



Figure 1: Martin Wicks demonstrates Internet calibration using generic software - SSfM club meeting, NPL, Autumn 2004.

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Internet-enabled metrology

A co-operative project among the members and partners of MetroNet involves the exchange of expertise in internet-enabled measurement.

Last December, Åsmund Sand of Justervesenet, Norway, made a short visit to NPL to compare the approach taken on their project called *iMet*, involving the secure control of instruments via the internet, with a solution developed at NPL involving generic client software, referred to as *iGen*. *iMet* uses .NET technologies.

Åsmund had no previous knowledge of *iGen*. With support from NPL, he took a simplified calibration task from *iMet*, and implemented it in the *iGen* server, using the generic client to control some simple electrical instruments over the internet.

This worked well and the comparison revealed many similarities between the two systems. There were some differences however:

- *iGen* uses scripts to control the instruments, which *iMet* does not. *[Note: this feature has since been added to iMet, based on ideas from iGen.]*
- *iMet* allows control of instruments by third parties, though this may prove impracticable due to internet delays.
- The development environment for *iGen* is more difficult than the .NET facilities available to *iMet*.

- Feedback to the client is much easier using *iGen* because of its embedded browser capabilities.

Åsmund gave a presentation summarising the above work, and future collaboration between NPL and Justervesenet is being discussed.

If you have an interest in internet-enabled metrology, please contact us to see how we can work together.

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Distributed computing update

NPL's distributed computing grid continues to develop. Two current projects demonstrate what can be achieved.

Rosemary Chandler of the Physics Department at Imperial College has collaborated with NPL to study electron transport in quantum dots. Using a single PC, her Monte Carlo model could handle quantum dot arrays up to 2 by 2 by 3 in size, and with 20 electron energy levels per dot. This system is too small to allow conclusions to be drawn about three-dimensional electron transport in quantum dot arrays, or to allow analysis of the effects of lattice disorder. Runtimes on a single machine would be unfeasibly long for larger systems.

With the NPL grid, Rosemary was able to study a 3 by 3 by 4 array with 34 energy levels per dot. In one month, she was able to complete the equivalent of five years' work on one machine.

A second collaboration is with Pacsys Ltd., who develop and market PAFEC finite element software. Working with staff from NPL's Process Materials team and the Mathematics and Scientific Computing group, Pacsys developed a method of running their FE software on the grid to tackle the analysis of a sonar transducer. They wished to study how the natural frequencies of the transducer varied as a function of the properties of the piezoelectric material of the transducer's active element. Given the large number

of parameters that govern the behaviour of piezoelectric materials this can be a daunting task on a single machine, but with the help of the grid, Pacsys were able to carry out an extensive analysis of the transducer's behaviour very quickly. NPL's Process Materials team are using similar methods to study the sensitivity of the outputs of finite element models to changes in material properties.

A related article appeared in Counting on *IT* issue 16. See www.npl.co.uk/ssfm/download/newsletters/

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A simple test harness for Excel™

Excel™ is widely used by scientists to deliver results even though mistakes can be made very easily.

Simple cut-and-paste errors have cost some companies considerable sums of money, e.g. a \$24 million loss in 2003 by TransAlta Corp., a Canadian electricity generation and trading firm.

To overcome these sorts of errors it is now widely accepted that Excel™ application development should be treated in the same way as software development. SSfM Best Practice

Guide No. 7, *Development and Testing of Spreadsheet Applications*, March 2004 not only recommends this, but also goes further, in suggesting that macros should be used as much as possible.

Tools are needed for this approach to developing Excel™ applications but, unfortunately, few exist. To support Excel™ testing, NPL has developed a simple test harness, EUnit, based on a very widely used unit testing framework exemplified in Java by Junit. Like Junit, EUnit supports the automatic execution of tests with

reporting of results, but it has not been implemented in the same way, as unlike Java, Excel™ is not truly object oriented.

EUnit has been used effectively at NPL on a few small demonstrations. It can be made available to interested parties under terms and conditions to be agreed.

Best Practice Guide No. 7 is available at www.npl.co.uk/ssfm/download/bpg.html

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SSfM "RoadMap" CDROM - Version 2

The first "RoadMap" CDROM contained deliverables from SSfM -1 (1998-2001).

In version 2, reports, guides and papers from the first two SSfM programmes (1998-2004) are included. The contents are structured in three different ways: lists of contents, a keyword index, and

interlinking between documents. The documents are listed in different ways: by project, by generic theme and with abstracts. The keyword index contains links to sections that relate to a given keyword/concept. Many documents have been enhanced so the reference sections link to other documents on the CDROM and to external documents.

The Good Practice Guides and SSfM reports included on the disc will be of interest to all metrologists.

The CDROM is sent free of charge to all SSfM club members; a further limited number of copies are available on request.

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e-mail: robin.barker@npl.co.uk



Workshop on best-practice in uncertainty evaluation

As part of the work within the SSfM programme to advance and promote best practice in uncertainty evaluation, NPL organised and hosted a workshop on this topic. The main objective of the workshop was to support the reliable evaluation of measurement uncertainty, reflecting the requirements of the Guide to the Expression of Uncertainty in Measurement (GUM) and current international activity to produce supplements to the GUM.

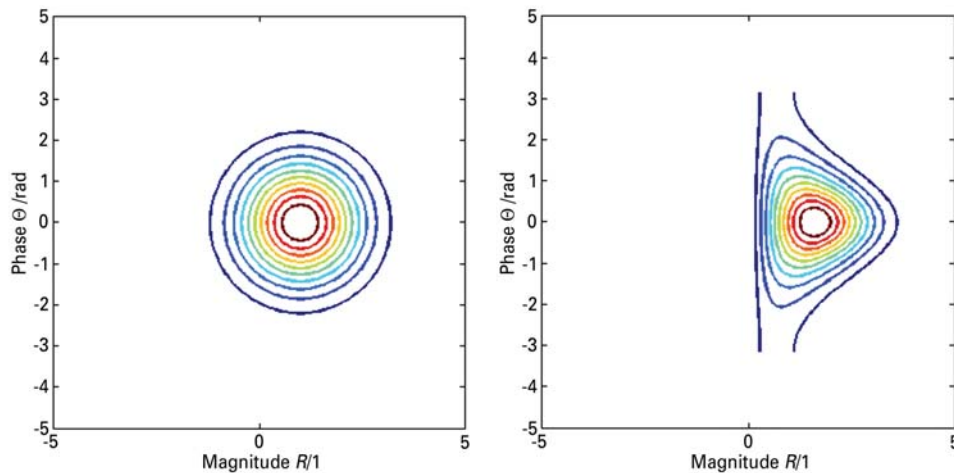


Figure 2: Comparing the results obtained from the law of propagation of uncertainty (left) with a solution obtained analytically (right). The problem concerns the transformation between Cartesian and polar representations of a measurement of a complex-valued quantity. The results are presented as the contours of the joint probability density function for the values of magnitude and phase.

The workshop was divided into three parts: fundamental concepts including the role of probability in uncertainty evaluation, solution approaches and examples, and a discussion session to address participants' questions and problems.

NPL speakers included Prof Maurice Cox on the fundamentals of uncertainty evaluation, Dr Ian Smith on the application of the law of propagation of uncertainty, and Mr Martin Salter on applying Monte Carlo simulation in the context

of microwave measurement. Additionally, attendance of two external speakers was funded under the European Thematic Network Advanced Mathematical and Computational Tools in Metrology (AMCTM). Prof Giovanni Rossi (University of Genova, Italy) spoke on a probabilistic approach to measurement, and Dr Jerzy Korczynski (University of Lodz, Poland) on the application of the Fast Fourier Transform to the evaluation

of measurement uncertainty. The workshop was attended by 34 participants, mainly from UK industry but also representing BSI (British Standards Institute), UKAS (United Kingdom Accreditation Service), LGC (Laboratory of the Government Chemist) and the Swiss Technical Institute of Technology.

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SSfM training courses and workshops - Have your say!

The SSfM programme runs training courses on a wide variety of topics relating to the application of mathematics and software in measurement. We are planning events for 2005/06 and invite you to have your say on what issues and techniques you are interested in.

Topics covered could include the following:

- Mathematical modelling and experimental data analysis
- Fundamentals of uncertainty evaluation and statistical modelling
- Developing software for metrological applications – e.g. scientific computation, instrument control, data acquisition and remote monitoring
- Visualisation of data
- Digital signal processing

Whether you have attended all, some or none of our previous events, your views are very important to us!

Please visit our website to take part:

www.npl.co.uk/ssfm/survey



Delivering numerical correctness over the internet

Software for the numerical processing of measurement data is a key component of metrology systems. Unfortunately, such software will often introduce inexactness into the measurement result (for given measurement data). This can be due to the finite precision of computer arithmetic, wrong choice of algorithm or incorrect implementation. Numerical software testing is therefore needed to show that the results are fit for purpose.

NPL has developed technology such that for many mathematical algorithms, test data and results can be generated with an accuracy that is understood. Also, the test data and results can be selected to mimic those encountered in practice.

NPL has been looking at ways to deliver the technology to industry. Three approaches are described here, and their advantages and disadvantages are briefly given. They are named *Applets*, *Servlets* and *Web Services*, after the underlying technology used to deliver them. *Applets* and *Servlets* are now available from the NPL website for ten numerical processing algorithms. *Web Services* has been shown to work over NPL's intranet for one of these algorithms.

Table 1: A comparison of the three approaches to delivering numerical correctness over the network.

Functionality

All three approaches take selected test results, and deliver test data for which a correctly implemented numerical processing algorithm should give those test results.

Servlets and *Web Services* also allow us to deliver a "test service" which takes selected test results and produces test data. The test data is such that when given as input to a correctly implemented numerical processing algorithm, "reference" results would be produced that are slightly different from the selected test results. The reference results are not known to the user of the test service. The user can apply the test data to a numerical processing algorithm and return the results to the test service for comparison with the reference results. A performance measure indicates how close the results are.

Summary

For ease of testing, the *Web Services* approach is most effective. Where testers do not wish to use *Web Services* then the *Servlets* approach is effective.

Web Services and *Servlets* are based on the same software.

Although the simplest to implement, the *Applets* approach is not only the least easy to use, but also the most difficult to maintain, and therefore will not be developed further.

All the software has been produced to meet NPL's quality system. The *Servlets* have also been developed to Measurement Software Level 2 as described in the Best Practice Guide No. 1, Validation of Software in Measurement System, March 2004, Version 1.1.

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	Comparator	Applets	Servlets	Web Services
Functionality	Reference test	Yes	Yes	Yes
	Test service	Would be difficult to do unless the security of the Applet is reduced	Yes	Yes
Attributes	Access to test data	Copy and paste	Save as file (also copy and paste)	Access through procedure call from software on the client
	User intervention required	Yes	Yes	No
	Runs on	Client	Server	Server
	Java	Must be developed to run on most versions of Java	Required to run on versions of Java on the server	Required to run on versions of Java on the server



Mean & Standard Deviation (1.3.3)

Generate reference dataset WITHOUT reference results

Sample (arithmetic) mean (x0) at least one in absolute value

Sample standard deviation (s) s ≥ 1

Number of points required (m) 2 ≤ m ≤ 500

Random number seed (S)

Identifier Your part of the unique identifier to identify a test set

Data Test Check

Procedure Disclaimer and copyright

http://wind.npl.co.uk:8080/dgf/data/mea...

File Edit View Favorites Tools Help

Title, Mean & Standard Deviation
Version, 1.3.3
date, 2005 Feb 10 09 15 44 970
Java version, 1.4.2_04
Type of service, Test
Identifier, NPL
Sample (arithmetic) mean (x0), 1.0
Sample standard deviation (s), 1.0
Number of points required (m), 200
Random number seed (S), 0
Data, 1.9438042629231471
Data, 0.11337081962635975
Data, 3.3169820554397864

Apply test data to software under test and upload the results

Get test data

Mean & Standard Deviation (1.3.3)

Check test results against reference results

Filename to upload Upload test results for checking

Data Test Check

Procedure

http://wind.npl.co.uk:8080/dgf/data/mean_std_dev7... ML...

File Edit View Favorites Tools Help

Sample (arithmetic) mean (x0)	1.0
Sample standard deviation (s)	1.0
Number of points required (m)	200
Random number seed (S)	0
Test computational precision	2.22044604925031E-16
Test Mean	1.07481078881608
Test Standard Deviation	1.05195512830152
Mean Performance measure	1.866706144227171
Standard Deviation Performance measure	1.5605648665440985

Performance measure calculated based on test results and computational precision

Figure 3: Screen shots illustrating various stages in the practical use of the Servlet approach

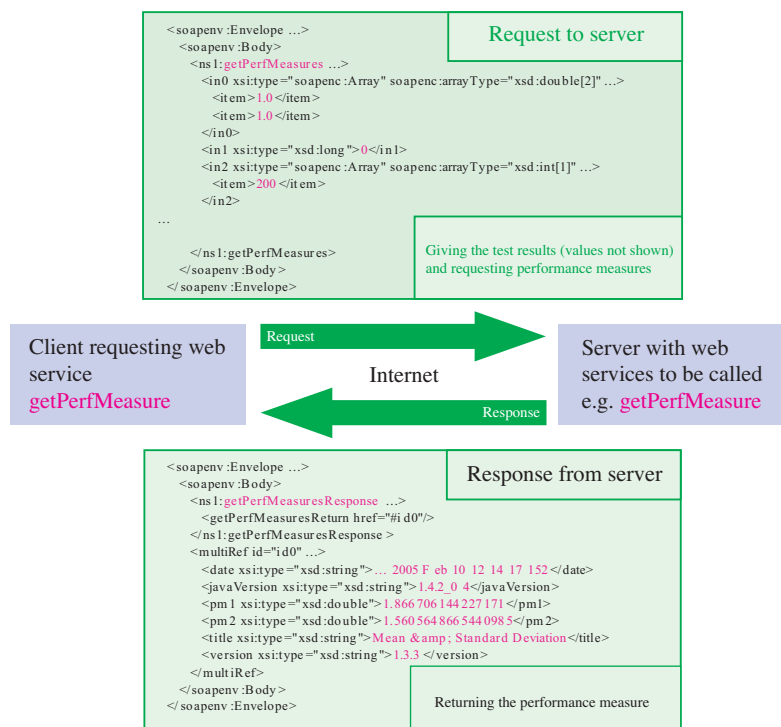


Figure 4: The software controlled Web Services approach. This diagram shows the data exchanged between the client and the server when requesting a performance measure.



Club Members' Page

From *Curvaceous Software Ltd* – A new method for data visualisation

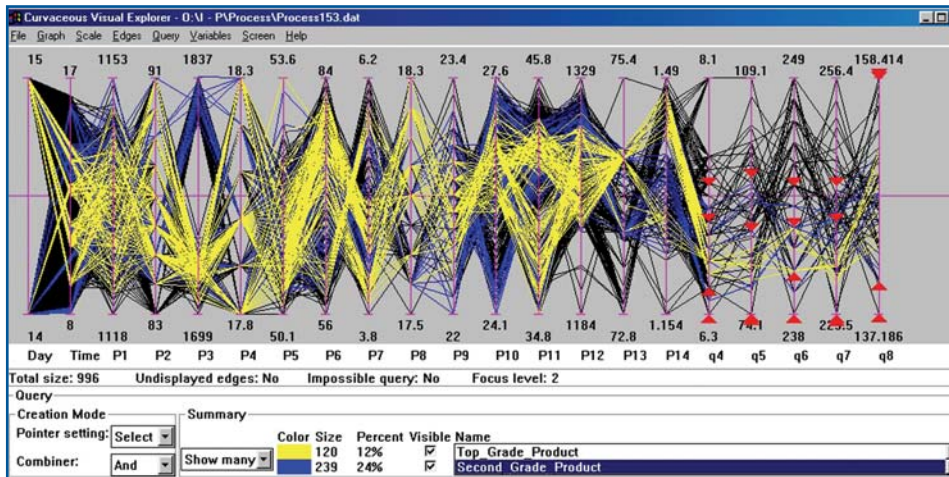


Figure 5: Snapshot of CVE display showing the date, time and the values of all the process variables (P 1-14) and quality variables (q 1-8) at that time. The blue and yellow sections show two different modes of process operation in this case creating specified quality results.

You can see the results before effecting a change.

This method provides immense value in development, data analysis and visualisation because, in comparison, x-y graphs are capable of showing only three or four variables at once.

C:Suite Visual Explorer (CVE) is based on award-winning Geometric Process Control (GPC) technology.

Contact: Curvaceous Software Limited
Telephone: +44 (0) 1753 893090
e-mail: enquiries@curvaceous.com

Using the science of parallel co-ordinate transformations, an interactive picture of hundreds of variables is formed on one screen. This represents an entire process. (See Figure 5)

The method really comes into its own when exploring the data. You can quickly see the interactions between all of the variables, and observe, for example, how other variables affect a particular chosen variable. Precise variable values or ranges can be tested and the results displayed clearly without any mathematics in sight.

From *CNR – IMEKO TC21* mathematical tools for measurement

In November 2004, as a spin-off from the European SofToolsMetroNet project that ends in June 2005, a new IMEKO (international Measurement Confederation) technical committee, TC21, *Mathematical Tools for Measurements*, was formed, with chairman F.Pavese, IMGC, Italy, and scientific secretary A.B.Forbes, NPL, UK.

Its scope is "to promote the harmonisation, the co-ordinated use

and the development of new mathematical and statistical tools for measurements, and their implementation in guides, procedures and codes, acting as a portal on an international environment." Its aims are to help advancement in research, to bridge the gap between scientists working in the fields of measurement science, metrology, testing, applied mathematics, statistics, databases and IT, allowing better and more efficient tools to be developed for specific purposes.

The activities should involve the synergy of specialists in all relevant fields: in production and services, to allow a more efficient transfer of research results to the users in enterprises and a better knowledge

of the needs of the enterprises on the relevant issues.

The principal benefit will be getting more value from measurements, particularly for users and manufacturers of measurement equipment who make extensive use of computational tools.

For more information on this, the AMCTM 2005 Conference, and on the previous issues, see

www.amctm.org



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A common view of industrial measurement uncertainty

The Industrial Measurement Uncertainty project within the SSfM programme aims to link uncertainty issues in three areas:

- **measurement**
- **testing and calibration method**
- **statistical process control**

Each of these areas has its own methodologies and language. The project's overall aim is to help manufacturers and instrument suppliers implement and use measurement systems more easily and effectively across the supply chain and industrial sectors, by developing a clearer and more consistent understanding of measurement uncertainty.

Measurement uncertainty evaluation

The methodology of measurement uncertainty is specified by the *Guide to the Expression of Uncertainty in Measurement* (GUM), published by the ISO in 1995. The GUM gives guidelines on how one should evaluate and express the uncertainty associated with the output of a system, given estimates of the inputs, their associated uncertainties, and a model specifying how the output depends on the inputs.

The uncertainty quantifies the likely variation in the output values if the measurement was to be repeated many times with all inputs allowed to vary in accordance with their uncertainties.

Assessing the accuracy of measurement methods

Although the GUM has wide applicability, it tends to be used in the uncertainty evaluation associated with a particular set of measurements – for example, in the preparation of a calibration certificate. ISO 5725

addresses the accuracy of measuring equipment or proposed measurement methods in terms of *trueness* and *precision*. Trueness relates to the difference between the expected measurement result using the method, and an accepted or reference value. Precision relates to the closeness of agreement between repeated measurements under stipulated conditions: the more the conditions are allowed to vary, the larger the expected variation of results. Typical factors that affect the precision are the operator, the environment, calibration of the equipment and time elapsed between measurements.

The *repeatability* of a system is the precision when all the influence factors are held as close to constant as possible – for example, the same operator.

The *reproducibility* is the precision when all likely sources of variation are allowed – for example, all operators using the equipment.

In measurement uncertainty evaluation, a model is used to propagate variation in the inputs to variation in the outputs. In a repeatability and reproducibility test, the inputs (operator, tool, etc.) are deliberately varied, and the variation in the output (the recorded measured values) is observed.

Systematic effects that contribute to all measurements are detected only if the reference value is known – through using a more accurate measuring system, for example.

Statistical process control

The principle behind statistical process control is that if the manufacturing process leading to the final product is sound, then the product itself will also be sound. By means of monitoring the process at key stages, we should be able to detect any change in the underlying system generating these products. The process capability relates



to the repeatability of the system, i.e., the variation inherent in the process, which is always expected to be present. The process performance relates to the actual observed variation (similar to “reproducibility”) and the difference between the average value of the outputs and their target values (akin to “trueness”).

All three areas are concerned with modelling, describing and making inferences about the stochastic behaviour of systems. They involve variation over the short term in which only a small number of factors will have influence and variation over a longer term where more factors come into play.

The Industrial Measurement Uncertainty project aims to:

- set all three areas into a common framework
- establish a more harmonised view and remove inconsistencies, mainly in the use of language rather than in concept
- promote the common concepts and understanding.

The main outputs of the project will be a methodology and guidance material covering the three areas. NPL is developing the methodology in conjunction with industrial partners through a number of case studies relating to the use of measurement systems in an industrial environment. Please contact us if you would like to be involved in a case study.

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The EUROMETROS website

EUROMETROS is the European repository of software for measurement, maintained by the SSfM programme for EUROMET. The website includes software implementations of functions used by measurement scientists, and associated algorithms, manuals, reports and guidance material. Free software can be downloaded, and there are links to commercial software.

Last year the site was re-engineered using generic software that is common to several other web-based measurement databases. It is now easier to submit software from external sites, and site management has been improved. EUROMETROS is hosted at

www.eurometros.org



SSfM is promoting best practice in measurement software by using EUROMETROS as a repository of software developed during the programme. Example software in reports and best-practice guides, and software developed as part of case studies will be also be included.

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e-mail: alistair.forbes@npl.co.uk
(for SSfM software in EUROMETROS)

Forthcoming events

17 - 18 May 2005, NPL

Audiometric Calibration
Techniques Course

Contact: timothy.sherwood@npl.co.uk

**18 - 20 May 2005, National Metrology
Institute of Japan, Tsukuba, Japan**

NMIJ-BIPM Workshop on the Impact
of Information Technology in
Metrology

www.nmij-bipm-workshop.com/

8 June 2005, NPL

**DC&LF Club Meeting - Software in
Measurement**

Contact: gill.roe@npl.co.uk
www.npl.co.uk/dclclub

20 - 23 June 2005, Lyon, France

12th International Metrology Congress
Contact: info@cfmetrologie.com

27 - 29 June 2005, Lisbon, Portugal

AMCTM 2005 Joint Event with IMEKO
www.amctm.org/index.asp

**27 - 30 June 2005, Cranfield
Management and Development
Centre, UK**

Lamdapam 2005, 7th International
Conference and Exhibition on
Laser Metrology
[www.lamdapam.com/default.asp?
chapterid=41](http://www.lamdapam.com/default.asp?chapterid=41)

18 - 22 July 2005, Chester, UK

Algorithms for Approximation V
Contact: jl1@mcs.le.ac.uk
+44 (0) 116 2523897
<http://scom.hud.ac.uk/scomjkb/a4a5/>

**5 September 2005, Centre for
Precision Technologies, University
of Huddersfield, UK**

Seminar on the History and Future
Prospects in the Field of Measurement
and Instrumentation

Contact: ISMTII.2005@hud.ac.uk
<http://ismtii.hud.ac.uk/>

**6 - 8 September 2005, Centre for
Precision Technologies, University of
Huddersfield, UK**

7th International Symposium on
Measurement Technology and
Intelligent Instruments

Contact: ISMTII.2005@hud.ac.uk
<http://ismtii.hud.ac.uk/>

14 - 17 November 2005, NPL

British Electromagnetic Measurement
Conference (BEMC)

Contact: electromagnetic@npl.co.uk
www.bemc2005.npl.co.uk

www.npl.co.uk/news-and-events/
www.npl.co.uk/ssfm/news/

