

TC21 "Mathematical Tools for Measurements"

Officers

Chairman: F. Pavese, INRIM^{*}, Italy (f.pavese@inrim.it)

Scientific Secretary: A.B. Forbes, NPL, UK

IMEKO TC21 was formed in November 2004.

Scope

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.

Aims

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, by allowing 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 scope should be getting more value from the measurements, particularly for the benefit of measurement equipment manufacturers and users who use extensively computational tools;
- ❖ in supplementing other IMEKO TCs with a focused viewpoint and activities concerning the development of specific tools in the relevant fields of the scope.

Membership

Membership aims at continuing to group of Institutions having participated to the AMCTM Community (see Appendix B) and to the SofTools_MetroNet Network either as members (formally participating to the network) or as partners (“friends” in IMEKO terms”).

The subdivision of these Institutions into members and “friends” is not formally established. In addition, cross-membership of persons active in other IMEKO TCs is welcome and encouraged, from TCs with complementary activities.

At present membership consists (2009) of 34 Members and 22 Friends from 25 Countries worldwide.

^{*} National Institute of Research in Metrology. Until 2005, IMGC of the National Research Council of Italy.

<i>MEMBERS</i>					
INRIM	Dr. F. Pavese	Istituto Nazionale di Ricerca Metrologica (INRIM)	Torino	Italy	f.pavese@inrim.it, frpavese@tin.it
NPL	Dr. A.B. Forbes	National Physical Laboratory (NPL)	Teddington	England	alistair.forbes@npl.co.uk
AIST-NMIJ	Dr. I. Kishimoto	National Institute of Advanced Industrial Science and Technology, National Metrology Institute of Japan (AIST-NMIJ)	Tsukuba	Japan	isao-kishimoto@aist.go.jp
BAM	Dr. W. Bremser	Federal Institute for Materials Research and Testing (for VDI/VDE)	Berlin	Germany	wolfram.bremser@bam.de
CFM	Dr. M. Priel	Laboratoire National d'Essais et Métrologie (for CFM) (LNE)	Paris	France	marc.priel@lne.fr
CARNet	Dr. M. Jurcevic	Croatian Academic and research network, Zagreb, Croatia	Zagreb	Croatia	Marko.Jurcevic@fer.hr
CEM	Dr. D. Del Campo	Centro Espanol de Metrologia (CEM)	Madrid	Spain	ddelcampo@cem.mityc.es
DFM	Dr. L.Nielsen	Danish Institute of Fundamental Metrology (DFM)	Lyngby	Denmark #	LN@dfm.dtu.dk
DIMEC	Prof. G.B.Rossi	Università di Genova (for National Group of Mechanical and Thermal Measurement)	Genova	Italy	gb.rossi@dimec.unige.it
INMETRO	Dr. G. Kyriazis	INMETRO (for SBM)	Duque de Caxias - RJ	Brazil	gakyriazis@inmetro.gov.br
INMETRO	Dr. H. Brandi	INMETRO (for SBM)	Duque de Caxias - RJ	Brazil	hsbrandi@inmetro.gov.br
IPQ	Dr. E. Filipe	Instituto Portugues da Qualidade (IPQ)	Caparica	Portugal	EFilipe@mail.ipq.pt
IRL	Dr. R. Willinks, Dr. R.White	Industrial Research Limited (IRL)	Lower Hutt	New Zealand #	R.Willink@irl.cri.nz
IRMM	Dr. P. Taylor	JRC-IRMM (EU JRC organisation)	Geel	n.a. #	philip.taylor@ec.europa.eu
MSL	Dr. B. Hall, Dr. V. Bubanja	Measurement and Standards Laboratory	Lower Hutt	New Zealand #	b.hall@irl.cri.nz, v.bubanja@irl.cri.nz
NIST	Drs. A. Possolo, Nien-fa Zhang, Raghu Kakher, Toman, Liu	National Institute of Standards and Technology (NIST)	Gaithersburg and Boulder	USA #	antonio.possolo@nist.gov, nien-fan.zhang@nist.gov, toman@nist.gov, liu@nist.gov, raghu.kacker@nist.gov, kacker@nist.gov
NRC	Dr. A. Steele, Dr. R. Douglas	National Research Council (NRC)	Ottawa	Canada	Alan.Steele@nrc-cnrc.gc.ca, Robert.Douglas@nrc-cnrc.gc.ca
PoliMi	Prof. G. D'Antona	Politecnico di Milano (for National Group of Electrical and Electronic Measurement)	Milano	Italy	gabriele.dantona@polimi.it
PTB	Dr. M. Baer, Dr. D. Richter	Physikalisch-Technische Bundesanstalt (PTB)	Berlin	Germany	markus.baer@ptb.de, dieter.richter@ptb.de
	Dr. K-D Sommer	Physikalisch-Technische Bundesanstalt (PTB)	Braunschweig	Germany	klaus-dieter.sommer@ptb.de
LNE	Dr. S. Amarouche			France	soraya.amarouche@lne.fr
SP	Dr. L. Pendrill	Swedish National Testing and Research Institute (SP)	Boraas	Sweden	leslie.pendrill@sp.se, Ragne.Emardson@sp.se

UNIAix	Prof. J.M. Linares	Université de Aix-les-Bains (for CFM)	Aix-les-Bains	France	jean-marc.linares@univmed.fr
UNILodz	Prof. J. Korczynski	University of Lodz	Lodz	Poland	jerzykor@p.lodz.pl
VNIIM	Dr. A. Chunovkina	VNIIM "Mendeleyev"	St.Petersburg	Russia	A.G.Chunovkina@vniim.ru
UTAC	Dr. C. Perruchet, T.Ageron	UTAC & ISO TC69		France	christophe.perruchet@utac.com, thierry.ageron@utac.com, Nicolas.Fischer@lne.fr
VSL-NMi	Dr. G. Rietveld	Netherlands Meetinstituut B.V. (VSL)	Delft	Netherlands	grietveld@nmi.nl
BEV	Dr. R. Edelmaier	Bundesamt für Eich- und Vermessungswesen	Arltgasse	Austria	r.edelmaier@metrologie.at

FRIENDS

CNR-IAC	Dr. P. Ciarlini	CNR, Istituto per le Applicazioni del Calcolo "O.M.Picone" (CNR-IAC)	Roma	Italy	p.ciarlini@iac.cnr.it
IAE	Prof. M.L. Collucci da Costa Reis	CTA		Brasil	mluisareis@iae.cta.br
INTiBS	Dr. A. Szmyrka-Grzebyk	Instytut Niskich Temperatur I Badan Strukturalnych-PAN (INTiBS)	Wroclaw	Poland	A.Szmyrka@int.pan.wroc.pl
JV	Dr. H.A. Froystein	Justervesenet National Standards Dpt JV)	Kjeller	Norway #	hans.froystein@justervesenet.no
LNEC	Prof. A. S. Ribeiro	Laboratorio Nacional de Engenharia Civil	Lisboa	Portugal	asribeiro@lneec.pt
MITUTOYO	Dr. A. Lazzari	Mitutoyo Italy	Milano	Italy	annarita.lazzari@mitutoyo.it
MIKES	Dr. A. Manninen	Mittatekniikan keskus Mättekniikan keskus Centre for Metrology and Accreditation	Helsinki	Finland	antti.manninen@mikes.fi
NAG	Dr. F. Brian	The Numerical Algorithm Group Ltd	Oxford	England	
ROA	Dr. F.J. Galindo	Real Instituto y Observatorio de la Armada en San Fernando	San Fernando (Cadiz)	Spain	jgalindo@roa.sp
SMU	Dr. P. Nemecek	Slovak Institute of Metrology	Bratislava	Slovakia	nemecek@smu.gov.sk
UNIFI	Prof. M. Catelani	University of Firenze	Firenze	Italy	marcantonio.catelani@unifi.it
UNIHUDD	Prof. A. Crampton	University of Huddersfield	Huddersfield	UK	a.crampton@hud.ac.uk
PMS	Prof. Z. Warsza	Polish Metrological Society	Radom	Poland	zlw@op.pl
	Dr. P. De Bièvre			Belgium	paul.de.bievre@skynet.be
ENBIS	Dr. Andrea, Dr.R.S. Kenett, S. Coleman	ENBIS		n.a. #	a.ahlemeyer@antz21.de, ron@kpa.co.il, Shirley.Coleman@ncl.ac.uk, irena.ograjensek@ef.uni-lj.si
TUS	Dr. Tomomichi Suzuki			Japan	suzuki@ia.noda.tus.ac.jp
UTEP	Prof. Vladik Kreinovich			USA	vladik@utep.edu
PTB	Dr. C.Elster			Germany	clemens.elster@ptb.de

no IMEKO M.O.

Prior activities

- “Advanced Mathematical and Computational Tools in Metrology” (AMCTM) International Conference series initiated in 1993 and held first at IMGIC (F.Pavese, Chairperson), 8 held since 2008.
- “SofTools_MetroNet”, European Union FP5 Thematic Network 2002-2005, 20 participants (F.Pavese Co-ordinator)

Main activities

The Technical Committee TC21 organises its activities in Special Interest Groups (SIG): see list below.

Its main events are the IMEKO World Congress (three-annual) and the Conference AMCTM (three-annual). TC21 is also co-sponsoring annually other events of its interest.

The next AMCTM Conference will be held on June 20-22, 2011, in Göteborg, Sweden, where also two joint-sessions with the EURAMET Focus Group on Mathematics and Software will be held.

Additionally, IMEKO TC21 has an intense editorial activity since 2005. The last outcomes were:

- Book “Advances in Mathematical and Computational Tools in Metrology VII” World Scientific Publ. Co., Singapore, in the Series on Advances in Mathematics for Applied Sciences, vol.72, 46 papers, 2006, pp 363 + CD-ROM.
- Journal “Measurement” Special Issue “Advanced Mathematical Tools for Measurement in Metrology and Testing”, F.Pavese Guest Editor, 10 research articles, 2006, pp 102.
- Book “Data modeling for metrology and testing in measurement science”, in the Series “Modeling and Simulation in Science, Engineering and Technology”, Birkhauser-Springer, Boston, F. Pavese and A.B. Forbes Editors, 14 review Chapters, pp 500 + DVD with addenda, January 2009.
- Book “Advances in Mathematical and Computational Tools in Metrology and Testing VIII” World Scientific Publ. Co., Singapore, in the Series on Advances in Mathematics for Applied Sciences, pp 420 + CD-ROM, April 2009.

External dissemination

The external dissemination of TC21 activities are planned to be performed by:

- continuing the publication of the website www.imeko-tc21.org (mirroring also the older www.amctm.org), and the mirrored by the IMEKO website www.imewko.org;
- other means which will come available through IMEKO, such as the MEASUREMENT Journal, new IMEKO Journal and the IMEKO website at PTB www.imewko.org;
- participation to World IMEKO Congresses;
- the AMCTM International Conferences, starting from AMCTM 2005, to be organised each time in a different Country, in years different from the World IMEKO Congress, and other TC-related events;
- continuing to publish the Series of books AMCTM (World Scientific, Singapore www.worldscientific.com, eight until 2009) and other books on relevant subjects;
- helping preparing material useful to organisations for written standards, International like ISO and National Committees.

TC21 also considers organising joint events, selecting topics of common interest and working together in specific areas where scientific interest converges. In this way, IMEKO TC21 will create new synergies and interest in areas only peripherally covered at the present time.

Established formal links

- **ENBIS Network**: formal link established in **2007** (www.enbis.org);
- **ISO TC 69**: formal link established in **2007** (www.iso.org);
- **Euramet “Interdisciplinary Metrology” TC-IM Focus Group “Software and Mathematical Tools for Metrology”** (AT, DK, ES, FI, FR, GE, IT, NL, NO, PL, PT, SK, SE, UK), link established since its constitution in 2006 (www.euramet.org).

For more information consult the website www.imeko-tc21.org (updating in progress).

Active Special Interest Groups (SIG) of IMEKO TC21 –*JOIN THE SIGs*–**SIG Training, Dissemination and Education** (permanent SIG)

(Coordinators: F Pavese (f.pavese@inrim.it), G A Kyriazis (gakyriazis@inmetro.gov.br)
Events, publications, documentary standards, websites, e-learning, software repository

SIG Instrumentation

(Coordinators: A S Ribeiro (asribeiro@Inec.pt)
Data acquisition, virtual instruments, Internet-enabled metrology

SIG Advanced tools for soft metrology

(Coordinators: G B Rossi (gb.rossi@dimec.unige.it), R Emardson (ragne.emardson@sp.se)
Measurement techniques and uncertainty evaluation in human perception

SIG Precision evaluation in non-quantitative measurements

(Coordinators: T. Suzuki (suzuki@ia.noda.tus.ac.jp), S Amarouche (soraya.amarouche@Ine.fr)
Support to ISO TC69 in studies toward a written standard on non-quantitative measurements

SIG Uncertainty and inference

(Coordinators: A B Forbes (alistair.forbes@npl.co.uk), N Fischer (nicolas.fischer@Ine.fr), A Chunovkina (A.G.Chunovkina@vniim.ru)
Uncertainty evaluation, including complex/ multivariate quantities, signal processing, dynamic measurements, model fitting and inference, support for the SI

SIG Interlaboratory comparisons

(Coordinators: R Douglas (robert.douglas@nrc-cnrc.gc.ca), F Pavese (f.pavese@inrim.it), N-F Zhang (nien-fan.zhang@nist.gov)
Key comparisons and support for the MRA, ILCs and laboratory capabilities

SIG Computational science

(Coordinators: M Bär (markus.baer@ptb.de), V Sohkan (victor.sohkan@npl.co.uk)
Solution of PDEs, finite element modelling, multiscale modelling, atomistic modelling, inverse problems, grid computing, virtual experiments, visualisation

SIG Measurement applications

(Coordinators: A B Forbes (alistair.forbes@npl.co.uk), L Pendrill (leslie.pendrill@sp.se), E Filipe (EFilipe@mail.ipq.pt), R Kenett (ron@kpa.co.il)
Entreprise applications: conformance assessment, statistical quality control, experimental design, implementation of written standards; health applications, environment applications; chemical metrology applications

SIG Measurement software development and validation

(Coordinators: D Richter (dieter.richter@ptb.de), G Parkin (graeme.parkin@npl.co.uk)
Validation framework, data access, XML, security, software libraries

SIG Dynamic measurements

(Coordinators: T Esward (tony.esward@npl.co.uk), C Elster (clemens.elster@ptb.se), P Hessling (peter.hessling@sp.se))

SIG Repository of inconsistencies found in guidelines and prescriptive documents

(Coordinators: F Pavese (f.pavese@inrim.it), M G Cox (maurice.cox@npl.co.uk), P De Bièvre (paul.de.bievre@skynet.be)

Appendix A

Detailed list of AMCTM Community activities

Data-acquisition and virtual instruments

Good practice guidance for data-acquisition procedures (including virtual instruments)

- Sharing existing guidance on development of data acquisition or virtual instrument procedures and software
- Sharing information on the procedures and software development environments used for data acquisition and virtual instruments
- Development of a guideline or good practice of setting-up and implementing data-acquisition procedures and software, building upon existing guidance where possible
- Case studies on the application of the guideline in some laboratory systems and instrument firmware / software.

Application of existing uncertainty best practice to measurement set-ups

- Outlier identification
- Uncertainty propagation in successive measurement steps
- Multivariate data capture and its impact on uncertainty evaluation
- Improving experimental design in order to reduce or make more reliable the estimation of Type B uncertainties
- Improving experimental design and sampling techniques in order to improve the reliability of Type A uncertainty evaluation, capturing sets of data with better statistical properties
- Investigation of uncertainty evaluations performed in SEVA (self-validating) instruments

Actual (informal) evaluations of data-acquisition procedures and software

Internet-enabled measurement

Good practice for implementation of internet-enabled measurement software

- Sharing and reviewing existing guidance material
- Security issues, including security policies, authentication, access control, data integrity, confidentiality and firewall issues
- Electronic calibration certificates
- Calibration history data tracking, including capture, storage, access and data mining
- Good practice for design and development of the control software, both at the client end and at the server end
- Software for online (web-based) services, such as software testing services, simulation and virtual testing services, expert system services, and measurement data processing services

Specification for an application programming interface (API) to be used in Internet-enabled measurement

- Identification and classification of interfaces used in existing and emerging instruments
- Clarification of requirements for a commonly agreed API
- Specification of the commonly agreed API
- Guidance on use of the commonly agreed API

Applicability of Internet-enabled measurement

- Sharing and reviewing existing information on applicability of internet-enabled measurement
- Clarification of new application areas of internet-enabled measurements
- Sharing of information on real applications and lessons learned. Indicate in the comment form the present area of application

Best practice in uncertainty evaluation

Uncertainty evaluation in the context of testing

- Understanding the requirements of testing laboratories, the consequences on the design of measurement procedures, and the relationship to uncertainty evaluation in the context of calibration.
- Relating the uncertainty associated with a measurements result to decision-making in testing.
- Case studies to promote appropriate statistical tools and methods, including investigating their use, benefits and limitations. Identifying the need for further tools and methods.
- Influencing input to and review of outputs from the EA Expert Group on uncertainties in testing.

Methods for expressing and evaluating uncertainties

- Promoting the probabilistic basis of uncertainty evaluation, and its relationship to the Guide to the Expression of Uncertainty in Measurement (GUM).
- Case studies to compare methods for uncertainty evaluation, including analytical methods, the GUM approach (based on the law of propagation of uncertainty), the propagation of distributions (and its implementation by Monte Carlo simulation), non-parametric and resampling methods (such as the bootstrap and jack-knife), robust estimators for Type A standard uncertainty component, convolution, use of moments, mixture distributions, and others.
- Influencing input to and review of outputs from JCGM Working Group 1 on measurement uncertainty.

Methods for inter-laboratory (including key) comparison data evaluation

- Input to the development of guidelines for the evaluation of interlaboratory comparison data. Cases to be considered include interlaboratory comparisons for which (a) a travelling standard does not possess good short-term stability, (b) several traveling standards are circulated, and (c) there are mutual dependencies among some or all of the laboratories' measurements.
- Relating the protocols and data evaluation methods used by NMIs for key comparisons and other organisations for interlaboratory comparisons.
- Case studies to promote the application of guidelines developed for interlaboratory comparison data evaluation.
- Influencing input to and review of outputs from BIPM Director's Advisory Group on uncertainties, and other organisations concerned with interlaboratory comparisons.

Methods for expressing and evaluating uncertainties for multivariate models, including spectral quantities

- Identifying applications for which the output measurand is multivariate and for coverage regions (the extension of coverage intervals for a univariate output measurand) are required.
- Investigating methods for uncertainty evaluation for multivariate output measurands, with input to guides and Standards.
- Application to key comparison data evaluation in the case that measurements are made at each of a number of stipulated values of a parameter, such as wavelength or frequency.
- Influencing input to and review of outputs from JCGM Working Group 1 on measurement uncertainty.

Discrete modelling, data fusion and data fittingReview and evaluation of algorithms and software

- Algorithms and software for established discrete modeling and data fitting (e.g. using polynomials or splines).
- Algorithms and software for newer univariate and multivariate empirical modelling and approximation, based on radial basis functions, wavelets, rational functions, etc.
- Best practice optimisation algorithms and software for use in total least squares (TLS) and other newer approximation methods.
- Algorithms and software for Gauss-Markov regression (correlation in uncertainty matrix), generalised distance regression (measurement uncertainty associated with response and explanatory variables) and generalised Gauss-Markov regression (correlation, measurement uncertainty associated with response and explanatory variables).
- Parameter estimation algorithms and software, such as generalised maximum likelihood estimation appropriate for the probabilistic models used in data fusion.
- Algorithms and software for feature detection in signal processing and data fusion.
- Best practice optimisation algorithms and software for use in maximum likelihood approximation and generalised regression.
- Automatic differentiation software tools.

Best practice guidance and guidance on

- established discrete modelling and data fitting (e.g. using polynomials or splines), reviewing current guidance material and proposing how to agree upon and then produce MetroNet approved guidance.
- newer univariate and multivariate empirical modelling and approximation, based on radial basis functions, wavelets, rational functions, etc.
- total least squares (TLS) and other newer approximation methods, and analysis of their behaviour.
- maximum likelihood approximation for more general distributions such as student t and other long-tailed distributions, and their relationship to TLS and robust estimation methods.
- incorporation of best practice optimisation algorithms into regression methods.
- probabilistic models for data fusion based on statistical models of sensor behaviour
- feature detection methods, for use in signal processing and data fusion.
- automatic differentiation methods.

Case studies on the use of the guidance, algorithms and/or software in metrology

- in established discrete modeling and data fitting.
- in newer univariate and multivariate empirical modeling and approximation.
- in total least squares (TLS) and other newer approximation methods.
- in maximum likelihood approximation.
- on regression methods (Gauss-Markov regression, generalised distance regression, generalised Gauss-Markov regression).
- on use of probabilistic models for data fusion.
- on applications of data fusion to metrology.
- on feature detection in signal processing and data fusion.
- on use of automatic differentiation methods.

Databases in metrology

Collection and review of existing solutions (data models, interfaces, application areas)

- requirements and solutions for the conceptual model (data model) of measurement databases or other metrological databases, i.e. the structure and the relations of the database tables or objects
- requirements and solutions for the implementation of interactive user interfaces with respect to different user roles such as data retrieval, data management or administration;
- requirements and solutions for the implementation of interfaces to measurement systems for automatic data input and output
- specification of desired data base support that could so far not or only partly realized (as, for example, systems for supporting an integrated management of calibration data including reference/standard devices used during calibration, calibrated devices and their calibration history and further data), analysis of the problems

Exercises using selected solutions

- exercises and evaluation of the kernel of a template database for registering different kinds of measurement, processing and evaluation; (e.g., the solution of PTB realized on the basis of the relational concept and implemented with the MS Access tool as the database 'db1' (file name: db1.mdb));
- exercises and evaluation of existing, remotely accessible measurement databases such as the PTB bio-signal database or the test environment of the PTB web enabled database for non invasive blood pressure measurements, further examples are highly welcome;

Development of recommendations for using standard/non-standard databases

- elaboration of recommendations as conclusions from the gathered examples, experiences and discussions
- recommendations supporting the initial design decisions concerning appropriate system architecture (stand alone or multi-tier systems), suitable DBMS (database management system), and selection of appropriate standard data bases or spreadsheet programs;
- recommendations supporting the selection of suitable data modelling activities;
- recommendations supporting suitable navigational means in user interfaces of metrological databases.

Validation framework for metrological software

Development of a common understanding of validation of metrological software

- Collecting and specifying the issues
- Classification of different types of validation to meet different requirements (e.g. model validation, validation of numerical stability and correctness, validation of correct implementation)

Evaluation of validations performed / further examples that will be performed

- Sharing information on cases studies already performed or that will be initiated by this COP, and on tools/methods used
- Evaluation of case studies including feedback for classification and development of criteria
- Identification of examples to be used as best practice recommendations
- Initiating new example tools using existing methodologies (e.g. developing new reference datasets for numerical correctness testing)

Classification of requirements / user needs

- Development of class definitions and limitations (e.g., for the above mentioned classes)
- Selection of classes so that validation procedures for practical applications can be provided, and/or validation is urgently required
- Commenting on how well existing guidance material and procedures meet these requirements and user needs, particularly identifying gaps that need to be filled

Development of criteria

- Classification of software
- Applicability of existing standards, guides, etc.; agreement on which guidance material can be recommended for use
- Application of further procedures and methods
- Acceptance criteria of validations performed
- Transferability of validations performed for similar but not identical software
- How to fill the identified gaps in existing guidance material and procedures in order to meet the full set of requirements and user needs.

Appendix B

Prior IMEKO TC21: *The International Community* “Advanced Mathematical and Computational Tools in Metrology”

A short history 1993-2004

Franco Pavese, INRIM, Torino, Italy

In October 1993, an International Workshop on “Advanced Mathematical Tools in Metrology” (AMTM) was organised in Torino by F. Pavese (International Programme Committee: A. Balsamo (IMGC), W. Bich (IMGC), P. Ciarlini (IAC), M.G. Cox (NPL), R. Monaco (Politecnico, Torino), F. Pavese (IMGC), F. Righini (IMGC), P. Tavella (IEN)), with great success and more than 100 participants. A book with peer-reviewed papers arising from the Workshop presentations was published by World Scientific under the Series on Advances in Mathematics for Applied Sciences.

The initiative was intended for bridging the gap between

“... people in universities, research centres and industries who are involved in measurements and need advanced mathematical tools to solve their problems, and to whoever is working in the development of these mathematical tools. Metrology aims at performing measurements at the highest possible precision level. Advances in metrology depend on many factors, related to improvements in scientific and technical knowledge, in instrumentation quality, in a better use of advanced mathematical tools and in the development of new ones. Only a few metrological institutions in the world have a tradition of close co-operation between metrologists and mathematicians, and include a division of applied mathematics. The Workshop aims to increase the extent of such a co-operation by calling scientists from both the mathematical and the metrological fields to meet and exchange experiences. Several industrial sectors, particularly those of instrumentation and software, are likely to benefit from this process, since metrology has a high impact on the overall quality of industrial products and applied mathematics is becoming more and more important in industrial processes.”

As a follow up, a proposal for a cycle of EuroConferences was proposed under FP4 to the EU and IMGC won the bid (Contract ERBCHECCT940254, F.Pavese co-ordinator), allowing two other AMTM Conferences to be held in Oxford (UK) in 1995 and Berlin (DE) in 1996. One multi-author book was published in the same series after each Conference (see references). It was followed by another proposal to the EU, where the words “and Computational” were added to the title, and another Contract to IMGC was obtained with F.Pavese as co-ordinator for two more Euro Conferences (ERBFMMACT970244), AMCTM, held in 1999 in Oxford (UK) again and in 2000 in Lisboa (Portugal), with two additional books published.

In 2001 it was decided to propose an upgraded tool, a thematic network under FP5, with the same title of the previous Conferences and the acronym SofTools_MetroNet. Again we won the bid and a new Contract (G6RT-CT-2001-05061) was assigned to IMGC with F.Pavese as co-ordinator for the period 2002-2005, later extended to June 2005. In addition to several other activities (see the website www.amctm.org), an annual conference was organized, and in particular the sixth AMCTM Conference in Torino in 2003, ten years after the first (with a new AMCTM book published). The seventh AMCTM is planned in Lisbon in 2005.

The original group of promoters and book editors composed of persons from IMGC (F. Pavese), CNR-IAC (P. Ciarlini), NPL (M.G. Cox, A.B. Forbes), PTB (D. Richter), IPQ (E. Filipe)) has been widened, especially thanks to the Network, to several other active partners (details in the indicated

website). Good relationships exist with other activities in the same field in Europe and abroad, namely with the SSfM programmes in UK (which may be considered initially as a spin-off of AMCTM.).

In the past 10 years, many activities and co-operations have been taking place in Europe in the field of the developments of “soft tools”, pioneered by the AMCTM group. These activities have now been recognized as an important area of future work in metrology (e.g., by Euromet in its MERA Project) – *and in measurements in general*. Some of the fields covered by the activities within this international group (the Networks extends also beyond the EU, covering up to 19 countries: IT, FR, DK, PT, NO, NL, UK, DE, SP, SE, SI, PL, TR, FI, GR, RU, CA, NZ; plus BIPM, CERN and JRC-IRMM) are the following, in both the fields of metrology, and more recently and with increasing accent, of testing:

Advanced statistical modelling – uncertainty evaluation, experimental design, optimisation, data analysis, applications, etc.;

Metrology software – engineering aspects, requirement specification, risk assessment; software development, software examination, software tools for data analysis, visualisation, experiment control; best practice; standards, etc.;

Numerical methods – numerical data analysis, numerical simulation, inverse problems, uncertainty evaluation of numerical algorithms, applications, etc.;

Data fusion techniques; Design and analysis of inter-laboratory comparisons, etc;

Databases and related issues;

Software validation, etc.

A more comprehensive list of activities can be found in the website www.imeko-tc21.org under the link www.amctm.org and heading COP “Co-Operative Projects”.

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