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Counting on IT

MATHEMATICS AND SCIENTIFIC COMPUTING

NPL hosts first international workshop on the Impact of IT in Metrology

NPL hosted the first international workshop on the Impact of Information Technology in Metrology from 16 to 19 September 2002. The workshop was organised as part of the SS*f*M programme and of the activity of BIPM's Information Technology Group. Two other organizations sponsored the workshop: NAG Ltd. and the European thematic network SofTools_Metronet. 110 delegates from 22 countries attended.

The main workshop aims were fully met. They were to:

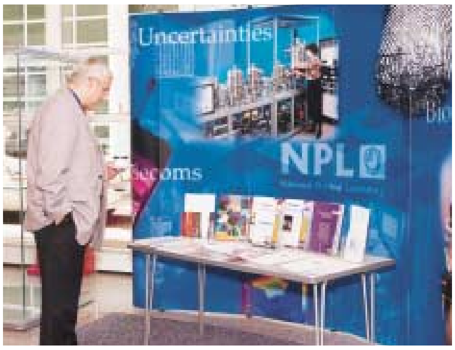
- Provide an overview of the software support that is currently provided to metrology
- Identify requirements, opportunities and benefits of IT for metrology
- Facilitate the cross-fertilization of IT within metrology institutes and other organisations
- Consider the state of the art in and opportunities for Internet-enabled metrology.

We were particularly pleased to receive compliments for both the workshop and the SS*f*M programme from BIPM, NIST and PTB.

Five countries expressed an interest in hosting future workshops.

Internet-enabled metrology day

NPL gave a tutorial on the concepts, and described the iPIMMS service for calibrating the impedance of vector network analysers and the iCOLOUR development for calibrating and monitoring spectrophotometers. Fluke gave a presentation on NPL's iVR prototype service for voltage and resistance calibration, which uses the Fluke 4950



Siegfried Hackel of PTB eyes up the SS*f*M programme

multi-function calibrator as a transfer standard. Adelard presented the associated iCAL software, which is designed to be readily adaptable and easily maintainable for use in any Internet-enabled calibration or monitoring service.

NIST (USA) described their use of Internet-enabled metrology for regional inter-laboratory comparisons.

PTB (Germany) is developing services for remote equipment monitoring. Their work includes the development of more robust travelling artefacts, such as a ball-cube containing sensors to monitor temperature, humidity and vibration.

NMi (the Netherlands) are collaborating with Fluke on Internet-enabled maintenance of a self-calibrating electrical calibrator, the Fluke 5700A. Four levels of checking are involved: internal checks, self-calibration, Internet-enabled calibration, and conventional calibration. This approach enables the user to get the right balance between cost and uncertainty.

NMIJ (Japan) together with AIST have an impressive 2001-2005 programme of

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NPL National Physical Laboratory

The National Physical Laboratory is operated on behalf of the DTI by NPL Management Limited, a wholly owned subsidiary of Serco Group plc

NPL hosts first international workshop on the Impact of IT in Metrology *(continued)*

Andrew Wallard opens the workshop on Key Comparisons

development of Internet-enabled metrology applications, called "e-trace". Areas covered are time and frequency, length through optical wavelength, AC voltage, radioactivity, coordinate measuring machines, and gas and liquid pressure.

Internet-enabled metrology is a fast-moving area of development internationally. PTB plans to host a further workshop in 2003, and NIST is hoping to arrange a workshop as a satellite event to a major metrology conference in the USA in 2004.

Second international workshop at NPL on the Evaluation of Interlaboratory Comparison Data

Presentations at this satellite workshop were made by the major NMIs on approaches to comparison data evaluation that ranged from classical and robust estimators of reference values to the linking of comparisons to detailed considerations of the factors that influence participants' results. The determination of the consequent degrees of equivalence was also much discussed. As anticipated, diverse views were expressed that were influenced by scientific and political considerations.

The results of key comparisons are arriving at the BIPM at an average of one per week, but the data evaluation aspects are not receiving the attention they deserve in terms of informed generic input. The BIPM Director's Advisory Group on Uncertainties is providing some assistance through advice and written guidelines. The first set of guidelines was presented. It will appear in Metrologia in December 2002.

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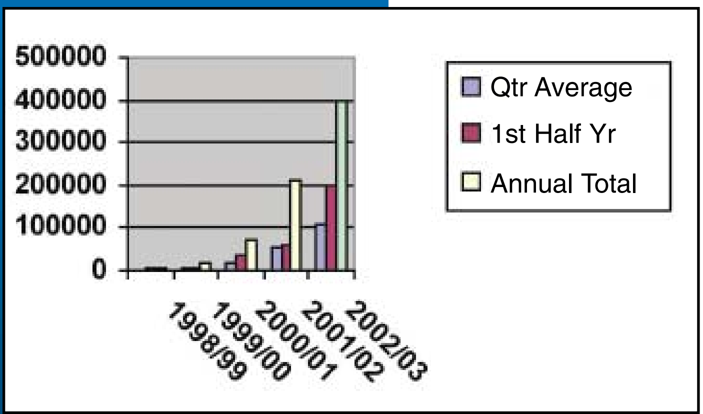
SS*f*M website is a goldmine!



Total accesses are projected to reach 400,000 this year

In his opening speech to the BIPM/NPL workshop on The Impact of IT in Metrology, Rainer Kohler of BIPM said: "The SS*f*M website is a goldmine". We always intended that the website should be our primary means of disseminating the programme outputs, especially the best practice guides and other reports, so it is very pleasing to receive such recognition for the site from the premier world metrology institution.

There has been an exponential growth in number accesses to the site, year on year, since it was first created in 1998, and hundreds of best practice guides are being downloaded every month. In the six months from April to September 2002, the average number of documents downloaded each month has exceeded 3400, of which one in six were best practice guides. The most popular best practice guide in this period by a long way was the Measurement System Validation guide, with its new safety-critical software extension.

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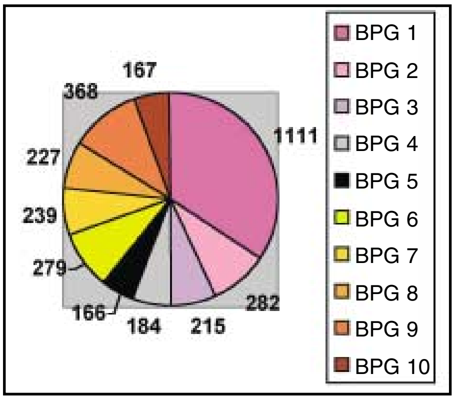


Number of downloads per best practice guide, April to September 2002

SSfM New Directions Digital Signal Processing study

Digital Signal Processing (DSP) is concerned with the digital representation of signals and the use of digital signal processors to analyse, modify or extract information from signals. The signals used in most forms of DSP are derived from analogue signals that have been sampled at regular intervals and converted into a digital form.

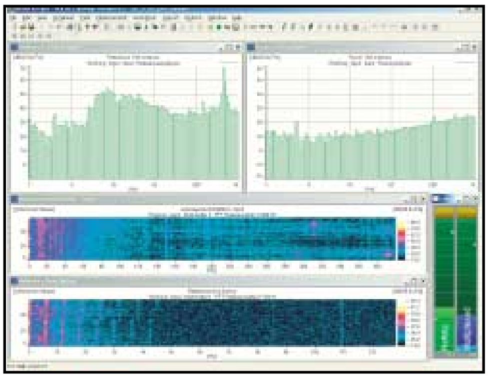
As part of the SSfM New Directions project, NPL is conducting a study to review the state of the art and the metrological requirements of DSP in order to identify key issues for the National Measurement System (NMS) that will need to be tackled in the next SSfM programme. Particular attention is to be given to error modelling, uncertainty evaluation, validation and traceability requirements.

Some of the DSP applications that are likely to occur in metrology are listed below:

- Collecting and applying statistical methods to discrete data
- Signal analysis using FFT techniques
- Calibration of sensors using transfer function estimates by comparing the output and input signals
- Identification of noise sources
- Two-dimensional signal processing
- Transforms for analysis of fluctuating harmonics (wavelets).

In the context of this study we wish to consider measurement errors that arise from the use or misuse of DSP. These may result from:

- Limitations of the hardware used (insufficient dynamic range of ADC card; highest available sampling frequency may not be enough for some applications; jitter on acquisition clock)
- Problems with underlying assumptions about the system under investigation (e.g. if the theory assumes this, is the system linear, time-invariant and causal for the type of signals used?)
- Extraneous noise sources contaminating signals under investigation (PC environment can be noisy)
- Signal truncation and use of windowing
- Artefacts of DSP algorithms used (sampling at twice the maximum frequency may not always yield the desired results).



DSP graphical output

DSP acquisition system

"We wish to consider errors that arise from the use or misuse of DSP"

In this study, NPL has contacted a number of recognised experts in the area of DSP and has requested their views on the use of DSP in the context of metrology. For the latest information on the outcome of the questionnaire, please visit www.npl.co.uk/ssfm/news.

In order to provide information for the study, on 21 November 2002, Dr T. Chilton, Senior Lecturer at the Centre for V.S.S.P. Research, University of Surrey, gave a seminar at NPL highlighting the consequences of DSP hardware and software limitations on measurement accuracy. His current research interests include speech recognition and the application of transforms to a variety of signal processing problems.

The results of the study will be published on the SSfM website in due course.

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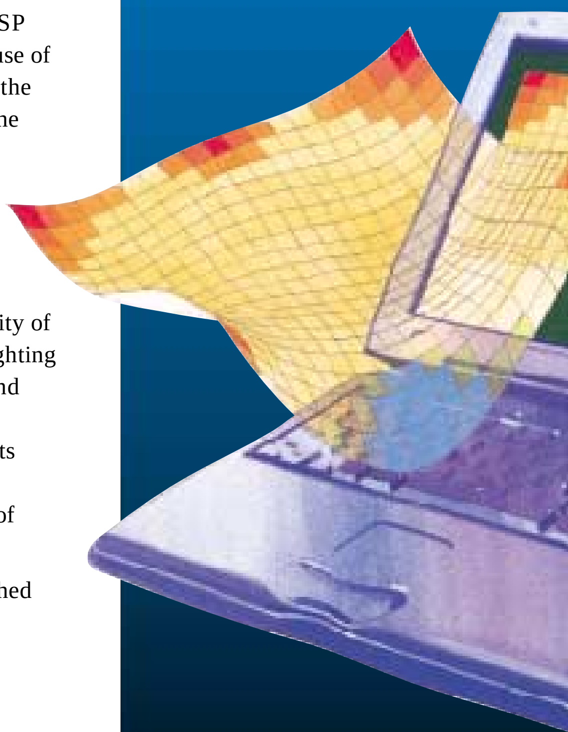

Visualisation of uncertainties in continuous modelling

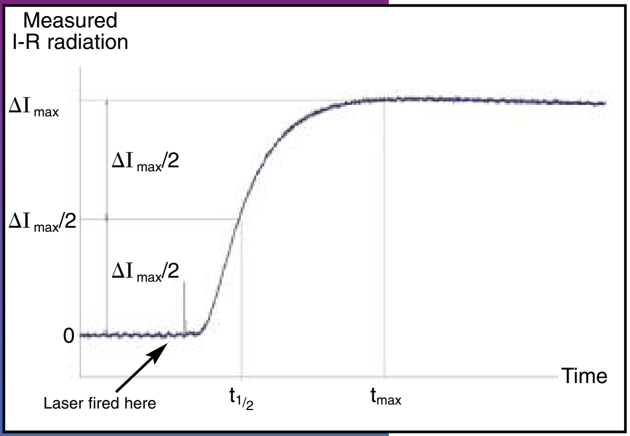

Figure 1: Typical infra-red radiation data showing $t_{1/2}$, the time taken to reach half the maximum measured value

Uncertainty calculation in continuous modelling is an under-developed area. Often the complexity of the calculations or the black-box nature of the software discourage people from evaluating uncertainties. The visualisation and interpretation of uncertainties in a continuous medium can be difficult because identifying and presenting the useful data is tricky.

One SS*f*M-2 project aims to develop techniques for visualising uncertainties in continuous models and uses a typical application as a case study.

The application chosen is an experimental procedure used to determine one of the thermal properties of a material sample. The experiment being modelled determines the thermal diffusivity of a material by heating the front circular face of a small cylindrical sample with a laser flash, and measuring the subsequent rise in thermal radiation from the rear circular face. The time taken for the rear face to reach half of its maximum rise ($t_{1/2}$, see Figure 1) is then used to determine the sample's thermal diffusivity. However, the analytical model on which this calculation is based contains a number of assumptions about the sample behaviour, such as:

- Sample is uniform and isotropic
- Radiative heat losses are negligible
- Thermal radiation is measured at the centre of the rear face
- Laser flash takes place instantaneously
- Laser intensity is uniform across the heated sample face

not all of which may be true in practice.

In particular, it is unlikely that the last of these will hold: measurements of laser profiles using burn tests have shown that generally laser intensity is spatially non-uniform. It would be very useful for metrologists to be able to determine the effects of non-uniform laser profile on thermal diffusivity and to understand how the uncertainty of the laser profile contributes to the uncertainty of the calculated diffusivity value.

If the assumptions listed are to be discarded, a numerical approximation method must be used in place of the analytic solution. A finite difference approximation has been developed to calculate the temperature distribution within the sample without using any assumptions of symmetry or uniformity of the laser profile. The model can be run with various laser intensity profiles to see how the calculated diffusivity values vary. The results of the calculations are compared with the measured values using a Matlab program, resulting in the display shown in Figure 2.

As the project progresses, the effects of the uncertainty in the various material and geometric input parameters on the calculated diffusivity will be investigated. This will make improved uncertainty estimation possible.

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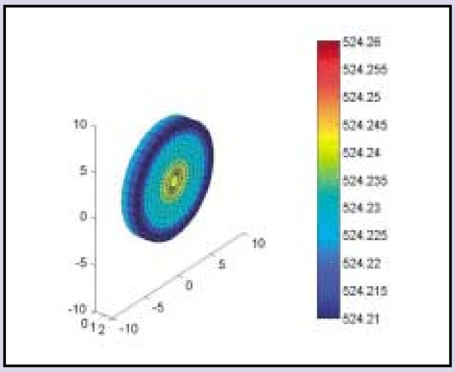

Material Properties

Thermal conductivity = 7.000e-006 mW/(mm.K)
Specific heat capacity = 2000 J/(kg.K)
Thermal diffusivity = 1.458e-003 mm^2/ms
Hemispherical emissivity = 0.9

Figure 2: Output from the Matlab visualisation program

Data Visualisation in Metrology

The use of computer graphics packages to visualise numerical data is becoming routine in many fields, including metrology. Although the packages are widely available, users often require guidance on the choice of a visualisation technique that is appropriate for their data. The SS*f*M-2 data visualisation project is aimed at helping metrologists to choose from the wide variety of techniques and tools, by highlighting 'good practice' in visualisation, along with a few pitfalls which might be unfamiliar to the metrology community.

For example, a common technique for the display of vector data (which typically arises from flow calculations or experiments) is known as *particle tracing*. Here, a weightless particle is introduced into the data at some point and allowed to move under the local influence of the vector field. The path traced by the particle gives a rather direct picture of the spatial distribution of the vectors in the data set. However, it has been shown that the shape of the path can be sensitive to the algorithm used to solve for it.

Figure 3 shows some results for particle tracing in a simple circularly symmetric vector field. One path (blue) is calculated using a simple, widely used algorithm, while a more sophisticated algorithm is used for the other path (red). The (black) arrows are drawn at each data point, and show the orientation of the vector field at that location. The figure clearly shows the dramatic difference between the two paths, with the sophisticated algorithm producing a circular path (which is correct, since the field has circular symmetry), and the simpler algorithm calculating an incorrect spiral path. This example highlights the importance of ensuring that the visualisation algorithm used for a data set is sufficiently accurate, otherwise it might produce a misleading representation of the data.

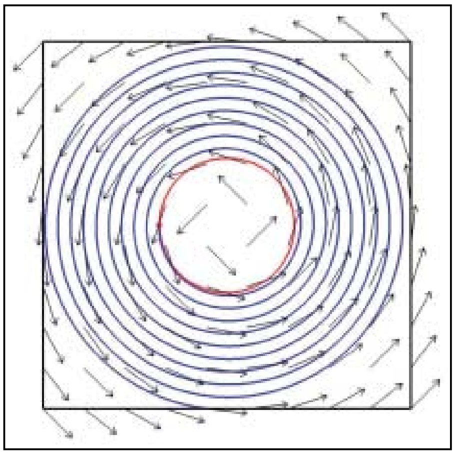

Figure 3:
Particle traces calculated for a circularly symmetric vector field using two algorithms: a simple one (blue line) and a more sophisticated one (red line)

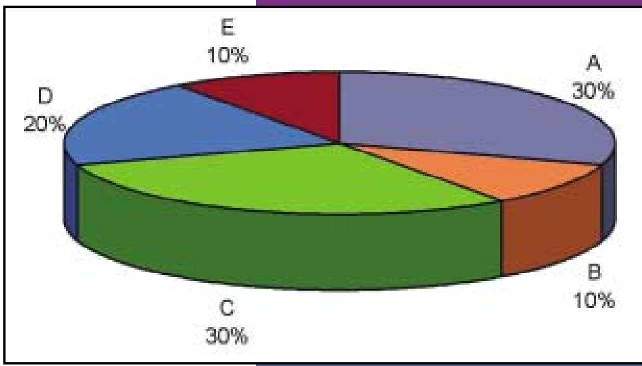

Figure 4:
A pie chart displayed in a 3D representation. Slices A and C represent the same percentage, but appear to have different sizes

In a similar way, the visual presentation of data can be fraught with pitfalls, leading to problems in the interpretation of the data by the end-user. For example, it is common to use a pie chart to present a set of percentages, but if this is done in a 3D representation (see **Figure 4**), mistakes could be made about the relative size of the slices. Thus, in the figure, slices A and C both represent the same percentage, but slice C appears bigger because it is at the front of the pie.

The SS*f*M-2 project will produce a training course and a good practice guide on data visualisation. These will include real examples of measurement data, visualised using different techniques. The project will produce material designed for metrologists as a practical introduction to data visualisation, its relevance for measurement data and the range of available tools and techniques.

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Training in Discrete Modelling

The broad topic of discrete modelling is a key part of Theme 1, *Modelling Techniques,* in the SS*f*M-2 Programme, and Training is included as an activity strand. It is necessary to be aware of the general implications and requirements of discrete modelling, and to plan a training scheme that exposes these.

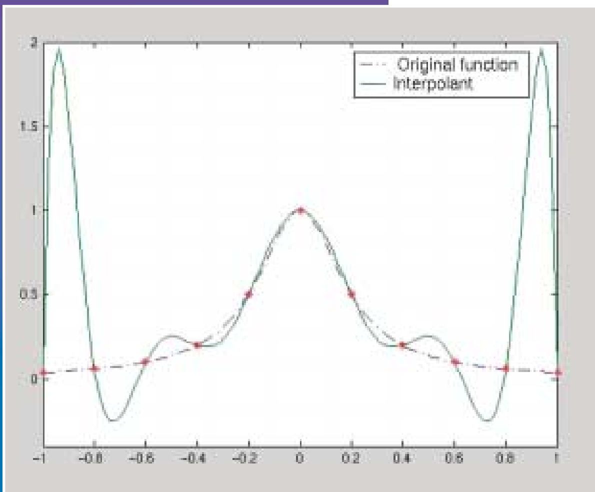

Figure 5:
Equally spaced interpolation

Discrete modelling has a long history, and early efforts were primarily concerned with fitting polynomials to discrete data. A number of myths, especially about polynomials, grew up from this early work. It is often now claimed that polynomials of high degree (e.g. over 10) cannot be used successfully but this is not true. What should more correctly be said is that a high degree polynomial approximation may be poorly determined if a power-basis, $y \approx \sum c_i x^{i-1}$, is adopted, but that polynomials up to degree 30-50 may be successfully formed by adopting a Chebyshev polynomial basis, $y \approx \sum c_i T_i(x)$. A similar situation holds in spline approximation, where a truncated-power form of high order is ill determined but a B-spline basis can give a very accurate form of high order.

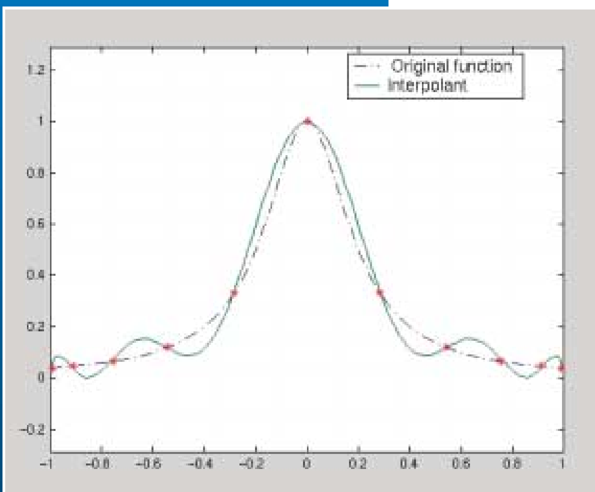

Figure 6:
Chebyshev spaced interpolation

One of the best examples of bad modelling comes from interpolating a polynomial at n equally spaced points of [-1, 1] to the function $(1+25x^2)^{-1}$. Figure 5 shows that the interpolant diverges around the end points. The fault here is not in the use of a polynomial, but in the choice of interpolation points - a better choice would be the zeros of $T_n(x)$, the Chebyshev polynomial of degree n, for which the interpolant converges - see Figure 6.

In progressing to multivariate problems, it is beneficial to think hard before adopting polynomials and splines. For three or more variables, these may well not offer the most compact forms, and we do well to consider alternatively the merits of radial basis functions (RBFs). For higher dimensions a discrete data domain is more appropriate for handling non-rectangular regions, and can be based on the shape of the domain and its interior. An RBF is formed by summing a discrete set of radial functions, each measured from a discrete centre, and so is very well suited to the problem. Each radial function is a one-dimensional function of a distance between two vectors (a centre and a data point), so there is an effective saving in dimension. Moreover, unlike polynomials and splines, RBFs do not require rectangular types of domains in order to function effectively.

University of Huddersfield are cooperating with NPL in providing training in discrete modelling. Two and a half day courses are offered to different groups in industry as required. Key components in the course are:

- Models - structure, functional models of physical systems
- Approximation (and data fitting) - data type, form of approximation, metric (and norm)
- Least squares (norm) - fitting, link to form and norm, and statistical aspects
- Least 1st power and minimax (norms) - linear programming, and wild points
- Spline approximation - B-splines, parametric splines, and knot selection
- Radial basis functions -multivariate approximation
- Nonlinear forms and nonlinear least squares - surface and metrology problems
- Metrology problems
- Software - discussion of: NPLfit, NAG library, Netlib, Matlab, Metros.

So far, courses have been run at NPL and at Rolls-Royce, Derby.

Please contact us if you would like to attend the next run of the course or if you want to have the course run at your organisation.

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From *The MathWorks* - Modelling and visualising the boundary of measured data

One of the problems with using statistical models is that users are tempted to extrapolate results away from the where the data was collected and thus potentially away from where the model is valid. To prevent this, we associate with the model a secondary model that models the boundary of the region where the data was collected. Thus any attempt to evaluate the model outside this region can produce an appropriate warning. Using spherical radial basis functions (RBFs) we can model complicated, non-convex boundaries in many dimensions. To allow modellers to verify that the boundary model adequately represents the boundary, we present them with plots showing this boundary and data. As the data is typically high dimensional, this means we need to use different ways of slicing and projecting the boundary model and the data to allow the modeller effectively to visualize the boundary model. This boundary modelling forms part of the Model-Based Calibration Toolbox from The MathWorks, developed in conjunction with the Ford Motor Company. This toolbox allows the modelling of modern engines with many control parameters. For this particular application, the boundary model in itself is interesting as it represents the operating envelope of the engine.

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From *The Measurement Standards Laboratory of New Zealand* Automating Uncertainty Calculation

We have developed a software design pattern to represent and propagate measurement values and uncertainties (www.irl.cri.nz/msl/mst). Implementations are compact, efficient and comply fully with the GUM.

The pattern introduces an abstract entity, combining value and uncertainty information. In many ways this resembles support for complex numbers. Arithmetic operations and a few basic functions are implemented in a common module, and there is no need to use rules for manipulating abstract type attributes: the software does that. For instance, our pattern automatically generates sensitivity coefficients so there is no need separately to define derivative equations.

The pattern is ideally suited to the propagation of uncertainty in modular systems, because it uses minimal resources and has an intrinsic modular structure. If incorporated in a system's architecture, it could provide dynamic uncertainty information even when configurations change.

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From *PTB* An Accredited Software Test Centre

Using a software product involves taking certain risks. For example, the correct implementation of software in compliance with functional requirements is a serious challenge. If the software is to be easy to handle and readily adaptable, the risks can even extend to code manipulation.

To minimise these risks, PTB has established a software test centre, serving both internal and external customers. (See www.softwarepruefstelle.de) Its objective is to ensure confidence in the correct and reliable function of measurement systems that rely on software.

The centre has been accredited as a testing laboratory in accordance with ISO/IEC 17025. The accreditation certificate was received in 2001 from the DATech (Deutsche Akkreditierungsstelle Technik e.V.), which is recognised by EA (European co-operation for Accreditation). Thus, test reports are accepted throughout Europe.

The accreditation covers testing software for functionality, reliability, usability and maintainability, and testing according to ergonomic criteria.

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DTI approves greater international emphasis for SS*f*M

At the SS*f*M Annual Review in July 2002, NPL and Adelard made presentations on the achievements of the first year of the current programme to DTI and their Measurement Advisory Committee Working Group. These achievements were covered in Counting on IT issue 11, summer 2002.

Possible changes to the programme were also discussed, and as a result it was agreed that there should be increased emphasis on international activities. It was accepted that additional work was needed in three areas.

Supplemental guides to the GUM

The Joint Committee for Guides in Metrology (JCGM) is producing a set of supplemental guides to accompany the Guide to the expression of Uncertainty in Measurement (GUM). The SS*f*M programme will now contribute to:

1. An introductory guide to the GUM and its supplements (based in part on NPL's existing Beginner's Guide by Stephanie Bell)
2. A new GUM supplemental guide on the modelling phase of uncertainty evaluation (benefiting from SS*f*M Best Practice Guide no. 6)
3. A new GUM supplemental guide on Least Squares adjustment (SS*f*M input based on current regression work)

Key comparison data evaluation

Guidelines are needed to cover commonly occurring cases, in addition to the existing guidelines for the simplest cases. It was agreed that SS*f*M would contribute to the guidelines for the following cases:

1. Unstable travelling artefact - modelling drift
2. Traceability to common sources

Standards representation

There was full agreement that SS*f*M involvement in relevant standards activities at the JCGM, ISO, CEN, EA and BSI levels needed to be greater than planned. Hence, funding was increased to guard against untimely withdrawal from any of the activities.

Areas being cut back

In order to find the funding for all this increased international activity, it was agreed that there must be commensurate cut-backs elsewhere in the programme. The areas that suffered were:

- Statistical-based rules for conformity decisions
- Generic procedures for standards and regulatory bodies
- Design reviews of algorithms submitted to MetroS
- Generic guidance on validation of software issued by professional institutions

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If you have a general enquiry or do not know who you should contact please call our general enquires number and we will be pleased to help you.

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