archives of climate data at European level. The development of a free, robust and secure climate database that facilitates access, use and interpretation of data is an important goal of the climate and meteorological monitoring systems.

This paper describes INRiM activities regarding the climate data archives creation, publishing on website, definition of algorithm for weather stations calibration, measurements and data treating, free public access, online graphic creation and free download availability.
Two Methods of The Simulation of a Electromagnetic Flowmeter

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Abstract
Technical possibilities of flowmeters simulation methods are formed by theoretical and experimental knowledge level about flow measurement method, and also by technology progress and by the circuit construction of the device. Now there were possible an application of simulation methods in metrology for research of majority of the electromagnetic flowmeters used in Russia. The simulation of electromagnetic flowmeters is an effective rational method of research, checking and graduation of devices, and its technical possibilities essentially are wider than possibilities down-pour plants.
Possibilities of the simulation method are the following:
- Unlimited range of simulated flows;
- Research of devices with diameters of channels from small values (an order of several mm) to unlimited big (to 2000 mm and more);
- Simulation of a flow of a liquid in a wide range of physical properties (viscosity, density, temperature, etc.);
- Simulation of the heterogeneity of the measured environment;
- Simulation of flows with various kinematic structure, at any numbers Re, at nonsymmetric distributions of velocity, and also with various levels and a frequency spectrum of pulsations;
- Modelling of hindrances of the various nature: thermal noise, electromagnetic hindrances of an industrial network, radio-frequency hindrances, single impulses, mechanical vibrations, hydraulic blows and etc.

Two methods of modelling of a flowmeter are considered, in a basis of both methods is necessary the research of the inductor magnetic field.
The first method consists in measurement of distribution of a magnetic field of a flowmeter by means of universal converters of a magnetic field and calculation of the metrological characteristic of the device at almost any modes and structures of a flow.
The second method provides measurement of a magnetic field by means of the special Sensor controls executed for narrowly private designs of devices and certain modes of the kinematic and phase structure of a flow.
Technical characteristics and possibilities of both methods are in detail analyzed.
NUMERICAL SIMULATIONS AND TURBULENT MODELLING
FOR APPLICATIONS IN FLOW METROLOGY

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Abstract
Measuring, quantifying and understanding the outcome of fluid flow processes is of importance in a wide range of metrological applications. Since many relevant measurement set-ups in NMI and industrial applications have macroscopic dimensions, turbulent flows are rather the rule than the exceptions. Hence, computational fluid dynamics (CFD), i.e. the numerical simulation of fluid flows, has become an important part of the discovery and design process, in data analysis and uncertainty estimation. This contribution surveys a number of recent applications of flow simulations in relation to experiments in PTB.

First, simulation results for the design of an experiment in environmental metrology are presented, that aims at finding the optimal geometry and process conditions for the mixing of air and soot for a homogenous soot distribution. The goal is to assist in the design of measurement equipment for the soot concentration at given gas properties.

Second, we describe two simulation examples involving pulsed free jets of variable density and compare to experiments with a background in explosion protection. The mixing process between emerging jets and the surrounding is of special interest concerning the autoignition inside internal combustion engines. The performance of different turbulence models (URANS, SAS, LES) and their comparison was studied.

Third, the coupling between flow processes and heat conduction in a turbulent buoyancy-driven flow is addressed and illustrated for an example in legal metrology. Detailed previous numerical studies for the two-dimensional case provide an essential support for correct results. Figure 1 shows the temperature and velocity distribution at different times in a domain with different boundary condition, left, right and top 5 °C and bottom 15 °C, initial temperature 5 °C.
The aim is an optimal measurement configuration with restrictions in sensor locations for the determination of the averaged temperature. Finally, methods for the evaluation of measurement uncertainties in flow metrology are outlined and discussed for future research.

Figure 1. Temperature and velocity distribution for a container with a warm bottom end at different times.

References

A METHOD OF WEIGHING MATRIX FOR SPECTROPHOTOMETRIC ANALYSIS OF OIL MIXTURES

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1. Formulation of the research problem

It is assumed that an oil mixture to be analysed is composed of three known components, and that the vectors of exact data \( \mathbf{s}_j \) (\( j = 1, 2, 3 < M \)), representative of the absorbance spectra of all those components, are available. According to the Lambert-Beer’s law, the vector of exact absorbance data \( \mathbf{s} \), representative of the spectrum of the mixture, satisfies the equation:

\[
\mathbf{s} = \mathbf{c}_1 \cdot \mathbf{s}_1 + \mathbf{c}_2 \cdot \mathbf{s}_2 + \mathbf{c}_3 \cdot \mathbf{s}_3
\]

(1)

where \( \mathbf{c} = [c_1, c_2, c_3] \) is the vector of concentrations of all components, subject to the following constraints: \( c_1, c_2, c_3 \in [0, 1] \) and \( c_1 + c_2 + c_3 = 1 \). It is assumed that the real-world absorbance data \( \mathbf{s} \), representative of the spectrum of a mixture, are corrupted with random errors \( \Delta s \) resulting both from inaccurate preparation of the mixture and imperfections of the spectrophotometer. The problem under study consists in determination of the concentrations of all components of the mixture.

2. Proposed solution of the research problem

Since \( c_1 + c_2 + c_3 = 1 \), the spectral data, representative of an unknown mixture, may be modelled by means of the equation:

\[
\tilde{\mathbf{s}} - \mathbf{s}_3 = \hat{c}_1 \cdot (\mathbf{s}_1 - \mathbf{s}_3) + \hat{c}_2 \cdot (\mathbf{s}_2 - \mathbf{s}_3) + \Delta \tilde{\mathbf{s}}
\]

(2)

where \( \Delta \tilde{\mathbf{s}} \) is an additive zero-mean random error introduced by the spectrophotometer. Let \( \mathbf{W}_{M \times M} \) be a weighing matrix whose elements assume the values \(-1/M\) or \(+1/M\) – for example, the matrix whose rows contain the discrete Walsh functions ordered according to the number of sign changes. Then the estimates of \( \hat{c}_1 \) and \( \hat{c}_2 \) may be obtained by solving the following system of linear algebraic equations:
using an algorithm of the ordinary least squares. The method to be studied differs significantly from standard chemometric methods since it does not require neither selection of wavelength values nor the use of calibration data other than the vectors $s_j$.

3. Results of testing

The performance of the proposed method is assessed with respect to worst-case uncertainty of the final result of measurement, using a large set of validation data representative of NIR spectra of olive oil corrupted with 0–10 % corn oil and nut oil. The component spectra are very similar; consequently, the problem is extremely ill-conditioned. The proposed method is compared with the partial-least squares method (PLS), considered to be a reference tool for remediating ill-conditioning of chemometric problems (Fig. 1).

![Comparison of the proposed method with PLS method](image)

Figure 1. Comparison of the proposed method (black line) with the PLS method (green line).

4. Conclusion

The proposed procedure may be viewed as the preconditioning of the LHS matrix combined with noise filtering in the RHS vector. This means that it may be applied for solving a broad class of ill-conditioned systems of linear algebraic equations. The full text of the paper will contain: multi-aspectual explanation of practical significance of the problem under study, detailed description and justification of the proposed method of estimation, systematic presentation of the methodology of study and of the results of study, as well as practical conclusions drawn from the results of study.
QUALITY ASSESSMENT AND FILTERING ALGORITHMS OF HIGH-FREQUENCY MEASUREMENTS OF GPS AND ROBOTIC THEODOLITES USING SUPERVISED LEARNING TECHNIQUES

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GPS and robotic theodolites (RTS), the new generation geodetic instruments, have been used to measure displacements of moving objects above certain thresholds of movement amplitude and period, and in particular have been applied for the monitoring of flexible civil engineering structures (high-rise buildings, suspension bridges, i.e. structures with dominating period > 1-2 sec). During the last years there has been an effort to “push the limits” of these instruments and use them for the monitoring of more stiff structures using stochastic supervised learning-based techniques in systematic experiments. During the experiments the instruments were forced to record different types of movements (rotations in a horizontal or vertical plane, horizontal and vertical linear oscillations) of known characteristics. The 3-D time series of the coordinates of the moving sensors were subsequently analyzed, in some cases in combination with accelerometer data.

At a first step the noise level of the system was identified from the time series or parts of time series corresponding to axes of no motion or to time intervals of no motion, conspicuously representing pseudo-displacements.

At a second step, the recordings of real displacements were analyzed in high and low frequency components, usually corresponding to dynamic and semi-static motions respectively. Then, algorithms for their filtering were developed on the basis of comparison of recorded and of real values and of optimization procedures focusing on the amplitude of displacements and of their spectral characteristics. Spectral analysis techniques in the time and frequency domain permitting to analyze non-equidistant RTS data due to jitter effect, and hence weakly only subject to the Nyquist criterion limitations, were adopted.
DIFFERENCES IN RECORDINGS OF COLLOCATED, IDENTICAL SENSORS

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It is widely assumed that calibrated, identical instruments operating under similar conditions record the same signal with only minor differences due to random noise; hence recordings of a single instrument are fully representative of a specific signal. However, experience from measurements of bridge oscillations of sub-cm level with collocated GPS receivers, at the limit of the instrument range of operation, revealed important differences in the instrument output, and this result led us to investigate this problem on the basis of systematic experiments. The latter were based on sets of different types of receivers focusing on short-duration (a few sec to a few hours) high-frequency (10Hz) measurements.

The output of these experiments was to confirm the existence of differences between identical, collocated instruments, even an absence of correlation between their recordings, which was not, however, due to phase shifts. Spectral analysis revealed that the observed differences are due to colored noise for low frequencies, and white noise for high frequencies. The limit between colored and white noise seems to be a function of the duration of observations, and for this reason, long-term observations are practically contaminated by white noise only and hence permit mm-level accuracy.

Differences between identical collocated sensors have been found also in other types of instruments recording dynamic measurements such as changing coordinates (robotic theodolites), acceleration, or rain-drop dynamics (disdrometer).

This result may suggest that certain instruments, especially when functioning close to the upper limit of their range, may be affected by an instrument-dependent, (non-systematic) colored noise.
Metrologists often interact with commercially sensitive data. For example, test data taken while installing and commissioning a machine tool could potentially be rich with performance indicating data, and should therefore be kept secure. It is often the case that a third party organisation is used for acceptance trials and highly likely that the data will be shared by a number of organisations. This should result in the organisation implementing all necessary precautions to secure the data so as to protect their client’s interest.

Critical within the field of metrology, especially when considering acceptance tests, is to establish the authenticity and traceability of the data to provide a reliable basis for processing the data. Taking machine tool calibration as an example; data will often be transferred from on-site engineers back to a central location for processing. The multiple stages of data transfer increase the likelihood of the data being corrupted or otherwise inadvertently modified and the possibility of data being associated with the wrong machine or measurement is greatly increased. The ability to implement checks and measures to identify any such change and take corrective action is imperative.

The use of cryptographic techniques has become essential for all organisations and individuals who wish to transfer private data within the public domain. This is made possible by the computational infeasibility of decrypting the data without the encryption key, therefore, ensuring data security [1]. Partial security aspects associated with internet-enabled metrology systems have been discussed and overcome within the Software Support for Metrology (SSfM) programme [2]. While this guide provides a sound basis for internet-calibration services, little of the content makes reference to data security, validity and authenticity where both the transfer protocol and storage medium are not restricted. Moreover, the guide contains little reference to non-invasive autonomous methods of data protection to minimise user inconvenience.

There are many different methods of implementing cryptographic techniques in a symmetric fashion by the use of an encryption key known by all involved parties [2]. However, the problems associated with key distribution have been significantly reduced by one of the more predominant methods of asymmetric public-key encryption [2]. This
method makes use of a mathematically related key set by which the public key can be used for encryption, but only the private key can decrypt.

In addition, the same public-key infrastructure can provide the inherent means of ensuring the authenticity and traceability of a dataset by the use of a digital signature. This would be performed by signing the calculated hash sum from a given dataset with the sender’s private key which can subsequently only be validated by the associated public key, thus ensuring the source of the data as well as the integrity.

Recent trends towards a ‘cloud’ computing infrastructure has resulted in a user’s data footprint increasing to a size where data is stored on a physical medium whose security system is unknown by either the software or the user. This presents the problem of how to prevent unauthorised individuals accessing this sensitive data.

This paper investigates the known problems that a software engineer or a metrology specialist can eradicate through the novel implementation of cryptographic techniques within their software. In addition, the ability for these techniques to overcome the impossibility of accounting for every potential security risk within software production is discussed. Considerations will be taken to the functional scalability in terms of data quantity, processing speed, and any associated network transfer overheads.

This paper concludes by describing a case-study project in machine tool calibration. Here we implement non-invasive, autonomous methods of cryptography by using the public-key infrastructure to overcome common complexities and to ensure a high degree of confidence to the data’s authenticity, validity, and security during transmission and storage, regardless of the chosen transfer medium. This novel contribution to the production and implementation of metrology software shows how cryptographic techniques can inherently provide a more rigorous means for data verification, security and traceability.


ON THE DIFFERENCE OF MEANINGS OF “ZERO CORRECTION”: ZERO VALUE vs. NO CORRECTION, AND OF THE ASSOCIATED UNCERTAINTIES

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Abstract
The expression of uncertainty in the field of metrology is based, since 1995, on the Guide to the expression of uncertainty in measurement (GUM), according to which “it is assumed that the results of a measurement have been corrected for all recognised significant systematic effects”.

There is a live debate going on about the way to comply with the GUM requirement, and, in general, to comply with the need of performing corrections for known biases, as occurring also in the testing field.

In tackling the problem, one is confronted with issues arising from practical difficulties, especially when:
(a) applying a small correction with large uncertainty;
(b) handling uncertainty for uncorrected results.

Concerning issue (a), e.g. CITAC recommends, contrarily to GUM, correcting also for small effects.

The paper deals with two commonly used meanings of the expression ‘performing a zero correction’:
1) applying to the measured data a correction \( \Delta \) of value zero and a non-zero associated uncertainty;
2) using uncorrected measured data and a method for evaluating the resulting additional uncertainty arising from that decision.

The paper discusses the differences arising from the two different ways of intending the fact that in both cases the measured values are effectively used, namely with respect to the reliability of the resulting estimate of the value assigned to the mean value with respect to an actual ‘true value’. For case (1), the CCT-proposed OME method is discussed; for case (2), the RSSu, RSSU and SUMU literature methods are discussed.
Concerning the OME method, the discussion in based on the fact that it assumes a correction \( \Delta := 0 \), so assuming that, in the total lack of any specific information about a possible value of the correction, the systematic deviations with positive and negative effect perfectly balance, a very strong assumption. Consistently with the total lack of information, the expected value is assumed be contained in an interval symmetrical to zero of equally probable values (a rectangular probability density distribution).

The RSS, SUMU methods were developed for cases where the correction \( \Delta \) is not applied to the measured data. However, they include an estimate of the correction value \( \Delta \) – not necessarily null – and of \( u(\Delta) \) in the uncertainty budget associated with the uncorrected effects. They differ basically with each other in the expression of the value of the correction in modelling the uncertainty. The paper discusses these methods starting from their assumptions.

The different methods are also compared as to the extent and position of the uncertainty interval with respect to the possible position of a ‘true value’ (the “value” tout court according to GUM terminology).

When, in particular, the correction is set to, or is evaluated to be, zero, both methods of correcting and not correcting the measured data obviously bring to the same uncertainty \( u \). However, being the underlying assumptions different for the two cases, the discussion reveals differences to be taken into account. In addition, in the case where one is not trusting the value of the correction to such an extent to prefer using uncorrected data, one may be tempted to assume \( \Delta = 0 \) especially when the interval of the measured values includes the zero, as a mere expedient to exploit this peculiar property of the statistical estimator.

It can be difficult to obtain a reasonably valid assumption about the value of the correction \( \Delta \); however, it can be incomparably less difficult than obtaining a valid evaluation of the correction. On the other hand, in this case, the uncertainty \( u(\Delta) \) should sufficiently be ‘enlarged’; however, how much enlargement is needed may remain a matter of debate. In all instances, an exactly ‘zero’ value of the correction should not necessarily be considered as the assumption with the highest probability, even in the total lack of knowledge, but an exceptionally favourable case.
NEED FOR CONSISTENCY OF TERMINOLOGY IN INTERNATIONAL STANDARDS AND GUIDELINES: SOME CASE STUDIES AND CONCEPT DIAGRAMS

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Abstract

In the scientific and technical arenas, the first must is a common understanding of the basic concepts and terms in scientific and technical, otherwise impossible.

There are several bodies historically devoted to achieve this goal, national and international, sectorial and general, prescriptive and advisory.

Some efforts have been spent in the last 1-2 decades to create such shared understanding, and improve the efficiency of this frame. The Joint Committee for Guides on Metrology established two advisory Committees (formed by representatives of BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP, OIML), one for defining concepts and associated terms and one on measurement uncertainty. The ISO, with IEC probably the major body on prescriptive standards, recently set up a database of terms used within ISO standards, of which the guides produces by the above mentioned Committees are part.

In the paper, some case studies are reported, in order to illustrate problems encountered and the method intended for use within IMEKO TC21 to facilitate solutions.

For example, one of these concerns a ‘family’ of concepts centred on “trueness”.

28 entries were found in the ISO database, out of a total of 32 entries on “(measurement) trueness” presently collected in TC21 repository. Each definition involves also other terms, which can, in turn, have several definitions, or can have had different forms in the past. A total of 70 definitions are presently collected and inter-related under “trueness” main heading in the TC21 repository. In addition, two concept diagrams are presently built under “trueness” from these definitions.
A first type of definitions of “trueness” uses the term “true value”:

• ISO 3534-2:2006 (3.3.3): “Closeness of agreement between the expectation of a test result or a measurement result and a true value. (& ISO/TS 13530:2009)

NOTE 1 The measure of trueness is usually expressed in terms of bias; NOTE 2 Trueness is sometimes referred to as “accuracy of the mean”. This usage is not recommended; NOTE 3 In practice, the accepted reference value is substituted for the true value.


• ISO 15195:2003 (3.10): “Closeness of agreement between the average value obtained from a large series of results of measurements and a true value” (& ISO 15189:2007)

A second type of definitions of “trueness” uses the term “reference value”:


• VIM3 JCGM200:2008 (2.14): “Closeness of agreement between the average of an infinite number of replicate measured quantity values and a reference quantity value.

NOTES: 1 — Measurement trueness is not a quantity and thus cannot be expressed numerically, but measures for closeness of agreement are given in ISO 5725. 2 — Measurement trueness is inversely related to systematic measurement error, but is not related to random measurement error. 3 — Measurement accuracy should not be used for ‘measurement trueness’ and vice versa.

• ISO DIS 21748:2008 (3.11): “Closeness of agreement between the average value obtained from a large set of test results and an accepted reference value.

NOTE The measure of trueness is normally expressed in terms of bias. The reference to trueness as ‘accuracy of the mean’ is not generally recommended.”

• EA 4/16:2003 (6.3.1): “Measured as bias with respect to a known reference value”
The main embedded terms (and entries in ISO database) were found to be:
“True value” (29 entries); “(Accepted) reference value” (19 entries); “Test or measurement result” (23 and 11 entries); “Accuracy” (180 entries); “Bias” (122 entries); “Systematic effect” (2 entries); “Systematic error” (26 entries); “Systematic uncertainty” (5 entries); “Definitional (intrinsic) uncertainty” (1 entry); “Correction” (18 entries); “Expectation” (3 entries).

Concerning the most important one, “true value”, 32 entries in total are presently included in TC21 repository. For the other most important, “reference value”, 22 entries in total are presently included in TC21 repository.

The paper aims at illustrating the study under way in IMEKO TC21, based on the contents of the repository, which is a broader collection of documents with respect to the ISO database, intended to look specifically to what looks, often obviously, as inconsistencies. An effort is being made to understand why, and whether they are due to historical stratification or to sound reasons (e.g. sectorial), and to find and suggest ways toward reducing their number –not necessarily toward a single set of meanings for the concepts and terms, but limited, in addition to their general meaning, to real and undisputable sectorial needs.

Preferred: poster presentation
UNCERTAINTIES FROM LINEAR LEAST SQUARES CALIBRATION

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With the recent publication of the ISO/TS 28037 Technical Specification¹, “Determination and use of straight-line calibration functions”, it seems to be the time to update the corresponding part of some international standards or guides. For instance, it is the case of the EURACHEM/CITAC Guide ”Quantifying Uncertainty in Analytical Measurement” Second Edition². Indeed, in the E.3 part of the Guide, “Uncertainties from linear least squares calibration”, it may be more pedagogical to introduce the uncertainty estimation of the predicted quantity from the measured response by means of the calibration function instead of only using the variability in the observed quantity. More precisely, the uncertainty measurement consists of components that are not only evaluated by type A evaluation, as displayed in the EURACHEM/CITAC Guide Second Edition E.3.1 to E.3.5 parts, but also by type B evaluation. That is to say, the uncertainty measurement is based on means other that statistical distributions of the quantity values. Therefore, this approach would enable to avoid misinterpretation of the Guide or mistakes like those found in some ISO Standards³, 4 dealing with evaluating uncertainties when using linear least square calibration.

After exhibiting the uncertainty expression for linear squares calibration, correctly including the type A and type B evaluations, this work displays applications in the field of the glucose aqueous solutions refractometry. Indeed, by using international tables⁴ of correspondence between refractive index and volume or mass fractions of these solutions, the values of the amount of substance derived quantities can be deduced from the measured refractive indexes. In a first step, due to the small magnitude of the uncertainty values of the tables, the linear least squares calibrations can be considered as un-weighted. By the same token, the corresponding results can be regarded as a limit case of the weighted linear calibration. Then, the latter approach is considered, in agreement with the ISO/TS 28037 Technical Specification. Anyway, it is the most realistic model to be used for linear calibration, and for the refractometers calibration in particular.

5. OIML R 124 Refractometers for the measurement of the sugar content of grape must (1997).
1. Introduction

The metrology of what might be called ‘semi-quantitative’ measurements is an area of increasing interest in many fields but where the usual tools for e.g. measurement uncertainty do not always work [Bashkansky and Gadrich 2010, White 2011]. The present work examines measurements on an ordinal scale, including how measurement uncertainty is expressed [§2]. Ultimately it is how the measurement results are to be used – such as in decision-making in conformity assessment – which determines the most appropriate way of handling uncertainties, the associated risks of incorrect decisions of compliance and the impact consequences of such decisions [§3].

2. Uncertainty in qualitative measurements

As rightly pointed out by [Bashkansky and Gadrich 2010], several statistical tools and measures, such as standard deviation – often employed in traditional interval or ratio measurements for the estimation of measurement uncertainty [JCGM 100:2008] – cannot be used on an ordinal scale. Limited time and resources to make measurements nevertheless result in some errors of measurement not being evaluated, leading to measurement uncertainty. For instance, measurements using olfactometry with human panels may place a certain odour in the range of ordinal scale 0: no odour to 6: intolerable [CEN EN 13725:2003]. Because of measurement uncertainty, a series of measurements will show a spread of odour values which, apart from bona fide variation in the measurement object, will also include a component of apparent variation associated with measurement uncertainty.

3. Decision-making with semi-quantitative measurements

Wherever there are uncertainties, there are risks of incorrect decision-making in conformity assessment. Underlying measurements may be made on a quantitative or qualitative scale – corresponding to the traditional division of statistical acceptance sampling by variable or by attribute, respectively [Pendrill 2008].

* This work is supported by the Swedish National Metrology Programme, VINNOVA
Irrespective of which measurement scale, the appropriate quality characteristic of interest for conformity assessment – the fraction non-conforming entities – is itself fully quantitative and provides a base for decision-making and the consequences of incorrect decisions caused by measurement uncertainty. It is important in qualitative testing not to confuse observations of (i) the qualitative measurand, distributed on an ordinal scale with its specification limit for attribute (go/no-go) testing, with (ii) the quantitative fraction non-conforming product, with its distribution of likelihood and corresponding specification limit [Trullols et al. 2004]. The latter, which is arguably the most relevant in qualitative testing, is determined by the uncertainties of sampling, e.g. a binomial distribution for statistical sampling or arising from sample heterogeneity.

A decision theory approach balances the costs of analysis against the costs associated with the consequences of incorrect decision-making. A general expression for the total cost, $E$, associated with a test procedure is the sum of costs of testing and the consequences of incorrect decisions:

$$E = D_{\text{measure}} + \int C_{\text{consequence}}(x, \mu) \cdot P(\mu) \cdot d\mu$$

(1)

where the cost, $D_{\text{measure}}$, of taking samples and making tests has to be balanced against the possible losses $C_{\text{consequence}}$ when the test results are used in decision-making [Pendrill 2008]. Examples as some of the first applications of a costs-based, ‘fitness for purpose’ approach in this field include the study of human perception of information signs and product quality, for instance for the disabled and in healthcare.

References

2. CEN EN 13725:2003 “Air quality – Determination of odour concentration by dynamic olfactometry”
RATE-OF-CHANGE ANALYSIS APPLIED TO MACHINE TOOL MONITORING AND MAINTENANCE SCHEDULES

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Despite the existence of condition based maintenance schemes, CNC machine service and calibration schedules are still largely based on the same premise as car services. Often, a yearly calibration is performed regardless of the asset's condition in the intervening period, with additional repairs being made in the case of emergencies. This assumption can lead to two situations where A, the machine is not being serviced frequently enough, or B, the machine is serviced more frequently than required. Both of these situations lead to costly machine downtime that could be avoided if a condition-based maintenance schedule was available.

Some of the factors hindering the adoption of these more efficient systems include initial startup cost, more frequent, though not unexpected downtime, additional calibration staff and efficient data handling and storage.

A system that could allow machine operators with minimal measurement training to take reliable measurements, automatically import and store these results, and alert the user when a tolerance is exceeded would allow wider implementation of condition based maintenance and improve machine tool availability.

This paper will investigate the development and implementation of such a system, and its effect on the productiveness of the case study machine.
APPLICATION OF SPLINE SURFACE PROFILE FILTERS TO SUBPIXEL CONTOUR DECOMPOSITION PROBLEMS

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Keywords: Digital Filter; Geometric primitives; Contour decomposition; Sub-pixeling

Extended Abstract

This article explains an approach using surface profile filters for detecting straight lines and arcs, enhancing subpixel-precision methods, based on the contour points approach by Schumann. In computer vision and image processing using a constant curvature criterion for contour decomposition is a common approach. The idea aims to split complex features into simple primitives. The contour decomposition is necessary for further structural analysis like spatial position, distance and angles between the shape primitives. Many ideas and approaches were published and implemented in the past, mostly targeting shape analysis and object recognition problems where pixel-scaled precision is sufficient. Modern optical measurement devices aim to reduce systematic measurement errors (user influence) by increasing the automation level of their measurement tasks to improve objectivity and accuracy of the measurement results. The automated segmentation also enables automated measurement of features within the image, that finally the manually positioned areas of interest (AOI, ROI) becomes dispensable. The advantages of the surface spline filter given by Krystek, namely the fast algorithm, the form filter property and the ability to apply the filter to open and closed profiles without end effects (Gaussian filter), caused the evaluation of spline filters for contour decomposition problems.

The approach by Wuescher/Boyer uses the curvature property of the contour as criterion to decompose straight lines and arcs as primitive fea-
tures. The resulting $\lambda$-segments of the contour are not sufficient for measurement applications. The sequential method proposed by Schumann\textsuperscript{1} takes a set of contour points as its input data followed by discrete low pass filtering using triangular filter. Schumann\textsuperscript{1} as well as Thiemann\textsuperscript{4} use estimators for finding model and process parameters. This results in non-optimal filter parameters for the contour shape to be detected since the process parameters were used for the whole contour as once. The contour not only represents its initial parameters like radius and arc-length but also inherits the characteristics of the production process parameters (e.g. vibration, material, etc.). Finally the object contour results in shape deviation $f(x)$ superimposed by waviness $w(x)$ and roughness $r(x)$.

$$z(x) = f(x) + w(x) + r(x)$$

With the ISO/TS 16610 documents besides the standard surface filter methods (2RC-filter, Gaussian filter) additional filter methods for surface measurement were introduced. The new spline filter proposed by Krystek\textsuperscript{3,5,6} is used to filter the contour, regarding improvements in initial indication of line and arc segments by the curvature criterion. Following the contour smoothening, the curvature $\kappa$ is calculated, where line segments correspond to intervals with $\kappa = \text{const.}$ and $\kappa' = 0$. Arc segments are denoted by a constant curvature too but distinguish from line segments through $\kappa \neq 0$. The resulting interval will be validated afterwards. A comparison of the spline filter with the Savitzky-Golay filter (based on mean-least squares) and common low-pass filters is given.

![Fig. 1. Spline filtered contour curvature data with different values for cutoff-wavelength $\lambda_c$ and the corresponding contour. The image shows a part with different surface finish. The starting point is the bottom-left, where the first line segment contains high roughness and waviness.](image)

The application of spline filters to contour decomposition problems delivers great differences regarding the quality of segmentation. Figure
1 shows the influence of scaling the cutoff-wavelength for the coordinate filter on the contour curvature. With little changes of $\lambda_c$ the contour will be smoothened only slightly but the curvature shows dramatic change. Since the spline filter needs to be handled with great care. In the outlook further improvements for the segmentation algorithm considering object contour data with different degree of waviness and roughness will be suggested.

References

RESOLVING POWER AND SUPERRESOLUTION FOR SPECTROMETERS USED IN RADIATION DETECTION

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Resolution is one of the most important concepts used to describe the performance of a spectrometer. The concept of resolution was originally developed in optics, where it is used to quantify the ability of an instrument (e.g., a telescope) to distinguish between two point sources (e.g., two stars) separated by a small angular interval. A commonly used definition is given by the Rayleigh criterion, which describes the resolution in terms of the effective width of the point spread function of the instrument. This approach, while often useful, is too simplistic because it does not take into consideration the algorithms that are used to improve the quality of images and which have become an integral part of modern optical instruments. The ability to achieve resolution that is better than the one derived from the Rayleigh criterion is known as superresolution.

For spectrometers used in radiation detection, it is in general not possible to introduce a definition of energy resolution that is analogous to the Rayleigh criterion used in optics. The spectrometers' response functions are in many cases irregular in shape, show substantial overlap, and are not localized around a given energy. Furthermore, many of the spectrometers used for radiation detection provide an indirect measurement of the energy spectrum and deconvolution methods are needed to analyze the data. A measure of resolution that is generally applicable must therefore (a) allow for response functions of arbitrary shape and (b) take into consideration the enhancement in resolution (superresolution) that is achievable with deconvolution methods. The aim of this paper is to present an approach that leads to estimates of the superresolution of spectrometers for radiation detection which is generally applicable.

Kosarev has derived an absolute limit for resolution enhancement,
known as Shannon’s superresolution limit for signal recovery, using arguments based on a well known theorem of Shannon. However, most of the calculations in the literature are based on the assumption of Gaussian, translationally invariant response functions and these results are therefore not directly applicable to spectrometers which do not satisfy these requirements. In this paper, a new approach based on the formalisms of Backus and Gilbert and of Kozarev is presented. The method follows a two-step procedure. In the first step, an analysis of the resolving power of the spectrometer is carried out following the approach of Backus and Gilbert. In the second step, this information is used to introduce a linear transformation that maps the original response functions to Gaussians of a FWHM which are determined by the resolving power in the energy regions of interest. In this new representation, the response functions satisfy the requirements of the theorem of Kozarev and the superresolution can be estimated.

*Keywords:* resolving power, superresolution, radiation detection
A SOFTWARE FOR THE EVALUATION OF THE STABILITY AND DRIFT OF MEASURING STANDARDS

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Abstract - Using the concepts of time series and standard error of estimate, we developed an automated system with the objective of determining the drift (tendency), the long term stability and to do predictions of future values, what constitutes a powerful tool in the control and in the conservation of measurement standards.

Keywords: stability, drift, time series, standard error of estimate.

1. Introduction

Usually the measurement standard manufacturers provide the long term stability of commercial standards. This parameter is sometimes the largest uncertainty contribution to the overall uncertainty of the standard. The software and specific statistical techniques presented in this paper allow one to know the actual behavior of the measurements standard in the long term and even to make predictions of its future behavior. It was verified, for different standards, that the stability estimate is smaller than the value specified by the manufacturers. This reduced estimate leads to a smaller overall uncertainty of measurement and consequently to an improvement of the calibration processes. This tool allows a complete control of the measurement standards and can be very useful to the metrology laboratories.

2. Stability and Drift

The stability is a property of a measuring instrument, whereby its metrological properties remain constant in time [1]. The stability of a measurement standard may be specified as short-term stability and long-term stability. The short-term stability is defined as measurement repeatability (measurement precision under a set of repeatability conditions of measurement), which is, by the way, condition of measurement, out of a set of conditions that includes the same measurement procedure, same operators, same measuring system, same operating conditions and same location, and replicate measurements on the same or similar objects over a short period of time [1]. The long-term stability refers to the ability of a measuring instrument to maintain constant its metrological characteristics along the time. Instrumental drift is a continuous or incremental change over time in indication, due to changes in metrological properties of a measuring instrument [1].

3. Standard Error of Estimate

The simple linear regression equation is also called the least squares regression equation. Its name tells us the criterion used to select the best fitting line, namely that the sum of the squares of the residuals should be least. That is, the least squares regression equation is the line for which the sum of squared residuals is a minimum. If there is linear regression we may write the formula for the mean Y when X is given as

\[ Y = mX + b \]  \hspace{1cm} (1)

Let us consider \( Y_{est} \) as the estimated value of Y for a given value of X. This estimated value can be obtained from the regression curve of Y on X, estimated from equation (1), where N is the number of measurements. A measure of the dispersion in relation to the straight line of regression of Y for X will be given by the equation:

\[ S_{y,x} = \sqrt{\frac{\sum (Y_i - Y_{est})^2}{N}} \]  \hspace{1cm} (2)

The equation (2) is called the Standard Error of Estimate of Y on X [2]. It is important to note that this Standard Error Estimate has properties analogous to those of standard deviation. So, we can interpret this quantity as having properties similar to the positive root of the "variance of the noise" and, as consequence, we can use the equation (2) to evaluate the long term stability of standard of measurement, mainly in the cases where the graph with base in the result of the periodic calibrations presents similar characteristics to the called cyclical movement of the time series.

4. The Software

The calculations of the stability, drift and the other parameters were totally automated. The data for the calculation of the stability are: the date and the result of the measurement of each periodic calibration. Equation (1) is used in the graph construction. These calculations of stability and others parameters are shown in Fig. 1, where in the upper left side there are some fields for graph plotting, while in the lower side some results obtained from the statistical calculation are shown. The graph also displays the regression line [3][4]. These data are used to quantify the stability of the standards, as well as to...
calculate other important parameters. The calculations of drift and estimated values for \( y \) are shown in Fig. 2, where similarly the previous figure, in the upper left side there are some fields for graph plotting, while in the lower side some results obtained from the statistical calculation are shown.

The full presentation of the software is composed of four display screens with several fields for standard identification, storage of data and statistical calculations. The first one is called history of the calibrations where the date of the calibrations, temperatures, reference values, uncertainties and series numbers (among other data) are stored. Figure 1, shows the second display screen of the software, where one can see the stability graph with the values obtained in the periodic calibrations as a function of the calibrations dates. The example used here is for a 10 H inductor.

In the upper side there are some fields of adjustments, while in the lower side are shown some results obtained in the statistical calculations. Besides the values obtained from the calibrations as a function of the dates, Fig. 2 also displays the lines resulting from linear and polynomial fit. These data are used to quantify the standard drift (tendency), as well as to make projections of future values. In the lower side the results estimate for the future calibrations are shown, which is quite useful in the control of the standards.

5. Conclusion

The results obtained in several set standards of Laboratories of Inmetro show that the new method and the automated system developed for the evaluation of the stability of measuring standards is very useful. The calculations show that for all standards the stability estimation is smaller than the value specified by the manufacturer. This reduced estimation leads to a smaller overall uncertainty of measurement and consequently to an improvement of the calibration process.

References


MEASUREMENT AND EVALUATION OF ASYNCHRONOUS RADIAL ERROR OF A HIGH SPEED SPINDLE

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In recent years, high speed spindles are commonly used for producing three dimensional and miniature components. Rotation accuracy of the spindle needs to be maintained at the highest level for realizing desired accuracy of the components. However, error sources such as imperfections of bearing components and structural motion of machine tool cause synchronous and asynchronous errors in the axis of rotation of the spindle [1]. Evaluation of asynchronous errors of rolling element bearing spindles is difficult as it is associated with the random motion of rolling elements and non repeatable in nature [2]. This work presents a statistical analysis method for interpreting and evaluating the asynchronous radial error of a high speed spindle. The experimental set-up with a master and a capacitive sensor used for measuring radial errors a high speed spindle is shown in Fig. 1(a). Fig. 1(b) shows the discrete time samples of measurement data obtained at the spindle speed of 50,000 rpm.

![(a) Experimental arrangement (b) Measured data at the spindle speed of 50,000 rpm](image)

Fig. 1 Measurement of spindle radial errors in a miniaturized machine tool

In the present work, Fourier series function as given by Equation (1) is fitted to the measurement data for decomposing the non repeatable components of measurement data.

\[
m_j = C + \sum_{k=1}^{\infty} a_k \cos(2\pi f_k t) + b_k \sin(2\pi f_k t)
\]

(1)

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Here $C$ is the mean of the measurement data, $a_h$, $b_h$ are the Fourier components, $t_i$ is the sampling time and $f_0$ is the fundamental frequency of the measurement data. Assuming the residuals to follow normal probability distribution, an iterative least squares method is used for estimating the coefficients of the Fourier model ($C$, $a_h$, $b_h$, $f_0$). Fitted curve for the samples of measurement data is shown in Fig. 2(a) and it closely follows the periodic, repeatable trend of the measurement data. Non repeatable components of the measurement data are estimated as the deviations between the fitted curve and the measurement data as shown in Fig. 2(b). Asynchronous radial error of the spindle is evaluated as the maximum range of the non repeatable components at the specific angular location in polar plot [1] as shown in Fig. 3. Table 1 shows the asynchronous radial error values evaluated using proposed method.

![Fitted curve for the measurement data](image1)

![Residuals](image2)

**Fig. 2 Decomposition of measurement data**

**Table 1: Asynchronous radial error of the spindle**

<table>
<thead>
<tr>
<th>Number of spindle revolutions</th>
<th>Evaluated value for asynchronous radial error</th>
<th>Standard deviation (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Magnitude (μm)</td>
<td>Angular location (deg)</td>
</tr>
<tr>
<td>10</td>
<td>2.5659</td>
<td>126.05</td>
</tr>
<tr>
<td>20</td>
<td>2.7895</td>
<td>303.74</td>
</tr>
<tr>
<td>40</td>
<td>3.065</td>
<td>303.69</td>
</tr>
<tr>
<td>60</td>
<td>3.5493</td>
<td>303.71</td>
</tr>
<tr>
<td>80</td>
<td>3.6272</td>
<td>303.71</td>
</tr>
<tr>
<td>100</td>
<td>3.5992</td>
<td>303.71</td>
</tr>
<tr>
<td>150</td>
<td>3.6321</td>
<td>303.71</td>
</tr>
<tr>
<td>200</td>
<td>3.6427</td>
<td>303.71</td>
</tr>
</tbody>
</table>

Proposed method is useful in analyzing the underlying behavior of the asynchronous radial error of the spindle and it can be extended for online monitoring of high speed spindles in a miniaturized machine tool.

**References**

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Measuring edges on pivot-mounted objects during rotation

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Keywords: Focus correction; rotary-mounted object; concentric runout.

Extended Abstract

For quality assurance during a production process it is necessary to check the condition of the tools used in that process. For cutting edge tools like drills, end mills and so on the main influence on the resulting quality is the geometry of the cutting edges. Measurement of such edges can be performed using 2D image processing technology and a setup according to figure 1, in which the tool is pivot-mounted with its rotary axis inside the plane of focus of the camera.

For this measurement task the state of the art uses 2 methods of measurement. Both of which rely on measurement of runout values \( x(\phi) \) for the tool according to the images acquired at different angles of rotation \( \phi \). The first method is to rotate the tool through the plane of focus and continuously measure the runout for which the local maximum value is calculated.
Afterwards the tool is rotated backwards until the user decides that the maximum position is reached once again using a graphical indicator based on the current and maximum runout values. At the position of maximum runout a static image is acquired which is used for measurement. The second method also requires the tool to be rotated through the plane of focus while measuring runout values. When the sequence of runout values shows a local maximum, the image that contained the maximum runout is used for measurement.\textsuperscript{2,4}

The first method suffers from high user influence due to the interpretation of a graphical indicator and manual return to focus position, the second method produces systematic errors. The new approach presented in this paper is an extension to the second method calculating a maximum speed at which the tool can be rotated and applying a mathematical correction to the results that compensates for the systematic errors.

The runout measured in an image acquired at rotary angle $\varphi$ can be described as $x(\varphi) = x_0 + r \cdot \cos(\varphi - \varphi_0)$, where $x_0$ is the offset of the rotary axis, $r$ is the actual distance of the edge point to the rotary axis (radius) and $\varphi_0$ is the angle of rotation at which the edge is in the plane of focus.

Based on a rough approximation of $r$ a range of angles is computed for which the edge is in focus. By fitting the runout values captured in this interval to the formula of $x(\varphi)$ the angle $\varphi_0$ and the correction factor $\alpha = \frac{1}{\cos(\hat{\varphi} - \varphi_0)}$ is computed and applied to the x-coordinates of all contour points in the image acquired at $\hat{\varphi}$, where $x(\varphi)$ was maximal among values captured in the interval.

This new extended method allows for measurement during rotation without stopping. This effectively reduces measurement time and is more objective than the first method in the state of the art biased by the user’s interpretation of an indicator. On the other hand it does not suffer from the systematic errors of the basic second method either.

References

THEORY AND COMPUTATIONAL PROGRAM FOR THE DETERMINATION OF REFERENCE VALUE IN KEY COMPARISON BASED ON BAYESIAN STATISTICS

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Our research group reported the robust determination method of key comparison reference value (KCRV) on the premise of underestimated uncertainties of individual participants based on Bayesian statistics (Metrologia 39:444-452, 2010) and computational program for Microsoft Excel 2007® for this method is developed. Besides the theoretical background is elucidated, the program is applied to an actual inconsistent comparison data.

1. Introduction

Our research group [1] proposed the robust determination method of KCRV based on Bayesian statistics on the condition of underestimated uncertainties of individual participants. And we developed the macro program for Microsoft Excel 2007® [2] to evaluate KCRV based on the procedure. In this study, both of the theoretical background and the application of the program are focused. And some developed approach [3] will be introduced briefly.

2. Theoretical background

Provided that \(x_i\) is reported as measurement value and its associated standard uncertainty is \(u(x_i)\) \((i = 1, 2, \ldots, n)\), we proposed the probability density function of the true value of measurand, \(\mu\), and the individual population variance, \(\eta_i\) \((i = 1, 2, \ldots, n)\), as follows:

\[
p(\mu, \eta | x, q) \propto \frac{1}{(\prod_{i=1}^{n} \eta_i)^{1/2}} \exp \left( -\frac{1}{2} \sum_{i=1}^{n} \frac{(x_i - \mu)^2}{\eta_i} \right), \quad \eta_i \geq u^2(x_i) \text{ for all } i
\]

(1)

\[
0, \quad \eta_i < u^2(x_i) \text{ for any } i
\]
This probability density function based on the premise that (1) the prior is given by Jeffrey’s rule, (2) data is derived from a normal distribution and (3) uncertainties of individual participants are underestimated. The third premise is natural when the data is inconsistent.

3. The program and its application

We developed the computational program to carry out the method in Sec. 2 [2]. The program is applied to analyze the result of APMP.L-K1 (Data for a ceramic gauge block with a nominal length of 80mm, in which there are values considered outliers). In reality, the determined KCRV was 0.127 μm as the weighted mean after the removal of the inconsistent reported values. Our procedure derives the value close to 0.127 μm (0.123 μm ± 0.34 μm (95 % level of confidence)) without any apparent removals or corrections.

![Data entry sheet of the program and (b) KCRVs of APMP.L-K1 (a nominal length of 80mm) calculated via Procedures A and B in ref. 4 and our procedure and the arithmetic mean. The error bars show the expanded uncertainties. The dotted line shows 0.127 μm, the actual KCRV in APMP.L-K1.](image)

References

2. [http://staff.aist.go.jp/k.shirono/download_KCRV_e.html](http://staff.aist.go.jp/k.shirono/download_KCRV_e.html)
MODELLING AND UNCERTAINTY EVALUATION FOR THE RADIATION QUALITY PARAMETERS USED IN METROLOGICAL MANAGEMENT OF DIAGNOSTIC RADIOLOGY DOSIMETERS

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ABSTRACT

Diagnostic radiology methods, which are increasingly used today, require appropriate metrological management of the dosimeters used for quality control of X-ray equipment. The first step in this management is the characterization of appropriate radiation qualities, following procedures and criteria given in international standard IEC 61267:2005: Medical diagnostic X-ray equipment – Radiation conditions for use in the determination of characteristics. The second step is the dosimetry.

In using IEC 61267:2005 to characterize the radiation qualities (RQR) of radiation beams emerging from the X-ray source assembly, an attenuation curve is first established. This curve is based on a set of measured values of air kerma $K_a$ for various thicknesses $d$ of aluminium absorber (in our work of 99.9 % purity) placed between the X-ray tube and the detector. The attenuation curve $A(d)$ describes the relation between $K_a$ and $d$. Then values of three key characterizing parameters (two half-value layers and a homogeneity coefficient) can be obtained from the curve.

The purpose of the work described here is to provide a mathematical interpretation of the above process, present a method of solution based on the mathematics, and also to evaluate the uncertainties associated with determined values of the characterizing parameters. Algorithmically, the process can be described by a series of steps:

1. For each of a number of thicknesses $d$ of aluminium absorber, measure the thickness $d$ and the corresponding value of air kerma $K_a$.
2. Evaluate the standard uncertainties associated with the values of $d$ and $K_a$.
3. Determine the parameters of an appropriate attenuation curve $A(d)$ that relates the thickness $d$ and air kerma $K_a$.
4. Use the attenuation curve $A(d)$ to determine $d_1$, the first half-value layer HVL₁, such that $A(d_1)/A(0) = 1/2$ and, similarly, $d_2$, the second half-value layer HVL₂, such that $A(d_1 + d_2)/A(0) = 1/4$.
5. Determine the homogeneity coefficient $h = d_1/d_2$.
6. Evaluate the standard uncertainties associated with $d_1$, $d_2$ and $h$. 
Step 3 involves the selection of a suitable model for air kerma as a function of filtration thickness. Sometimes $A(d)$ is modelled by an exponential function, in which case Step 3 requires two parameters to be estimated: the amplitude and decay rate of the exponential term. Here the energy distribution of the X-ray spectrum justifies the use of a model with two exponential terms, which requires four parameters to be estimated. The model parameters are obtained using a non-linear least squares algorithm.

Step 4 needs to take into consideration that the two-exponential model has to be inverted to provide values of $d$ corresponding to particular values of $K_a$. As this inversion cannot be carried out explicitly, we use an appropriate numerical scheme that takes account of properties of the model.

Step 6 involves two main stages of propagation of uncertainty, described here in terms of the GUM uncertainty framework [3][4]:

A. The covariance matrix associated with estimates of the parameters of the attenuation curve in Step 3 depends on the uncertainties associated with the measured values of $d$ and $K_a$.

B. The uncertainty associated with $d_1$ and $d_2$ in Step 4 involves propagating the parameter estimates through the computational process of inverting the model. It is indicated how this step can be accomplished using a generalized form [1] of the law of propagation of uncertainty in the GUM [3]. The uncertainty associated with $h$ is then readily obtained.

We also consider the use of the propagation of distributions, as implemented by a Monte Carlo method [4], in order to determine the adequacy of the GUM uncertainty framework for this problem.

The uncertainties obtained in Stage A relate to limits specified in IEC 61267:2005 on values obtained for $A(d_i)/A(0)$ and $h$, and provide a means for the acceptability of those values. It would also be possible to establish a criterion for the HVL values.

The methodology presented will contribute to a better characterization of RQR and thus to improved metrological management of dosimeters used for diagnostic radiology methods. The radiation dose delivered to patients should follow the ALARP (As Low as Reasonably Practicable) principle and accurate measurements of dose are crucial for this purpose.

REFERENCES


MODEL-BASED RECONSTRUCTION IN MEASURING SYSTEMS FOR RECKONING AND CONTROLLING OF ENERGY DISTRIBUTION GRIDS

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Abstract
The establishment of a sustainable energy supply, efficient generation, transmission and distribution, as well as efficient consumption pose one of the grand challenges and technological trends of today and the decades to come. Especially the intensified exploitation of renewable energy sources like solar energy, wind energy or the fuel and gas generation from biomass and its feeding in the energy grids make high demands on both, grid stability, efficient capacity use and accurate metering and billing. Proper controlling of the energy grids means to almost completely understand their performance, behavior, and state. This requires coping with an appropriate modeling of both the energy grid, i.e., electricity or gas grid, and the fitted (distributed) measuring network. Only this information allows for a model-based description and reconstruction of the (time-dependent and distributed) state of the grid and therefore, for determining the relevant parameters needed for ensuring grid safety and stability as well as for correct metering. As a matter of course, the quality of all estimates made should be represented by a degree of belief or an uncertainty.

This paper describes the metrological challenges resulting from the (smart) energy grids of the (near) future and identifies the most relevant state and quality parameters for proper controlling and efficiently utilizing the energy
grids. The mathematical and modeling problems to be solved are identified along with a brief survey of the existing mathematical approaches.

One promising approach for a model-based reconstruction and prediction of distributed phenomena and its application to energy-grid reckoning is considered in more detail: It utilizes partial differential equations for modeling the considered systems. The novelty of the proposed reconstruction method is the systematic approach developed and the consideration of uncertainties resulting from (naturally) imperfect measurement results and/or under-instrumentation of the grid observed. The described approach makes it possible to reconstruct the complete density function (belief) of the state (of the grid), which characterizes the entire distributed phenomenon. In particular, it is demonstrated how the partial differential equation for the distributed-parameter system is spatially and temporally decomposed leading to a lumped-parameter finite-dimensional system in state-space form. Based on this form, both classical estimators, e.g., Kalman filters, and more advanced estimation/filter approaches, e.g., covariance bound filters, can directly be applied to estimate the solution of the underlying partial differential equation. Especially the use of advanced estimators allows for GUM-compliant consideration of systematic effects in “uncertainty propagation”.

Additionally, based on this solution, a method for optimal sensor placement is suggested. The applicability of the methods proposed is, in principle, demonstrated with an example of a gas-grid reconstruction.

Finally, challenges of the treatment of nonlinear systems and problems of decentralized information fusion, necessary, for example, for large sensor networks, are stated.
Vibration damping using laser vibrometry investigated with the ANOVA method

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Keywords: Laser vibrometry, damping, vibration, ANOVA.

In this abstract we present the effects of a free oscillating pendulum on the damping vibrations of a panel embedded at one of its ends (Deciu 2001). The results of the study are of interest as they can provide useful data to implement counter-measures in order to reduce the earth-quakes impact on old buildings. According to our paper, a building wall is assimilated with the embedded panel subject to periodical vibrations, so predictions on infrastructure deformations under external excitation can be modelled (Bougard 1998).

In our case, on a panel about 18x20 cm, with one fixed end, a pendulum having the weight of $mg$ and $l$ length is hanged at a distance $q(t)$ from the panel plane.

Previous studies have investigated the damping properties of the oscillating pendulum by evaluation the pendulum mass movement. The previous model investigated the panel movement by studying the pendulum angular elongation in time - $\theta(t)$. The novelty of our approach is provided by the evaluation of the panel movement using the 1D scanning laser vibrometry. In this way, the panel vibration is measured directly, while the pendulum is used only as a damping element.

In our experiment, the pendulum was fixed in three different positions based on the model indicated in Figure 1.

Figure 1. The theoretical model of the damping effect introduced by a pendulum.
The studied tests include the use of different masses (0, 7.681, 14.191 g), positions (a number of 3) and lengths for the pendulum wire (7, 9, 11 cm), in order to assess its influence in damping the panel vibrations. The considered type of material for the investigation was aluminium (0.3 mm thickness).

In order to optimize our number of experiments we are going to use the Latin squares method (3x3) from the design of experiments theory. The final number of experiments is going to be $3 \times 3^2$ instead of $3 \times 3^3$ as we are going to repeat our measurements three times. The most significant factors are studied with the Analysis of Variance method (ANOVA) Two factor with and without replication, respectively.

![Figure 2. The set-up of the damping effect introduced by a pendulum with the three studied positions.](image)

The vibration modes of different panels were measured with the Polytec Scanning Vibrometer PSV-3D. In the 1D scanning mode, the system makes possible the mapping of the vibrating surface. This is done by estimating the temporal variation of the velocity vector over a user predefined grid. In our case, 11 x 11 testing points were used.

In order to evaluate the temporal variation of the panel vibrations in each testing point the panels were excited with acoustic waves generated by a loudspeaker, the acoustic source being excited by the internal generator of the PSV-3D. The system allows also the FFT analysis of the acquired date in each investigated point. A sinusoidal signal with the frequency of 50 Hz having an 3 (a.u.) amplitude was selected.

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Testing AUTOSAR software components with QuickCheck

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Software is getting more and more complex and traditional and manually created test cases are too costly and cumbersome to create for industrial size software projects. Within the AUTOSAR consortium, effort have been made to create a conformance test suite for software components for cars.

Creating models of the system and automatically generating test cases from these models is a more effective way of testing these large, well specified software systems. We applied the model based testing tool QuickCheck to demonstrate this effectiveness by modelling three components specified in 1500 pages AUTOSAR standard.

Keywords: Software Testing; Model Based Testing; AUTOSAR; QuickCheck

Extended Abstract

The increasing complexity and size of software in modern consumer products makes it harder to test with traditional techniques.

Standard software platforms, such as AUTOSAR,¹ allow car companies to share and reduce development cost. The AUTOSAR standard prescribes in detail how the software should behave in a car, such that the thirty or more computing units in the vehicle can reliably work together, share information and respond with correct data when asked for.

The AUTOSAR standard allows a lot of features to be configured, enabled, disabled or just parametrized for a certain purpose. The configuration is input for the compilation tools, thus, depending on the configuration the compiled software is different. That is, no two car models have the same
software in all on-board computers. How then, does one test the software?

One could write manual test cases, which the AUTOSAR consortium has been doing. These tests apply to one module at a time, for example, the CAN communication stack consists of seven modules, the tests focus on each of the layers, not on the stack as a whole. All these tests depend on a configuration. Often these configurations are small and specific for the feature under test, such that people can read the test and its configuration to understand what is tested. A test for routing a signal needs a configuration with one or two signals, a sender and a receiver. In the real software there are far more signals, senders and receivers and undoubtedly these signals differ in one way or the other from the simple configuration in a conformance test. Therefore, this kind of testing leaves a lot untested.

We use QuickCheck\(^2\) with its roots in academia\(^3\) and an application track record in the telecommunication industry.\(^4\) With QuickCheck we build models of clusters, which are a number of modules that logically belong together, for example a CAN stack, a FlexRay stack, or the Com and PDU Router modules in AUTOSAR. QuickCheck takes a model and a configuration file as input and generates tests that respect that specific configuration. We use the configuration that a car manufacturer actually uses in the car, a huge but realistic configuration. From this we automatically generated and executed thousands of tests. Writing the model is less effort than writing a large test suite by hand. In addition, we test many features at once in the generated tests. We also always have all assertions present in each test, which made us find a number of errors that had slipped in traditional testing.

We applied our model to the software of a number of vendors and detected anomalies in each of them.

References

The paper describes a PC application which can be used for calibration/verification of the electronic balances. The application is friendly used, complex and safe application. It realizes the necessary functions for calculating the errors of indication and associated measurement uncertainties giving also information regarding the fact that the results are (or not) within the maximum permissible errors.

Also, the application offers the possibility to calculate from the discrete values obtained at calibration the approximated error, together with uncertainty associated.

Some of the advantages of the application are:

- the well known Excel procedure is easy to use;
- the same interface for calibration an verification is used; it is possible to select which of them is performed. In the case when the calibration is chosen, the interface contains tables with specific tests which are normally performed in calibration. (the same happens in the case of verification).
- the loads can be chosen by the operator, or can be automatically selected from a list. In this latter case, calibration /the verification will be started after the initial generation of a table (that will contain the loads where the tests are performed); thus, the conventional mass value of the weights (together with uncertainty of measurement) automatically appear;
- depending on the maximum weighing capacity, the loads used are automatically filled for:
  - the repeatability of indications;
  - the errors of indications;
  - the effect of eccentric application of a load on the indication;
  - Tare effect.
- marking out when the results are accepted or rejected;
- calculation from the discrete values obtained at calibration, errors and assigned uncertainties for any other reading within the calibrated weighing range;
- the possibility to stock in the data base all the data, including the results of the calibration/verification. These can be visualized and printed at any time;
- to protect and save the electronically stored records and to prevent the unauthorized access to these records, the application meets a specific procedure, according to [3].

The document contains detailed examples of the calculation.

It was used a brief presentation of the application, following that in the full paper be done a more detailed description.

References

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APPLICATION OF THE UNCERTAINTY THEORY IN THE LEAK TESTING OF THE SPACECRAFT

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Leak testing is the necessary means in order to assure the sealing character of the spacecraft, so it is very important for the manufacture of the spacecraft. At present, the helium mass spectrum leak testing method is usually adopted for the leak testing of the spacecraft in China. It often includes the sniffing probe method, the non-vacuum accumulation method, the vacuum chamber method and so on, which were widely used in the manufacture process of the spacecraft. But until now, the leak testing results were only given with these methods, and the uncertainties of these results were not considered, which is imperfect from the measurement view point. So it is necessary to evaluate the uncertainty of the leak testing result. The uniform mathematical model of the measurement was firstly provided here so as to evaluate the uncertainty, according to the general character of these methods. Secondly, two detail mathematical model of the measurement were divided from the uniform model and their detail evaluated processes were also given respectively in which the correlation coefficient was emphatically discussed. Thirdly, the uncertainty component induced by the random effect was researched when the single measurement occurred. Finally, a detail example was given so as to illustrate the uncertainty evaluated process of the uniform mathematical model. The conclusion obtained here may be useful for the uncertainty evaluation on the leak testing result of the spacecraft.
Evaluation and numerical presentation of the results of multidimensional indirect measurements - outline of the theoretical backgrounds

Extended Abstract

This publication is a brief introduction to the principles of the correct numerical expression and evaluation of multi-parameter measurement results. It provides the theoretical basis of determining the estimates, their uncertainties and correlation coefficients of the indirectly obtained multi-measurand processed from data of the simultaneously measured variables. The algebra of random vectors is used. Numerical examples illustrate the linear transformation of two variables and the types of improperly evaluated results - that may occur with over-rounding. Possibility of application above considerations in measurement and in upgrading GUM-2008 and CODATA publications is considered in the second paper.

Key-words: uncertainty, indirect multidimensional measurements, multi-measurand, correlated data

Simultaneous measurements of several statistically related quantities, i.e. correlated are performed in science, education, technology and many other disciplines of economy. From the digitally processed on- or off-line data of m variables directly measured on input the n other variables are determined indirectly on output if are known their mutual dependencies. Additionally to estimators of values and uncertainty knowledge about correlation coefficients of output quantities is especially important, when several of these variables, or all of them can be farer jointly processed. Issues considered in this work as a joint product of physicist and metrologist [3] are:

• How "safely" rounding the processed original multidimensional data of measurements in such way that would not damage them - assuming that initial data are considered as been perfectly obtained? (V. E.)
• How finally to round multi-measurand output data in relation to a designated uncertainty of input data? (Z. W.)

In indirect multi-dimensional measurements there are two border types of the uncertainty $u_A$ and $u_B$ relations [1].

First case: uncertainty $u_A < u_B$. In such situation it is enough to provide the necessary instrumental resolution and accuracy of input values and determine cross-links to the output values.

Second case: $u_A > u_B$. Should be taken care to achieve maximum accuracy in measurements of mean values and of standard deviations and correlation coefficients of output quantities, i.e. that the information gained in the experiment is not partially lost in the processing of the random input data and in the rounding obtained results. Carefully have to be eliminating all effects interacting on input measurements up to the uncertainty of type B be lower compared to the range of random scatter of the results of individual measurements. Made up are also as large as possible numbers of observations to minimize the statistical type uncertainty $u_A$ and its uncertainty. Accuracy of estimates of output multi-measurand data depends on the statistical uncertainties of given parameters of input multi-measurand and on the accuracy of its the processing.

Input multi-measurand can be expressed by random vector $X = [X_1, X_2, ..., X_m]$ and output multi-measurand as $Y = [Y_1, Y_2, ..., Y_n]$ (in physics variables $Y_i$ are named as observables). These vectors of dimensions $m$ and $n$ respectively describe the multi-dimensional normal distributions of both measurands. Their relation is presented by

$$X = F Y$$

For a linear operator $F$ there is $n \leq m$. In the case of nonlinear $F$ number $n$ of relations may be arbitrary.

The basic structure of the numerical estimation of multi-measurand should contain an average components of the random vector and a description of the multidimensional scatter region. If this region can be defined by the joint $n$-dimensional probability distribution, then for given probability density $p(X_1, ..., X_m)$ of $n$-dimensional normal distribution such area is $n$-dimensional hyper-ellipsoid with its center at the end of the average vector. For standard deviation it is internally tangential to sides of the $n$-rectangular prism $\pm(\sigma_1, ..., \sigma_m)$. Covariance matrices of hyper-ellipsoids of the output and input multi-measurands are connected analytically by relation

$$c_y = S c_x S^T$$

Where: $S = \partial Y / \partial X$ is matrix of sensitivity coefficients).

The matrix $r$ of the correlation coefficients defined by the relation $c = \sigma c \sigma^T$ is called the correlator. If multidimensional distribution model have to be normal then matrices $c$ and $r$ should be positively defined, i.e. their eigenvalues $\lambda_n$, which are roots of the characteristic equation $det [A - \lambda I] = 0$ for any matrix $A$, should be positive.
[3]. This requirement was not yet given in GUM [1] and other metrological guides. So, to express correctly the result of measuring or evaluating vector quantity the **minimal data structure** should contain [2, 3]:

- **Mean vector**,
- **Vector of standard deviations and their uncertainty (or numbers of measurements)**,
- **Positive definite correlation matrix, i.e. with minimal eigenvalue higher than null**, and
- **Machine precision used to compute vector parameters and eigenvalues of correlation matrix**.

With these data the user will have complete information to plan and control the safe usage of data in computations.

On Fig 1 is shown some example of linear transformation of two dimension (2D) “Greek” vector \( X = [\eta, \zeta] \) to “Latin” vector \( Y = [x, y] \). Basic equations are given in Table 1 and typical distortions of output data are on Fig 2.

![Linear transformation of „Greek” random vector \([\zeta, \eta]^T\) with horizontal scatter region to „Latin” random vector \([x, y]^T\)](image)

**Fig 1.** Linear transformation of the 2D random vector.

![Cases of improper presentation of correlated 2D data](image)

**Fig 2.** Cases of improper presentation of correlated 2D data.

### Table 1. Basic formulas of the 2D random vector transformations

<table>
<thead>
<tr>
<th>( \zeta )</th>
<th>( \eta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 1 )</td>
<td>( 1 )</td>
</tr>
<tr>
<td>( 1 )</td>
<td>( -1 )</td>
</tr>
<tr>
<td>( \zeta )</td>
<td>( \eta )</td>
</tr>
<tr>
<td>( \zeta \sigma_x )</td>
<td>( \eta \sigma_y )</td>
</tr>
<tr>
<td>( \zeta \sigma_x )</td>
<td>( \eta \sigma_y )</td>
</tr>
</tbody>
</table>

**Rounding of the result of** \( Y = [1.845(100); 1.155(100)] \), \( \rho_{xy} = 0.9998 \) and Mahanolobis distance \( \chi \) between the center of ellipse of transformed original raw data and end of vector \( Y \) (to ellipse border \( \chi = 1 \)) given by

\[
\chi^2 = \Delta Y \frac{1}{\sigma, \sigma} r(x, y)^{-1} \Delta Y^T
\]

- Rounding to 2 digits after decimal point: \( Y_1 = [1.84(10); 1.16(10)] \); \( \Delta Y_1 = Y_1 - Y = [-0.005; 0.005] \); \( \chi^2 = 25 > 1 \)
- Rounding to 1 digit after decimal point: \( Y_2 = [1.8(10); 1.16(10)] \); \( \Delta Y_2 = Y_2 - Y = [-0.045; 0.045] \); \( \chi^2 = 2500 > 1 \)

In both cases result is over-rounded as the vector end is laying outside of the ellipse of the transformed original not rounded input data.

**Conclusion**

From above short considerations it is clear that standards of rounding procedures for multivariate data are more complicated than for scalars and are urgently needed. Rounding limitations should be established not only for output data parameters when input data are considered as fully accurate – e.g. as data of the whole random population but also when standard deviations and correlation coefficients obtained from measurement samples of limited number \( N \) of multivariate observations have their own not negligible uncertainties.

**Literature** (selected)

Some upgrading suggested in Guide GUM and CODATA, Proposal of the double form publication of the experimental data

Abstract. In this paper considered are: thresholds of the safe uniform rounding of matrix elements of random vectors, suggested order of Taylor polynomials for nonlinear vector function approximation, upgrading of the GUM Example H2 and equation for the uncertainty of nonlinear functions, mistakes in data of basic physical constancies recommended by CODATA and proposal of the experimental data publication in double form - on paper and by e-publishing.

Thresholds of the safe uniform rounding of elements of transformed multivariate data

From spectral theorems of matrix theory V. Ezhela obtained thresholds of the safe independent uniform rounding of the random vector parameters after transformation, all expressed in decimal numbers, i.e.:

For standard deviations $U_i$ of vector components $V_i$, $A'_i \geq A''_{ih} = \text{Upper Integ} \left\{ \frac{1}{2} \log_{10} \left( \frac{n}{2 \lambda_{\text{min}} T_{CL}^2 U_i \text{unit}} \right) \right\}$

For values of the components $V_i$ of the average vector $A'_i \geq A''_{ih} = A''_{ih}$

For elements of the correlation matrix $A^c \geq A^c_{ih} = \text{Upper Integ} \left\{ \log_{10} \left( \frac{n-1}{2 \lambda_{\text{min}}} \right) \right\}$

Where: $\lambda_{\text{min}}$ - minimal eigenvalue of the correlation matrix, $T_{CL}^2$ - “tolerance” factor at defined confidence level.

In case of the nonlinear processing of input vector the widely used differential “linear uncertainty propagation law” does not work. The nonlinear uncertainty propagation should be used with the obligatory positivity constraints

$$C_i = [\delta C_m, \delta C_k]$$

$$F_i(C_i) = [\delta F_m, \delta F_n]$$

COMPONENT of X (input)                     COMPONENT of Y (output)

$$[\delta F, \delta F] = \sum_{i=k}^{m} \frac{1}{k!} \frac{\partial^k F_i}{\partial x_m \cdots \partial x_n} (\delta x_m, \cdots, \delta x_n)$$

Covariance matrix $[\delta F_m, \delta F_n]$ is non-degenerate and positive definite if dimensions $\text{dim}(C)=m$, $\text{dim}(F_i)=n$ and the order $T$ of the approximation the measuring vector function $F_i$ by Taylor polynomials obey the inequality:

$$n \leq n_{ih} = \frac{(m+T)!}{m!T!} - 1$$

Notice about GUM clauses connected with multidimensional measured data

All official metrological documents and guides aimed to establish the uniformity of measurements and to create commonly accepted standards for measured data quality are applicable to "one measured" quantity only. (Supplement 2 is now still on the draft level). But statements of the GUM [1] are formulated in such a manner that reader get the impression that generalization to the multivariate case is straightforward. Will be considered in detail Example H.2 which illustrates clauses 7.2.5 and 7.2.6.

There are given five raw simultaneous measurements of input vector $X = [U, J, \Phi]^T$ in Table H.2 and it is needed to evaluate vector $Y = R = (U/J) \cos \Phi, X = (U/J) \sin \Phi, Z = U/J$ T. Results obtained in Example H.2 GUM are given in Tables H.3 and H.4. Rounding of correlation coefficients is not properly done in GUM as the smallest eigenvalue of correlator matrix is negative and then the scatter region is not of the 3D-ellipsoid type. Also final output data of Example H.2 not satisfied "physical low" of impedance element $X^2 + Y^2 = Z^2$ ($\sigma^2 = -71.57$) [2, 4].

If for establishing requirements of digital processing purposes the input multivariate measured data of H.2 Example can be treated as fully accurate, then for the such theoretical case thresholds of digit numbers after decimal point are as follow: for mean values and standard uncertainty of $R$ and $Z$ - 5 digits, of $X$ - 4 digits and for cor-
relation coefficients 8 digits! [2, 3, 4]. Such large numbers of digits can not be accepted in reality and can be used only as reference valid for the random multivariate data population with statistical parameters similar as for samples of H.2 Example. This numbers are so high according assumptions that: input data are treated as fully accurate, numerical results of processing are safety and uniformly rounded and vector is maintained in the scattered area of the transformed original input data. But for the sample of input vector X from Table H.2 GUM with \( N=5! \) measurements only the uncertainty of each SD value and of correlator elements is very high, e.g. about 36% for SD - Table E1 in GUM. So, farer rounding below above thresholds valid only for digital processing has to be done. Two methods of such rounding are tested for data of Example H.2:

- **Method 1** (by ZLW) - to maintain a constant values of no-diagonal elements \( \sigma_i \sigma_j k_{ij} \) of the positive defined covariance matrix, i.e.:

\[
\begin{align*}
    k_{xx} &= \frac{\sigma_x \sigma_x}{\sigma_x^2} k_{xx} \\
    k_{xz} &= \frac{\sigma_z \sigma_x}{\sigma_z^2} k_{xz} \\
    k_{xz} &= \frac{\sigma_z \sigma_z}{\sigma_z^2} k_{xz}
\end{align*}
\]

Where: signs in the upper index indicates the direction of change.

- **Method 2** (by V.E.) - decline further digits after the last accepted.

Method 2 gives a smaller Mahalanobis distance of the vector end from original ellipse center, but the smallest eigenvalue is closer to zero than in method 1. Correlator keeps positive definition, but there are no theoretical justification jet. **Conclusion**: rounding level of output vector Y mainly depends on the uncertainty of vector X parameters.

### Upgrading the ISO GUM formula 5.1.2 on nonlinear uncertainty propagation

For the determination of uncertainty of non-linear function \( y=f(X) \) in the Notice to clause 5.1.2 of GUM [1] is recommended that the linear propagation of variance have to be supplemented by higher-order components, i.e.:

\[
u_i^2(j) = \sum_{k=2}^{N} \left( \frac{\partial f}{\partial x_k} \right)^2 u_i^2(x_k) + \sum_{k=2}^{N} \sum_{l=2}^{N} \left[ \frac{1}{2} \left( \frac{\partial f}{\partial x_k} \frac{\partial f}{\partial x_l} \right)^2 + \frac{\partial f}{\partial x_k} \frac{\partial^2 f}{\partial x_l^2} \frac{\partial f}{\partial x_l} \right] u_i^2(x_k) u_l^2(x_l)
\]

Calculation of the variance \( u_i^2(j) \) according to this formula may give a false negative value. This will be illustrated by the example from [3] and [4]. A component in parentheses with the third derivative is not needed.

So, clause 5.1.2 of GUM should be also corrected by

**Notice about last data of Fundamental Physical Constants**

The adjustments of the fundamental physical constants (FPC) are regularly performed by the Fundamental Constants Data Center at NIST and recommended by CODATA as the unique source of the current FPC values. There are 325 adjusted quantities, from which 79 are called basic algebraically independent constants \( C_\alpha \). As example below are given values of selected four FPC in SI units together with their correlation matrix

**Reviews of Modern Physics**

<table>
<thead>
<tr>
<th>CODATA: 2006</th>
<th>Basic constant symbols are in red</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elementary charge</td>
<td>e ( = 1.602 176 66 ) ( \times ) 10(^{-19} )</td>
</tr>
<tr>
<td>Planck constant</td>
<td>( h ) ( = 6.626 068 96 ) ( \times ) 10(^{-34} )</td>
</tr>
<tr>
<td>Electron mass</td>
<td>( m_e ) ( = 9.109 382 75 ) ( \times ) 10(^{-31} )</td>
</tr>
<tr>
<td>1((\text{ specialized const.}))</td>
<td>( f ) ( = 100 ) ( \times ) 10(^{-31} )</td>
</tr>
</tbody>
</table>

Eigenvalues of above correlation matrix are: \( [2.99942, 1.00006, 0.000719993, -0.000202165] \). Last eigenvalue is negative. Only two of these constancies may be used together in common precision calculations. More - in paper.

### Final Conclusion

Traditional form of the scientific communications based on the paper oriented e-publications is not now the proper way to exchange the multidimensional experimental or observational data. Fortunately the e-publishing could offer the way-out. It seems that the transition to the two-component form of the scientific publication is unavoidable. First component will be the traditional descriptive scientific text already well formalized by editorial boards and publishers, but the second part should be the computer files associated with the first part. Some problems which should be solved for that will be discussed in full paper.

### Literature (selected)

3. Ezhela V.: Comments on some clauses of GUM which provoking the incorrect presentation of measured data in scientific literature. Proceedings of V Kongres Metrologii KM 2010, on CD. Technical University, Lodz Poland.

PROPERTIES OF COS² FUNCTION AS PROBABILITY DISTRIBUTION MODEL OF UNCERTAINTY EVALUATION

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Extended summary

The authors working on methods of measurement uncertainty evaluation noticed some possibilities for an unconventional distribution model of which range is limited. Distribution based on trigonometric shifted up cosine function seems to appropriate model for many application. General mathematical model of its pdf is given by (1) and graphic form is presented in Fig. 1.

\[ f(x) = B + A \cos 2\pi \frac{x}{X_T} \quad \text{for} \quad -X_T \leq x \leq X_T \quad (1) \]

Where: \( x \) – value representing actual value of quantity under observation, \( f(x)>0 \), \( X_T \) – range of dispersion of observed values - equal to one period of cosines (1\( X_T \) as frequency in time functions), \( A, B \) - constant parameters.

The function \( f(x) \) is shifted up one period of cosine function with a proposed symbol of distribution: +COS. The function given by (1) of which \( A=B \) is \( \cos^2(x) \) if \( f(x)>0 \) and in the is range of \( \pm(X \leq 0.5X_T) \) if the area under curve (1) \( 2BX_T=1 \) then such a function might be regarded as model of the probability density function, PDF of distribution called COS².

![Figure 1](image)

Figure 1 PDF distributions: 1 – Normalized Gauss \( N(0,1) \) (i.e. \( \sigma=1 \)) and three tangential to axe x functions of \( A(1+\cos2\pi Ax) \): 2 - passing through the top point of Gauss PDF, 3 - of which standard deviation \( \sigma_{\cos}=1 \), 4 - the Green proposal \( f_{GR}(x) \) [7].

The properties of +COS distribution for various \( A, B, X_T \) are analyzed very detailed in a full paper. First of all different variants of +COS and COS² distribution was compared to a Normal distribution 1 in fig.1, used in GUM [1] and also to one of functions cos² which in 1961 was mentioned in journal Psychometrika by Raab and Green [2] called here as Green function (presented also in Fig 1).
In the full paper comparisons and quantitative differences of PDFs CPDFs of several variants of the unconventional model vs. Normal distribution are listed in tabular and graphical forms. One of the very important conclusion is that COS² distribution can approximate Normal distribution in the range ±2,5σ with accuracy ±2,1%.[3].

Further considerations were concentrated on real applications of COS² and their advantages and disadvantages. One of the advantage of COS² model is that operates over a define and limited range of measurement data spreading. COS² distribution better fits to collected data. It is find that Kolgomorov-Smirnov test definitely is more appropriate than χ² for properly choosing COS² distribution for sample data. Test χ² even is not recommended at all in this case.

Very important advantage of COS² model is simplification of mathematical operations, so procedures are easier implemented in embedded systems which are now more often used as part of intelligent sensor system or stand alone measuring devices.

Authors in this extended summary would emphasises one of few tested examples which refers to synchronization of frequency generator for telecommunication. COS² distribution characterized better than Normal dispersion the stability of cesium quartz clocks. The test referred to a cesium oscillator of accuracy of 5.0 E-12. Measurements were performed at intervals of 2 hours. Deviations from the mean value 2.048 MHz are shown in Figure 2. From 281 observations only two were excluded, the remaining 279 were subjected to further processing. In the collected results no influence of periodic or aperiodic trends were found and no autocorrelation was observed. Figure 3 shows the histogram and two approximating models: the conventional Gauss-function and function COS². Table 1 contains comparison of uncertainty comparison of standard generator frequency obtained for Gaussian and COS² models.

![Fig. 2. Apparent errors of generators frequency vs. time.](image)

![Fig. 3. a. Histogram of apparent errors and relevant Gaussian and COS² models calculated based on minimal square error method.](image)

<table>
<thead>
<tr>
<th>p</th>
<th>kυUr²</th>
<th>Uυcos² [Hz]</th>
<th>ketasn</th>
<th>Uetasn [Hz]</th>
<th>Δ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.265</td>
<td>2.08E-06</td>
<td>0.675</td>
<td>2.38E-06</td>
<td>15</td>
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<td>0.683</td>
<td>0.385</td>
<td>3.02E-06</td>
<td>1.65</td>
<td>3.53E-06</td>
<td>17</td>
</tr>
<tr>
<td>0.9</td>
<td>0.596</td>
<td>4.67E-06</td>
<td>1.65</td>
<td>5.89E-06</td>
<td>24</td>
</tr>
<tr>
<td>0.95</td>
<td>0.683</td>
<td>5.35E-06</td>
<td>1.96</td>
<td>6.92E-06</td>
<td>29</td>
</tr>
<tr>
<td>0.99</td>
<td>0.816</td>
<td>6.40E-06</td>
<td>2.58</td>
<td>9.09E-06</td>
<td>41</td>
</tr>
<tr>
<td>0.997</td>
<td>0.878</td>
<td>6.88E-06</td>
<td>2.97</td>
<td>1.05E-05</td>
<td>52</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>7.84E-06</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It is a very good symptom for a development of unconventional distribution COS² model, that the cosinusoidal model of probability distribution is quoted in just recently approved (on 2010-07-13) ANNEX 3 for “The Measurement Uncertainty Analysis Principles and Methods NASA Measurement Quality Assurance Handbook”[4].

**Selected references**

3. Warsza Z.L., Koczynski M.J., Galovska, shifted up cosine function as model of probability distribution IMEKO World Congress Fundamental and Applied Metrology September 6–11, 2009, Lisbon, Portugal paper No 530
Methods of Research of Electromagnetic Flowmeters for Reynolds Numbers of Order of 2000-5000.

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Abstract
One of the most valuable features of electromagnetic flowmeters consists that their metrological characteristic depend on density, viscosity and temperature of the measured environment a little. Therefore, it is possible to apply a flowmeter, tested on water at normal temperature, to measurement of the flow of the various conducting liquids in various operating conditions. In other words the factor of transformation of the expense practically does not depend on Reynolds's number.
However for flowmeters, at which the range of Re numbers of 2000-5000 is related to the normalized portion of the characteristic, not always it is possible to provide independence of readings from the Reynolds number. In this range, as it is known, there is a reorganisation of kinematic structure of a flow from developed turbulent to laminar modes.
To supply the necessary properties of a flowmeter there should be a certain structure of a magnetic field in the channel.
The experimental researches of the flowmeters at Re numbers of 2000-5000 in natural conditions present considerable difficulties.
In the report two methods of researches without application down-pour plants are considered: by means of numerical simulation on the COMPUTER and by means of application of special equipment.
The first method consists in measurement of function of distribution of a magnetic field of a flowmeter and calculation of its metrological characteristic at laminar, transitive and turbulent distribution of velocity of a flow in the channel.
The software package of calculations is developed and results of experimental researches of flowmeters of firm "ТБНЭНЕРГОСЕРВИС" are presented.
The second method provides measurement of a magnetic field by means of two special flat printing induction coils. Coils of one of them reflect superficial function of a flowmeter at a laminar mode, and another, accordingly at a turbulent mode. Analytical expressions of superficial weight functions, schemes and designs of induction coils and results of experiments are presented.
A NOVEL METHOD FOR AN AUTOMATED ANALYSIS OF A MEASUREMENT SCENE

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Extended Abstract:
A common task in applications of optical measurement technology is to analyze complex measurement scenes and find sensible measurement evaluation techniques for it. This task introduces two major problems: First of all the measurement results strongly depend on the user’s knowledge and experience due to the user's direct influence. Hence the objectivity of the measurement is often very limited. Second of all the potentially high variability of a measurement scene complicates an automated analysis.

This paper proposes a method, which reduces the user’s influence by preselecting measurement requirements and thus advance handling. This is done using combinations of existing geometrical features like lines and circles effectively simplifying the complex measuring chain. The detection of the required geometrical elements is a prerequisite. They could for example be extracted from a silhouette of a measurement object using contour tracing and a feature extraction algorithm for contour points.

These calculation rules, named ‘Measurement Tasks’, need to be adapted regarding their number and specifics to the measuring process they are supposed to be used in. Each Measurement Task requires a fixed number of geometrical features as input to generate a vector of results. For instance, possible results might be properties of one element (radius of a circle, orientation of a line) or combinations of several elements (intersection points of lines, distance between two elements).

The concept and usage of Measurement Tasks reduces the number of possible measurement results from near infinity to a manageable number. Thereby, the
choice of measurement strategy is constrained by existence and number of certain geometrical elements. If this method is used to assist during the development of an inspection plan for quality control or a measuring strategy all applicable Measurement Tasks are simply presented to the user. In this scenario the workflow can be enhanced further by priority based preselection, reduction in number of Measurement Tasks or restrictions concerning valid combinations.

If the users influence is to be eliminated entirely an automated selection of a subset of usable Measurement Tasks must be performed. Besides the execution of all applicable Measurement Tasks selecting one or more of these based on priority is also feasible. Assuming there is no clear correlation between Measurement Tasks and the number and type of geometrical elements found in measurement scene, their properties can also be utilized for selection of Measurement Tasks. The Measurement Task applied to circles can for example depend on their radii, the evaluation of lines can be determined by their angle, length and so on. Furthermore, with these properties a fine selection of Measurement Tasks can be performed exactly. Even the application of machine learning techniques for automated selection is conceivable.

In case of detecting too many elements in one scene the field of measurement needs to be limited by setting a defined area of interest (AOI) in order to easily find the correct correlations. By saving position and size of the AOI the measurement can then easily be repeated several times with the correct Measurement Task. This leads to advance handling and a better repetitious accuracy of measurement while time consuming user interaction is reduced significantly.
1. Abstract

Modern industry requires the presence of several kinds of sensors for system measure and control. New sensors of increasing complexity are constantly being developed, and the increasing engineering brings very hi-tech sensors, often non-linear, capable of more than a single input and single output. A problem which gains more and more importance for sensors like these is calibration. Classic linear calibration procedures, when applied to this extremely engineered sensors, lend to poor accuracy and are generally not satisfying at all.

Object of this paper is the definition of an algorithm using radial basis functions (RBF) and Nelder-Mead simplex method for multi-dimensional interpolation of data clouds and so for the determination of the calibration diagram for multi input - one output measurement device. A radial basis function (RBF) is a real-valued function whose value depends only on the distance from the origin, so that

\[ \varphi(x) \sim \varphi(\|x\|) \]

or alternatively on the distance from some other point \( c \), called a center, so that

\[ \varphi(x, c) \sim \varphi(x - c) \]
Any function $\phi$ that satisfies this property is a radial function. The norm is usually Euclidean distance, although other distance functions are also possible. Assuming $r = \|x - c\|$ and $\sigma$ being an additional parameter, commonly used types of radial basis functions are:

- **Linear**
  \[ \phi(r) = r \]

- **Gaussian**
  \[ \phi(r) = e^{-r^2/\sigma^2} \]

- **Multi-quadratic**
  \[ \phi(r) = \sqrt{r^2 + \sigma^2} \]

Given $N$ data points $\{x_1, x_2, ..., x_N\}$ in a $M$-dimensional environment, and values $\{y_1, y_2, ..., y_N\}$, the purpose of the algorithm is to approximate this data cloud with the real function:

\[ y \approx y_0 + w \cdot \vec{x} + \sum_{i=1}^{L} \alpha_i \cdot \phi_i (c_i, \vec{x}) \]

where the approximating function $y \approx y_0$ is represented as a sum of a polynomial (linear) part and the sum of $L$ radial basis functions, each associated with a different center (node) $c_i$ and weighted by an appropriate coefficient $\alpha_i$.

The weights $\alpha_i$ can be estimated using the methods of Linear Least Squares, because the approximating function is linear in the weights.

When no starting guess for nodes are given in input, nodes coordinates are the output of a non-linear optimizer using the Nelder-Mead simplex method, whose goal is to locally minimize the objective function:

\[ \sigma_0^2 = \frac{\sum_{k=1}^{N} \| x_k - y_k \| \approx y_k \|}{N - L} \]

For each iteration the number of nodes is increased by one, placing a new node, and the algorithm stops itself whenever it reaches a certain tolerance level, a user-specified number of nodes or when the previous iteration has a better value of the objective function.

In this paper will be presented how a differential (for various RBF classes) application of this method has been used for a two-dimensional contactless position sensor – a photodiode – capable of measure the two coordinates of a laser-light point hitting his square surface. In this way metrological behaviors, in terms of accuracy, of the sensor has been increase instead of classical linear calibration model traditionally used.
MEASUREMENT UNCERTAINTY AND PROCEDURES OF CONFORMITY ASSESSMENT

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(Abstract of a submission for oral presentation at AMCTM2011)

The area of conformity assessment is currently attracting the attention of measurement scientists. The relevant area of statistical analysis is that of ‘acceptance sampling’, where a population (batch) of goods is subjected to a pass/fail procedure, uncertainty of measurement is deemed negligible and all uncertainty is deemed to arise because of the finite nature of the sample taken from the population. This talk will consider the treatment of non-zero measurement uncertainty in that context and in the context where the population and sample are of size one, i.e. where products are accepted or rejected individually.

If the idea of measurement uncertainty is to feature in conformity assessment then questions that must be addressed include:

- What should producers of goods and consumers of goods be able to expect from a conformity-assessment procedure?
- Should the doubt that is represented by the measurement uncertainty act in favour of the producer or the consumer?
- Should the producer be disadvantaged because a measuring authority acting on behalf of the consumer uses a technique with large uncertainty?
- Should the producer’s own pre-submission test of quality carry any weight in the conformity-assessment procedure?
- Are there different types of conformity assessment requiring different treatments of measurement uncertainty?
- Is the test for acceptance of a claim about quality or for verification of
this claim – acceptance and verification being different things?

- Conformity assessment exists to ensure that a product is fit for purpose. Can an assessment procedure be employed without this procedure itself being shown fit for purpose?

The overarching question is:

How compatible are modern notions of measurement uncertainty with the requirements of conformity assessment as perceived by the producers and consumers of the goods?
The Guide to the Expression of uncertainty in measurement (GUM, [1]) has become widely accepted in metrology for evaluating measurement uncertainty. While the GUM is based on the concept of propagating uncertainties using a linearized model function, the recent Supplement 1 to the GUM (GUM S1, [2]) utilizes a Monte Carlo method (MCM) for the numerical calculation of a probability density function (PDF) subsequently used for uncertainty evaluation. Advantages of the PDF approach are that nonlinearities of the model function are taken into account and that the distributional restrictions made in the GUM are not required. GUM S1 gains additional importance as it is recommended for the validation of results obtained by GUM.

Due to its stochastic nature (and in contrast to the GUM) a MCM result exhibits a (slight) variability when the calculation is repeated (with different random numbers). Therefore the results of an uncertainty evaluation utilizing MCM need to be accompanied by a statement regarding their quality. Adaptive Monte Carlo schemes can be used in this regard in order to determine the number of Monte Carlo trials required to achieve a prescribed numerical accuracy for a chosen confidence level. For these schemes the number of trials is
not specified in advance but determined by (periodically) applying a stopping rule during the Monte Carlo calculation.

GUM S1 describes one such adaptive scheme, which terminates the Monte Carlo calculation when various results of interests have stabilized in a statistical sense [2, clause 7.9]. As suggested in [2, clause 7.9], the standard deviation of the estimate and the standard deviation of the associated uncertainty are checked by the stopping rule simultaneously. It has been demonstrated recently [3] that the performance of the scheme underlying the adaptive GUM S1 procedure can be improved by utilizing a suitable factor from the t-distribution rather than the factor of two stated in GUM S1. The statistical theory underlying this improved variant is discussed in [4]. In this work this improved variant of the GUM S1 adaptive scheme is analyzed together with a recently proposed alternative adaptive scheme [3], which is based on a two-stage procedure [5].

For the performance assessment the adaptive schemes are repeatedly (10^5 times) applied to particular examples for which exact results are known. By subsequently analyzing the output obtained by the repeated application of the adaptive schemes it is checked whether the specified accuracy and confidence level are reached. On the basis of these examples, we demonstrate that while the improved GUM S1 adaptive scheme can fail in certain cases, the recently proposed alternative two-stage procedure achieves the specified accuracy at the chosen confidence level.

References
A COMPARISON METHOD USED FOR CALIBRATING LEAKAGE RATE OF HELIUM VACUUM REFERENCE LEAK AND COMBINED STANDARD UNCERTAINTY EVALUATION

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Leakage rate testing of helium vacuum reference leak is the comparison standard for the most basic, commonly used and also most sensitive helium mass spectrometry leak detector. It has the advantages of measuring quickly and exactly, which is very important on the product sealing performance. At present, there are two categories of calibrating methods for the reference leak. The first method is constant pressure and constant volume method, which are conducted under the lab condition, the other one is comparison method, which can not only be conducted in the lab but also in the scene.

Comparison method is to introduce the helium gas that flow from reference leak and the known quantity helium that from standard leak into a calibrating chamber, then measuring the ion flux using helium mass spectrometry leak detector when it works steadily. By comparing the test value of two ion flux, the leakage rate of reference leak can be calculated. The calibrating range for reference leak is from $1\times10^{-11}$Pam$^3$s$^{-1}$ to $1\times10^{-7}$Pam$^3$s$^{-1}$.

Factors that affecting the measurement deviation of comparison method are as follows: value of standard leak, linearity, stability and reading of helium mass spectrometry leak detector, environment condition, staff, etc. As for the same reference leak, when using the same calibrating method, we can adopt Gauss distributing statistics to get the calibrating uncertainty, and other uncertainty left are determined by the adjusting devices, the whole uncertainty of those can achieve to 10%.
TOOLS TO IMPROVE THE ESTIMATION OF THE CALIBRATION LINE AND THE CALCULATION OF FORECASTS

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Different methods are used to estimate the calibration line considering uncertainties on variables x and y. Among them, generalised least squares have two advantages: taking into account the heteroskedasticity of variables and generalising the ordinary least squares method widely used in metrology.

Nevertheless, the application of these methods to examples of the laboratory showed that the tools proposed in metrology publications do not allow to estimate efficiently the calibration line. They are essentially used for the calculation of the value of parameters and associated uncertainties. The validation of the results is tackled succinctly.

In order to guide the user, this article considers the three steps of the statistical estimation of a model - specification, estimation, validation – in the case of the calibration line.

For each step, the different options compatible with the metrological context are indicated and their meaning and consequences on the next steps are specified.

During the first step “Specification of the model”, the user selects a set of hypotheses a priori the most representative of his calibration data.

In the errors-in-variables model, used in this article, these hypotheses cover true variables, the statistical distribution of the errors and the model equation. Once the hypotheses are made, the user checks that his data set is coherent and sufficient to correctly estimate the specified model.

During the second step “Estimation of the model”, the user selects the appropriate method for his model and data.

To guide this choice, this study deals with the properties of different methods and lists some influence parameters. The influence of covariances on the parameters uncertainties is shown.

The difficulty to assign some uncertainties – on x or on y – is also considered.

During the last step “Validation of the model”, the user validates the estimation of the coefficients and the associated uncertainties.

The main tool used is the test of the adequacy between the uncertainties on variables (input data) and the deviations from the straight line (output data). In this article, we consider the two cases for inadequacy: input uncertainties are “more” or “less” important than the deviations of the straight line. Then, factors explaining the rejection of the test are suggested and solutions are proposed.

Other tools are also discussed : tests used in the ordinary least squares method, Monte Carlo simulations and the forecast of known values.
Then this article deals with the forecasts of a new value for $x$ or $y$.
The calculations are developed taking into account the distinction between mean and 
individual value, for the predictor and for the forecast value. The individual value has a 
supplementary term of uncertainty to propagate in the calculation.
We also discuss of the symmetry of the model and its influence on the inverse evaluation.

As a conclusion, the statistical model defined during step 1 is, generally, a presentation of the 
calibration line which is more accurate than the ordinary least squares model. In return, the 
metrologist must acquire more knowledge on its measurement process and modelling methods 
to analyse and estimate it.
The diffusion of detailed examples and operating processes from experience would allow to 
constitute a set of tools or procedures to use these metrological models efficiently.

Key words: calibration line, generalised least squares, uncertainty

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Linking the Results of CIPM and RMO Key Comparisons with Linear Trends

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The work of linking the results of International Committee for Weights and Measures (CIPM) and Regional Metrology Organization (RMO) key comparisons (KC)s is an important part of implementing the CIPM Mutual Recognition Arrangement (CIPM MRA) of the CIPM. Recently, several methodologies have been proposed to deal with the linkage problem. Delahaye and Witt (2002) proposed a practical method, which used an additive correction to link a CIPM KC of 10 pF capacitance standards to results obtained by a corresponding EUROMET comparison. A similar method was used to link key comparisons CCEM-K8 and EUROMET.EM.K8 by Marullo Reedtz and Cerri (2004). Elster, Link, and Wöger (2003) suggested a method based on a ratio correction, which can be applied when the results of the CIPM and the RMO comparisons are of different magnitude or different physical dimension. Nielsen (2002) and Sutton (2004) suggested combining the measurements from CIPM and RMO key comparisons by applying weighted least squares or generalized least-squares estimation. However, this approach will generate a completely new analysis, which obviously will influence the existing results. Kharitonov and Chunovkina (2006) and Decker, Steele, and Douglas (2008) have also discussed linking of CIPM and RMO key comparisons.

Zhang et al. (2004) proposed a statistical approach to KCs with linear trends. Later, Zhang et al. (2006) extended the results to the case of multiple artifacts. Discussions of key comparisons with trends can also be found in other papers. In this paper we propose a method to link the existing results from CIPM and RMO KCs both of which have linear trends.
We provide the statistical models and major results for key comparisons with linear trends based on the general case discussed in Zhang et al. (2009). The difference between the degrees of equivalence of the two comparisons is defined and used to establish the relationship between these two comparisons. An estimator of this quantity is proposed, and is used to estimate the degree of equivalence of a laboratory that participated only in the RMO KC, with respect to the key comparison reference value (KCRV) of the corresponding CIPM KC. Then, degrees of equivalence with their corresponding uncertainties, are established between pairs of National Metrology Institutes (NMIs) that only participated in one of the two comparisons. In this study we assume that the artifacts in the two KCs have the same nominal values or values of the same magnitude. When two comparisons have different nominal values, linking would be a challenge unless there is strong correlation between the two and the corresponding uncertainty is estimable. As an example, the methodology is applied to link the CCEM-K2 and SIM.EM-K2 key comparisons for instance at the 1 $G\Omega$ level.
VISUALIZATION-ASSISTED ANALYTICAL METHOD FOR EVALUATING PROPAGATION OF UNCERTAINTY

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Abstract

Propagation of uncertainty is a key factor in uncertainty evaluation. In this paper, we propose a Visualization-assisted Analytical Method for Evaluating Propagation of Uncertainty (VAEPU). Comparing to Lineal Propagation of Uncertainty (LPU), the analytical method, i.e. method that provides a mathematical representation of the PDF for measurand, is preferable in that it does not introduce any approximation\textsuperscript{1-3}. But the mathematical representation is not suited to be used directly as a component in evaluating the uncertainty of another measurement\textsuperscript{1}. Visualization and data analysis are used to solve this problem. Appropriate use of visualization and data analysis can be helpful to provide a qualitative overview and quantitative analysis for the uncertainty\textsuperscript{1}. The quantitative analysis delivers more accurate result than LPU. Comparing to Monte Carlo method, VAEPU need not consider the numerical stability and the convergence\textsuperscript{1}.

In this paper, the main stages of the VAEPU as shown in figure1 are described. Then, the use of VAEPU in linear and nonlinear models is illustrated. To introduce the usage of VAEPU in nonlinear models, the procedure of evaluating propagation of uncertainty for EVM which is the most important parameter for signal quality evaluation in wireless communication is presented. After formulation and analytical treatment, the mathematical representation of the PDF for EVM is gained\textsuperscript{4}. In figure2, data marked with circles is obtained from sampling the PDF for EVM corresponding to particular value of parameter $\mu$ which characterizes the PDFs for the input quantities in the nonlinear model. It is easy to gain a qualitative overview that the PDF tends to show a Gaussian distribution. Since curve fitting can provide accurate quantitative analysis, here

\textsuperscript{*} This work is supported by Project of National Institute of Metrology Research Foundation (AKY-1039)

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we fit the data with the Gaussian function. This yields an excellent fit (line in figure 2). The goodness-of-fit statistics\(^5\) (e.g. SSE=0.0004) validate the assumption of Gaussian distribution. In addition, Curve fitting provides more accurate value of standard deviation for the Gaussian distribution i.e. combined standard uncertainty for EVM. Figure 3 shows how the PDF for the value of EVM varies as a function of the parameter \(\mu\). The trend that as \(\mu\) gets larger the PDF approaches a Gaussian distribution can be identified.

![Figure 1. Main stages of the VAEPU](image1)

![Figure 2. The PDF for the value of EVM and its fitted curve](image2)

![Figure 3. Elevated surface showing, as a function of \(\mu\), the PDF for the value of EVM](image3)

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