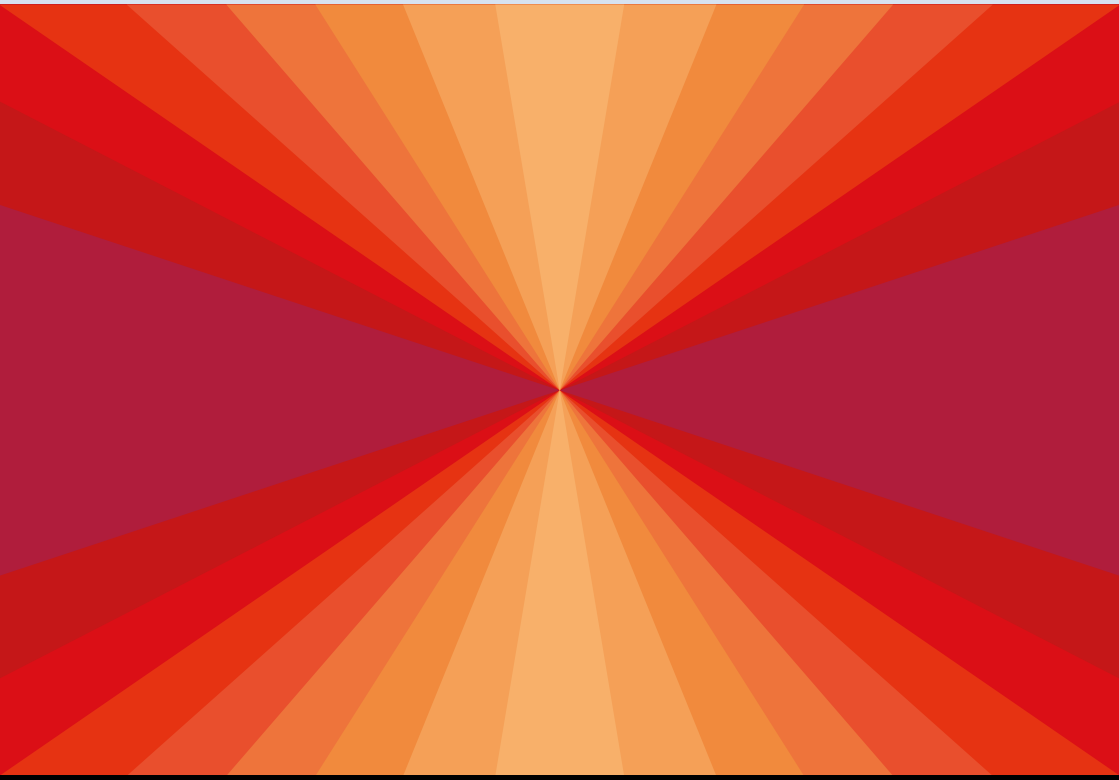
Measurement Science and Technology

iopscience.org/mst

Highlights

A compilation of outstanding papers from the last year and special 90th anniversary content



IOP Publishing | science first

How to submit your research

Are you inspired by all this great research and want your work to be included within our future collections? Here are our recommendations for successfully submitting your article to *Measurement Science and Technology*.

Plan

Consider the best way to structure your article before you start. *Measurement Science and Technology* does not have a template, but asks that you submit your manuscript in single-column, double-spaced format.

Choose a title that best serves your needs — an eye-catching one to attract as many readers as possible, or a descriptive one to engage readers with a specific interest in your area.

Give some thought to your abstract. It should very concisely describe the content of your article, and encourage readers to view the entire article. No jargon or undefined abbreviations should be used.

Writing

Be clear and concise. Consider the readership of your chosen journal, bearing in mind the knowledge expected of that audience. All content of your article should be relevant to your main scientific result.

Editing

Reconsider your original plan. You may decide to rewrite portions of your article to improve clarity and conciseness. You should repeat these processes over several successive drafts if necessary. Once the draft is ready to be submitted to the journal, carry out one final spelling and grammar check before submission.

Submission

All of our journals operate a fast online submission system. Simply visit the journal homepage **iopscience.org/mst** and click on the 'Submit an article' link. This will take you through to our online submission pages, where you will need to follow the steps described.

To help early career researchers prepare their papers for publication, we have published a digital brochure 'Introductory guide for authors' available at **iopscience.org/author-guide**.

Welcome

D J S Birch
Editor-in-Chief

In 1923 the newly formed Institute of Physics launched the *Journal of Scientific Instruments* to capture the essential information regarding the design and performance of instruments, which was then often unobtainable from books or articles focused on results. This journal, now *Measurement Science and Technology* (MST), has moved with the times over the 90 years since its first publication, changing its name and scope to ensure that it reflects the community that it serves, but the dissemination of useful measurement knowledge has always been its core purpose. We will be celebrating the sustained success of the journal with a series of articles and events throughout the year, including a 'Frontiers of Measurement' symposium at the Institute of Physics.

We continue to rely on our esteemed reviewers for their help in determining which articles make a significant contribution to the field of measurement. Their work is highly valued, not only by those of us who work directly on the journal, but also by the readers who can continue to refer to MST knowing that only work of a high standard is published here.

I also wish to thank the IOP Publishing team and the whole Editorial board of MST. Their professionalism, expertise and dedication have, together with the fine work of authors and reviewers, led directly to the journal's 2012 impact factor rising to its all-time high of 1.494. In research, as in commerce, competition raises quality and it is especially encouraging that our impact factor is now, for the first time, the highest in the sector of wide-ranging instrumentation and techniques.

From the Publisher

Ian Forbes
Publisher

Welcome to MST's highlights collection for 2012. As a journal with a broad scope we have endeavoured to select a group of papers that showcases the quality, impact and variety of the papers that we publish. There are many more papers of excellent quality that we are unable to include here, which can be found on IOPscience. An expanded version of this highlights collection can be found on our website alongside our 90th anniversary content at **iopscience.org/mst/90thanniversary**.

Our thanks must go out to our hard-working board members, guest editors, authors and referees who as ever support us in commissioning, organizing, submitting and reviewing excellent-quality work throughout the year, alongside their everyday work as scientists and engineers.

Contents

Cover image: An artistic interpretation of the error distribution in PIV image data, showing that when measuring the peripheral displacement in the *y*-direction, measurements performed close to the *x*-axis result in the highest errors **A Armellini *et al*** 2012 *Meas. Sci. Technol.* **23** 025302.

Introduction

Welcome to *Measurement Science and Technology*'s newest highlights collection, bringing you selected highlights from 2012, ordered by subject area. This booklet also contains some archival papers picked out by our editorial team to celebrate the 90-year anniversary of the launch of the journal's predecessor, *Journal of Scientific Instruments* – the world's first English-language measurement journal, which started regular publication in October 1923.

To find out more about our 90-year anniversary including free-to-read articles and a history of MST, visit **iopscience.org/mst/90thanniversary**

Journal scope

With 12 issues per year, *Measurement Science and Technology* publishes articles on new measurement techniques and associated instrumentation. Papers that describe experiments must represent an advance in measurement science or measurement technique rather than the application of established experimental technique. Authors must make this novel aspect clear, bearing in mind the multidisciplinary readership of the journal. Subject coverage includes the theory, practice and application of measurement in physics, chemistry, engineering, and the environmental and life sciences from inception to commercial exploitation.

Publications in the journal should emphasize the novelty of reported methods, characterize them and demonstrate their performance using examples or applications.

JOURNAL TEAM

Our dedicated *Measurement Science and Technology* team at IOP Publishing is here to ensure the peer-review and production processes run as smoothly as possible for our authors.

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Ian Forbes

Publishing Editor
Joan Patrick

Publishing Administrator
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Production Editor
Alan Evans

Marketing Executive
Fabrice Baker-Livingstone

Editorial board

History of Measurement Science and Technology

Measurement Science and Technology is the oldest measurement journal in the world. It was first published under the name *Journal of Scientific Instruments*, and was set up to be the official publication of the newly formed Institute of Physics.

The Institute of Physics held its inaugural meeting on 27 April 1921. In 1917 the Council of the Physical Society had started to explore with the Faraday Society, the Optical Society and the Roentgen Society ways of improving the professional status of physicists. The Institute was incorporated by special licence from the Board of Trade in November 1920, with the Royal Microscopical Society and the Roentgen Society associated as participating societies. Sir Richard Glazebrook was the first President of the Institute and in 1920 Sir Joseph Thompson was elected as its first Honorary Fellow.

The newly formed Institute needed a publication and, in May 1922, a preliminary issue of *Journal of Scientific Instruments* appeared. Regular publication began in October 1923.

The journal was initially edited at the National Physical Laboratory (NPL) under the supervision of a scientific advisory committee appointed by the Institute. The need for interdisciplinarity was recognized even then, with the desire to co-opt biologists, engineers, chemists and instrument makers, 'as well as physicists', on to the scientific advisory committee.

The journal's name was changed to *Journal of Physics E: Scientific Instruments* in 1968, the fifth in the Journals of Physics series, after the 1960 merger of the Institute of Physics and the Physical Society, and the subsequent combination of their applied physics journals.

In 1986 Institute of Physics Publishing was set up to be the sole vehicle through which the Institute's publishing was carried out.

In 1990 it was decided to rename the journal *Measurement Science and Technology* to reflect the shift away from many scientists making their own instruments and to recognize the new technology that would be of interest to researchers making measurements of physical, chemical and biological measurands.

IOP Publishing's full electronic journals service was launched in January 1996, ahead of other publishers. Today the journal flourishes under an international Editorial board and publishes hundreds of articles a year, which can be accessed from all over the world via libraries and the internet.

To find out more about MST and how we are celebrating its 90th anniversary, visit our '90 years of measurement' website at **iopscience.org/mst/90thanniversary**

A history of measurement

1920

1921

Inaugural meeting of the Institute of Physics held

1923

1930

Journal of Scientific Instruments begins regular publication

1934

James Chadwick discovers the neutron

1935

Radar invented at the National Physical Laboratory

1960

Merger of Institute of Physics with the Physical Society

1962

SQUID superconducting quantum interference device invented

He–Ne laser created at the Bell Telephone Laboratories

1964

Dorothy Hodgkin awarded Nobel prize for Chemistry for studying structure of crystals using x-ray diffraction

1968

Journal becomes *Journal of Physics E: Scientific Instruments*

1969

CCD invented by Boyle and Smith at AT&T Bell Labs

1985

Patrick Gill (NPL) achieves first UK laser cooling of trapped atoms

1986

IOP Publishing created

1988

Physics World magazine launched

1990

Journal is renamed *Measurement Science and Technology*

2000

A more detailed version of this timeline can be found on our 90 years of measurement webpage at **iopscience.org/mst/timeline**

1940

1941

Konrad Zuse presents the Z3 computer

1943

Tommy Flowers presents the Colossus computer

1947

Shockley, Bardeen and Brattain invent the first transistor

1950

1970

IOP granted Royal Charter

Silica optical fibres grown by Corning Incorporated

1971

The seventh base unit, the mole, added to the SI

1973

First meeting of the MRS held

1980

2003

Paul Lauterberg and Sir Peter Mansfield awarded the 2003 Physiology or Medicine Nobel prize for their discoveries concerning MRI

Digitised journal archive launched online

2010

IOPscience launched

2012

MST achieves impact factor of **1.494**, its highest ever

2013

Journal's 90th anniversary

Measurement science

J P Schwarz
University of Colorado /NIST (Boulder, CO) (now NOAA Earth System Research Laboratory)

The paper below by Schwarz *et al* was published in *Measurement Science and Technology* in 1999 as part of a special section entitled 'The Gravitational Constant: Theory and Experiment 200 Years After Cavendish'. The section was based on a meeting held in November 1998 at the Institute of Physics to mark the bicentenary of the publication of Cavendish's determination of Newton's constant of gravitation, relating back to the first measurements of *G* made by Henry Cavendish in the 1790s.

FROM THE ARCHIVES

A new determination of the Newtonian constant of gravity using the free fall method

J P Schwarz, D S Robertson, T M Niebauer and J E Faller

1999 *Meas. Sci. Technol.* **10** 478

We report on a recent determination of the Newtonian constant of gravity, *G*, using a new 'free fall' method. This method uses a freely falling test object to sense the gravitational field of a ring-shaped mass placed alternately above and below the drop region. The measurement of the changes in acceleration of the test object allow determination of *G*. Because the test mass is unsupported, systematic errors associated with the free fall method are significantly different from those of the traditional torsion experiments that constitute the great majority of *G* measurements. This characteristic makes this method potentially valuable in the context of today's uncertainty about the value of *G*.

The raw data have been examined in a variety of ways. We describe our methods which allow us to extract, besides *G*, information about various experimental parameters and possible systematic errors. A number of sources of systematic errors have been investigated, including magnetic and vibratory signals arising from the dropping action of our apparatus. We outline the steps we have taken to ascertain the magnitude of errors introduced by these effects.

Using the free fall method, we have completed a determination of *G*, obtaining a result of $G = (6.6873 \pm 0.0094) \times 10^{-11}\ m^3\ kg^{-1}\ s^2$.

MEASUREMENT SCIENCE

Error mapping of high-speed AFM systems

Petr Klapetek, Loren Picco, Oliver Payton, Andrew Yacoot and Mervyn Miles

2013 *Meas. Sci. Technol.* **24** 025006

In recent years, there have been several advances in the development of high-speed atomic force microscopes (HSAFMs) to obtain images with nanometre vertical and lateral resolution at frame rates in excess of 1 fps. To date, these instruments are lacking in metrology for their lateral scan axes; however, by imaging a series of two-dimensional lateral calibration standards, it has been possible to obtain information about the errors associated with these HSAFM scan axes. Results from initial measurements are presented in this paper and show that the scan speed needs to be taken into account when performing a calibration as it can lead to positioning errors of up to 3%.

Intelligent sampling for the measurement of structured surfaces

J Wang, X Jiang, L A Blunt, R K Leach and P J Scott

2012 *Meas. Sci. Technol.* **23** 085006

Uniform sampling in metrology has known drawbacks such as coherent spectral aliasing and a lack of efficiency in terms of measuring time and data storage. The requirement for intelligent sampling strategies has been outlined over recent years, particularly where the measurement of structured surfaces is concerned. Most of the present research on intelligent sampling has focused on dimensional metrology using coordinate-measuring machines with little reported on the area of surface metrology. In the research reported here, potential intelligent sampling strategies for surface topography measurement of structured surfaces are investigated by using numerical simulation and experimental verification. The methods include the jittered uniform method, low-discrepancy pattern sampling and several adaptive methods which originate from computer graphics, coordinate metrology and previous research by the authors. By combining the use of advanced reconstruction methods and feature-based characterization techniques, the measurement performance of the sampling methods is studied using case studies. The advantages, stability and feasibility of these techniques for practical measurements are discussed.

Sensors and sensor systems

Branko Glišić
Princeton University

Branko Glišić is assistant professor of civil and environmental engineering and head of the Structural Health Monitoring Lab at the Department of Civil and Environmental Engineering at Princeton University. He has two degrees in structural engineering and theoretical mathematics from the University of Belgrade, and gained his PhD at the Swiss Federal Institute of Technology Lausanne (EPFL). He has published three times in *Measurement Science and Technology*, and answers some questions about his work below.

Q & A

What led you to the research that you published in this paper?
Long-gauge fiber-optic strain sensors transformed the area of structural health monitoring (SHM), but their packaging must be carefully selected because it may alter the strain in a monitored structure. To accurately measure the strain and assess the condition of the structure, it is necessary to quantify the influence of geometrical and mechanical properties of the sensor on the measurement. The visit of Professor Calderón to my lab made this multidisciplinary research possible and his expertise in numerical modeling and construction materials was crucial.

Where do you see the work in your paper leading in the future?
The outcome of our paper is a good departure point for research into the accuracy of innovative fiber optic distributed strain sensors, while the developed methodology can be used to assess the accuracy of many other types of sensors, where the packaging may influence the measured quantity. In practical applications, the outcomes of our research can be extended to any other strain-sensing technology, e.g. vibrating wire-based sensors and resistive strain gauges.

Why did you select MST to publish this paper?
MST was a natural choice because the topic of our paper falls well within its scope, and the journal features high-quality papers and a positive international reputation. My experience is that MST uses an excellent set of reviewers who truly try to help authors to improve the paper rather than to simply criticize it, while keeping the overall time to publication much shorter than many other journals. In addition the correspondence with the MST staff is always smooth, with prompt and accurate answers to questions.

SENSORS AND SENSOR SYSTEMS

Pedro A Calderón
Universitat Politècnica de Valencia

Influence of mechanical and geometrical properties of embedded long-gauge strain sensors on the accuracy of strain measurement

Pedro A Calderón and Branko Glišić

2012 *Meas. Sci. Technol.* **23** 065604

In many civil and geotechnical applications it is of interest to monitor strain deep inside the structure; consequently, it is necessary to embed the sensors into the structure's material. Construction and geotechnical materials such as concrete and soil can be affected by local defects, e.g. cracks, air pockets and inclusions. To monitor them at a structural level it is necessary to use long-gauge sensors. As the sensor has to be embedded in the host material, its presence causes strain field perturbation and influences the strain measurement accuracy. The aim of this research was to identify the critical parameters that influence the strain measurement accuracy, to study how they it, and to give recommendations for sensor users. The study was based on finite element analysis and all materials were assumed to have the Möhr–Coulomb elastic, perfectly plastic behavior. Suitability of the numerical model was verified using the experimental results of two cases from the literature and one on-site application. The study revealed that the most important parameters that influence the strain measurement accuracy are the strain transfer between the host material and the sensor's anchor pieces, the ratio between the sensor's equivalent Young's modulus and the Young's modulus of the host material, the radius of the anchor piece and the gauge length. The numerical model and parametric study are presented along with practical recommendations.

CdSe/ZnS core/shell quantum dots as luminescence lifetime sensors for Cu^{2+}

Jens U Sutter, David J S Birch and Olaf J Rolinski

2012 *Meas. Sci. Technol.* **23** 055103

We report the use of CdSe/ZnS core/shell quantum dots QDot800 (Invitrogen) as luminescence lifetime sensors for copper ions $Cu^{2+}(H_2O)_8$ in solution with a sensitivity of <1 ppb, relevant to intracellular copper concentrations. Excitation of QDot800 at 485 nm was found to be optimum in that it caused no change in the level of luminescence intensity or lifetime in the absence of copper ions. When excited at 485 nm a bi-exponential luminescence decay of QDot800 was observed suggesting two distinct emitting states, both capable of undergoing metal ion quenching that facilitates Cu^{2+} detection. Selectivity for copper, as against other transition metal ions, as well as other evidence, suggests the primary origin of the quenching is luminescence resonance energy transfer to both free and bound copper ions. The luminescence kinetics of quantum dots and their optimization and applicability for resonance energy transfer-based lifetime sensing in general is discussed.

Optical and laser-based techniques

Christoph Weichert
Physikalisch Technische Bundesanstalt

Christoph Weichert is a researcher at the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, Germany. He has a diploma in technical physics from the Friedrich Schiller University of Jena. This is one of three 2012 MST papers he has contributed to.

Q & A

What led you to the research that you published in this paper?
The interferometer and phase meter were the result of a joint research programme called 'Nanotrace' founded by EURAMET. To provide improved traceable dimensional metrology a minimal uncertainty level was targeted.

Where do you see the work in your paper leading in the future?
The results obtained with this set-up should stimulate further research to minimize the uncertainty of interferometric displacement measurements.

Why did you select MST to publish this paper?
MST provides a useful forum for scientists in the area of dimensional metrology to exchange information and transfer novel peer-reviewed work to the scientific community.

A heterodyne interferometer with periodic nonlinearities smaller than ±10 pm

C Weichert, P Köchert, R Köning, J Flügge, B Andreas, U Kuetgens and A Yacoot

2012 *Meas. Sci. Technol.* **23** 094005

The PTB developed a new optical heterodyne interferometer in the context of the European joint research project 'Nanotrace'. A new optical concept using plane-parallel plates and spatially separated input beams to minimize the periodic nonlinearities was realized. Furthermore, the interferometer has the resolution of a double-path interferometer, compensates for possible angle variations between the mirrors and the interferometer optics and offers a minimal path difference between the reference and the measurement arm. Additionally, a new heterodyne phase evaluation based on an analogue to digital converter board with embedded field programmable gate arrays was developed, providing a high-resolving capability in the single-digit picometre range. The nonlinearities were characterized by a comparison with an x-ray interferometer, over a measurement range of 2.2 periods of the optical interferometer. Assuming an error-free x-ray interferometer, the nonlinearities are considered to be the deviation of the measured displacement from a best-fit line. For the proposed interferometer, nonlinearities smaller than ±10 pm were observed without any quadrature fringe correction.

OPTICAL AND LASER-BASED TECHNIQUES

Paul Köchert
Physikalisch Technische Bundesanstalt, Braunschweig

Phase measurement of various commercial heterodyne He–Ne-laser interferometers with stability in the picometer regime

P Köchert, J Flügge, Ch Weichert, R Köning and E Manske

2012 *Meas. Sci. Technol.* **23** 074005

In order to be able to resolve displacements of a picometer with widely used commercially available heterodyne interferometers, an advanced phase meter was developed at PTB. Key to this level of accuracy is the use of a state-of-the-art analogue-to-digital converter (ADC) board enabling the implementation of a phase-evaluation method by using embedded field programmable gate arrays. Experimental results obtained with commercially available heterodyne laser interferometer components prove that the proposed phase-evaluation procedure is capable of interpolating an optical fringe down into the picometer regime. The phase evaluation was moreover extended to track simultaneously two heterodyne beat frequencies with only two photodetectors and ADCs. Potential limitations of the long-term stability of heterodyne interferometers are discussed. The phase meter was tested, has been readily applied, can be easily adapted and is therefore to be used in a wide field of applications.

Dr Laura Russell
University College Cork (now Okinawa Institute of Science and Technology Graduate University)

Kieran Deasy
University College Cork (now University of Sheffield)

Sub-Doppler temperature measurements of laser-cooled atoms using optical nanofibres

Laura Russell, Kieran Deasy, Mark J Daly, Michael J Morrissey and Síle Nic Chormaic

2012 *Meas. Sci. Technol.* **23** 015201

We present a method for measuring the average temperature of a cloud of cold ^{85}Rb atoms in a magneto-optical trap using an optical nanofibre. A periodic spatial variation is applied to the magnetic fields generated by the trapping coils and this causes the trap centre to oscillate, which, in turn, causes the cloud of cold atoms to oscillate. The optical nanofibre is used to collect the fluorescence emitted by the cold atoms, and the frequency response between the motion of the centre of the oscillating trap and the cloud of atoms is determined. This allows us to make measurements of cloud temperature both above and below the Doppler limit, thereby paving the way for nanofibres to be integrated with ultracold atoms for hybrid quantum devices.

OPTICAL AND LASER-BASED TECHNIQUES

Multiplexing a serial array of tapered optical fibre sensors using coherent optical frequency domain reflectometry

Renata Jarzebinska, Edmon Chehura, Stephen W James and Ralph P Tatam

2012 *Meas. Sci. Technol.* **23** 105203

The use of high spatial resolution optical frequency domain reflectometry (OFDR) to facilitate the multiplexing of a serial array of tapered optical fibre sensors is presented. Changes in the attenuation of the Rayleigh backscattered signal from the tapered regions are used to monitor the refractive index of the surrounding medium. The use of an array of five tapered regions to monitor liquid flow is demonstrated. An analysis of the performance of the system shows that, for tapers of diameter 50 μm, up to nine tapers could be multiplexed using commercial OFDR instrumentation.

TOPICAL REVIEW

Optical fibre laser velocimetry: a review

Thomas O H Charrett, Stephen W James and Ralph P Tatam

2012 *Meas. Sci. Technol.* **23** 032001

Reviews the use of optical fibres in point-wise laser velocimetry techniques such as laser Doppler velocimetry and laser transit anemometry, as well as in planar measurement techniques such as particle imaging velocimetry and planar Doppler velocimetry.

Measurement methods for fluids

The fluids section has a strong showing in this year's highlights, with three topical reviews from 2013's first issue (see p19). It also includes a a paper (Oishi *et al*, below) by previous winners of an MST Outstanding Paper Award. Masamichi Oishi, on behalf of all of his co-authors, was presented with the award for 'Simultaneous measurement of internal and surrounding flows of a moving droplet using multicolour confocal micro-particle image velocimetry (micro-PIV)' at the 2012 APS Division of Fluid Mechanics meeting in San Diego in November 2012 by MST board member Professor John Foss.

See our website for more information on the Outstanding Paper Awards at **iopscience.org/mst**

Professor Marie Oshima
The University of Tokyo

Continuous and simultaneous measurement of the tank-treading motion of red blood cells and the surrounding flow using translational confocal micro-particle image velocimetry (micro-PIV) with sub-micron resolution

M Oishi, K Utsubo, H Kinoshita, T Fujii and M Oshima

2012 *Meas. Sci. Technol.* **23** 035301

In this study, a translational confocal micro-particle image velocimetry (PIV) system is introduced to measure the microscopic interaction between red blood cells (RBCs) and the surrounding flow. Since the macroscopic behavior of RBCs, such as the tank-treading motion, is closely related to the axial migration and other flow characteristics in arterioles, the measurement method must answer the conflicting demands of sub-micron resolution, continuous measurement and applicability for high-speed flow. In order to avoid loss of the measurement target, i.e. RBCs, from the narrow field of view during high-magnification measurement, the translation stage with the flow device moves in the direction opposite the direction of flow. The proposed system achieves the measurement of higher absolute velocities compared with a conventional confocal micro-PIV system without the drawbacks derived from stage vibration. In addition, we have applied a multicolor separation unit, which can measure different phases simultaneously using different fluorescent particles, in order to clarify the interaction between RBCs and the surrounding flow. Based on our measurements, the tank-treading motion of RBCs depends on the shear stress gradient of the surrounding flow. Although, the relationship between the tank-treading frequency and the shear rate of the surrounding flow is of the same order as in the previous uniform shear rate experiments, our results reveal the remarkable behavior of the non-uniform membrane velocities and lateral velocity component of flow around the RBCs.

MEASUREMENT METHODS FOR FLUIDS

Miguel R Oliveira Panão
Technical University of Lisbon

Assessment of measurement efficiency in laser- and phase-Doppler techniques: an information theory approach

Miguel R Oliveira Panão

2012 *Meas. Sci. Technol.* **23** 125304

Laser- and phase-Doppler diagnostic techniques provide information on particle characteristics in the form of discrete probability distribution functions. Most methods assess the information required for an accurate measurement through the 1st- and 2nd-order moments of these. However, considering that a measurement sufficient for an accurate statistical analysis. The methodology and stopping criteria are presented and used in previously reported measurements obtained with laser- and phase-Doppler techniques. Results show that using an IT approach to assess the reliability of data provided by a measurement means evaluating the degree of stabilization of a discrete probability distribution, where more information acquired doesn't necessarily imply a more accurate measurement. The statistical analysis performed using the number of samples indicated by the IT method, compared to the total sample size previously measured, has similar results. Measurement time is reduced if the IT method is used, improving efficiency.

R Theunissen
University of Bristol

Theoretical analysis of direct and phase-filtered cross-correlation response to a sinusoidal displacement for PIV image processing

R Theunissen

2012 *Meas. Sci. Technol.* **23** 065302

The response of PIV image processing routines adopting cross-correlation is commonly categorized as that of a moving average (MA) filter. This paper addresses the intrinsic response of the statistical operator to a sinusoidal displacement from a theoretical perspective. Evaluation of the derived analytical expressions for the correlation indicates the response is to not behave as that of an MA filter, contrary to the generally adopted simplification. Instead the inherent signal modulation is non-linear and is determined by the ratio between displacement amplitude and particle image diameter. This finding is expected to be important and have implications for recursive image processing routines. Also, readily available spectral filtering techniques are assessed in terms of effectiveness in minimization of correlation deterioration due to pixelization and displacement filtering inherent to particle image self-correlation. It is shown that the best possible correlation response in digital PIV is dictated by the convolution between particle image self-correlation and displacement distribution function, retaining particle image inherent amplitude modulation.

MEASUREMENT METHODS FOR FLUIDS

Samuel G Raben
Virginia Tech,
Blacksburg, VA

Adaptive gappy proper orthogonal decomposition for particle image velocimetry data reconstruction

Samuel G Raben, John J Charonko and Pavlos P Vlachos

2012 *Meas. Sci. Technol.* **23** 025303

This work presents a novel method for replacing erroneous measurements in digital particle image velocimetry (DPIV) data using an adaptive reconstruction with gappy proper orthogonal decomposition (POD). Previous studies have shown that gappy POD can be used to replace erroneous data with high accuracy. Conventional gappy POD methods employ a spatially constant number of modes for reconstructing the missing information across the entire field. In contrast, the method presented herein proposes a locally adaptive criterion that allows for determination of the optimum number of POD modes required for the reconstruction of each replaced measurement. This reconstruction produces higher accuracy results using more POD modes than with previous POD methods. The new method was compared against commonly utilized techniques for DPIV vector replacement, namely Kriging, bootstrapping and basic interpolation, as well as previously presented POD reconstruction techniques. The results showed that the adaptive gappy POD reconstruction provides higher accuracy and robustness.

TOPICAL REVIEW

Tomographic PIV: principles and practice

Fulvio Scarano

2013 *Meas. Sci. Technol.* **24** 012001

TOPICAL REVIEW

Review of ultra-high repetition rate laser diagnostics for fluid dynamic measurements

Brian Thurow, Naibo Jiang and Walter Lempert

2013 *Meas. Sci. Technol.* **24** 012002

TOPICAL REVIEW

Three-phase flow measurement in the petroleum industry

R Thorn, G A Johansen and B T Hjertaker

2013 *Meas. Sci. Technol.* **24** 012003

Imaging techniques

Peter Mansfield
Now emeritus professor at the University of Nottingham, UK

Research activity in NMR imaging entered a particularly fruitful period between 1980 and 1990. With the advent of high-speed imaging and sensor arrays, research output and system development led to important medical imaging applications.

Peter Mansfield at the University of Nottingham, later to become Sir Peter Mansfield, pioneered much of this work with various collaborators. The first hint of developments that were to take place was publications in 1976, including the paper below published in *Journal of Physics E: Scientific Instruments*, with further contributions in the following two decades. In 1988, Mansfield was awarded the Duddell Medal and Prize by the Institute of Physics. In 2003, P C Lauterbur and Sir Peter Mansfield were jointly awarded a Nobel Prize in Physiology or Medicine for their discoveries concerning MRI.

FROM THE ARCHIVES

Fast scan proton density imaging by NMR

P Mansfield, A A Maudsley and T Bains

1976 *J. Phys. E: Sci. Instrum.* **9** 271

A new fast scanning method of producing proton density images by NMR is described which could be useful for the examination of plants as well as biological tissue *in vivo*. Examples are given of images produced from small samples of plant and biological material. Calculations show that imaging equipment, if scaled to deal with objects of human proportions, could under ideal conditions produce pictures close to television quality in times ranging down to a few minutes by this method.

TOPICAL REVIEW

Measuring protein dynamics with ultrafast two-dimensional infrared spectroscopy

Katrin Adamczyk, Marco Candelaresi, Kirsty Robb, Andrea Gumiero, Martin A Walsh, Anthony W Parker, Paul A Hoskisson, Nicholas P Tucker and Neil T Hunt

2012 *Meas. Sci. Technol.* **23** 062001

Reviewing recent advances in the methodology and application of ultrafast two-dimensional infrared (2D-IR) spectroscopy to biomolecular systems.

IMAGING TECHNIQUES

Carlo Dri, Friedrich Esch, Cristina Africh and Giovanni Comelli
IOM-CNR Laboratorio TASC, Technische Universität München, University of Trieste

How to select fast scanning frequencies for high-resolution fast STM measurements with a conventional microscope

Carlo Dri, Friedrich Esch, Cristina Africh and Giovanni Comelli

2012 *Meas. Sci. Technol.* **23** 055402

The implementation of fast measurement modes in conventional scanning tunneling microscopes (STM) generally implies that at least the fast scanning frequency reaches or exceeds the first resonance frequency of the scanning stage. We present a straightforward protocol for the determination of accessible frequency windows, where high spatial resolution can be routinely achieved and maintained during the fast scanning movement. This protocol relies on a simple, *in situ* method to locate these frequency windows by measuring the response in the characteristic probe signal while varying the tip–sample distance. The method is compared to other approaches used to characterize the resonant behavior of STMs. In principle, the protocol can also be applied to other types of scanning probe microscopes with sufficiently fast probe signal detection, as a general approach to upgrade these instruments to faster imaging rates.

M Soleimani
University of Bath

H Y Wei
University of Bath

Volumetric magnetic induction tomography

H-Y Wei, L Ma and M Soleimani

2012 *Meas. Sci. Technol.* **23** 055401

Magnetic induction tomography (MIT) is a new and emerging type of tomography technique that is able to map the passive electromagnetic properties (in particular conductivity) of an object. Because of its non-invasive feature, it becomes a suitable technique for many industries, such as metal processing and mining. This paper presents a volumetric MIT (VMIT) system based on an existing measurement setup in our 2D system (MIT Mk-I). By increasing the number of sensors in the axial direction, volumetric imaging can be realized and hence can improve the spatial resolution of the reconstructed images. All of the system control, data acquisition and signal demodulation are accomplished by a commercial data acquisition card and the National Instruments graphical programming language. In this paper, both the system architecture and the forward 3D sensitivity model will be presented. The image reconstruction scheme is modified by introducing a 3D sensitivity map to replace the previous 2D sensitivity map used for the MIT Mk-I system. The iterative Landweber technique was implemented as the inverse solver to reconstruct the images. Several laboratory-based experimental results are demonstrated in this paper, with different shapes of imaging objects. The reconstructed images are satisfactory showing for the first time volumetric conductivity reconstruction using a multi-layer MIT system. The results indicate the high-quality image reconstruction using our novel VMIT system for potential use in industrial applications, such as metal flow imaging.

Spectroscopy

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Magnetic induction spectroscopy: non-contact measurement of the electrical conductivity spectra of biological samples

A Barai, S Watson, H Griffiths and R Patz

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Measurement of the electrical conductivity of biological tissues as a function of frequency, often termed 'bioelectrical impedance spectroscopy (BIS)', provides valuable information on tissue structure and composition. In implementing BIS though, there can be significant practical difficulties arising from the electrode–sample interface which have likely limited its deployment in industrial applications. In magnetic induction spectroscopy (MIS) these difficulties are eliminated through the use of fully non-contacting inductive coupling between the sensors and sample. However, inductive coupling introduces its own set of technical difficulties, primarily related to the small magnitudes of the induced currents and their proportionality with frequency. This paper describes the design of a practical MIS system incorporating new, highly-phase-stable electronics and compares its performance with that of electrode-based BIS in measurements on biological samples including yeast suspensions in saline (concentration 50–400 g l^{-1}) and solid samples of potato, cucumber, tomato, banana and porcine liver. The shapes of the MIS spectra were in good agreement with those for electrode-based BIS, with a residual maximum discrepancy of 28%. The measurement precision of the MIS was 0.05 S m^{-1} at 200 kHz, improving to 0.01 S m^{-1} at a frequency of 20 MHz, for a sample volume of 80 ml. The data-acquisition time for each MIS measurement was 52 s. Given the value of spectroscopic conductivity information and the many advantages of obtaining these data in a non-contacting manner, even through electrically-insulating packaging materials if necessary, it is concluded that MIS is a technique with considerable potential for monitoring bio-industrial processes and product quality.

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SPECTROSCOPY

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On the calculation of the *D*-optimal multisine excitation power spectrum for broadband impedance spectroscopy measurements

B Sanchez, C R Rojas, G Vandersteen, R Bragos and J Schoukens

2012 *Meas. Sci. Technol.* **23** 085702

The successful application of impedance spectroscopy in daily practice requires accurate measurements for modeling complex physiological or electrochemical phenomena in a single frequency or several frequencies at different (or simultaneous) time instants. Nowadays, two approaches are possible for frequency domain impedance spectroscopy measurements: (1) using the classical technique of frequency sweep and (2) using (non-)periodic broadband signals, i.e. multisine excitations. Both techniques share the common problem of how to design the experimental conditions, e.g. the excitation power spectrum, in order to achieve accuracy of maximum impedance model parameters from the impedance data modeling process. The original contribution of this paper is the calculation and design of the *D*-optimal multisine excitation power spectrum for measuring impedance systems modeled as 2R-1C equivalent electrical circuits. The extension of the results presented for more complex impedance models is also discussed. The influence of the multisine power spectrum on the accuracy of the impedance model parameters is analyzed based on the Fisher information matrix. Furthermore, the optimal measuring frequency range is given based on the properties of the covariance matrix. Finally, simulations and experimental results are provided to validate the theoretical aspects presented.

TOPICAL REVIEW

Photoacoustic spectroscopy for analytical measurements

Christoph Haisch

2012 *Meas. Sci. Technol.* **23** 012001

Summarising basic principles and possible applications of photoacoustic and other optothermal methods for analytical measurements.

Techniques for materials and materials processing evaluation

Jiří J Mareš
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Application of the electrostatic Thompson–Lampard theorem to resistivity measurements

Jiří J Mareš, Pavel Hubík and Jozef Krištofik

2012 *Meas. Sci. Technol.* **23** 045004

A method for measurement of resistivity of flat samples and thin layers complementary to the well-known van der Pauw technique has been proposed. The method is based on the application of the Thompson–Lampard theorem of electrostatics used in metrology for the realization of calculable capacitor, according to which a large variety of electrode systems can be designed. A prototypic electrode arrangement is shown on which the practical performance of the method was tested.

Yi Lu
Iowa State University

John R Bowler
Iowa State University

Four-point probe measurements of a direct current potential drop on layered conductive cylinders

Yi Lu and John R Bowler

2012 *Meas. Sci. Technol.* **23** 115603

We have determined the steady state electric field due to direct current flowing via point contacts at the cylindrical surface of a uniformly layered conductive rod of finite length. The solution allows one to use four-point probe potential drop measurements to estimate the conductivity or thickness of the layer assuming that the other parameters are known. The electrical potential in the rod has a zero radial derivative at its surface except at the injection and extractions points. This means that the required solution can be expressed in terms of a Green's function satisfying a Neumann boundary condition. Four-point measurements have been made to demonstrate the validity of theoretical results.

TECHNIQUES FOR MATERIALS AND MATERIALS PROCESSING EVALUATION

Experimental setup for measurements of transport properties at high temperature and under controlled atmosphere

Céline Byl, David Bérardan and Nita Dragoe

2012 *Meas. Sci. Technol.* **23** 035603

Several devices able to measure the Seebeck coefficient have been devised over the years but most of these were designed to perform under vacuum or under inert atmosphere. We describe here a system designed for measuring thermoelectric power, electrical resistivity and differential conductance up to 1200 K, under the controlled partial pressure of oxygen including vacuum or reducing atmosphere for samples that are sensitive to oxygen, which allows the *in situ* investigation of the electrical properties of oxide materials and their phase diagram. The instrument we present here can also be used to 'tune' the properties of a compound through thermal treatment. This system is reliable and has been in use in our laboratory for more than three years.

Zhanwei Liu
Beijing Institute of Technology

Xiaobo Yang
Beijing Institute of Technology

A real time deformation evaluation method for surface and interface of thermal barrier coatings during 1100 °C thermal shock

Xiaobo Yang, Zhanwei Liu and Huimin Xie

2012 *Meas. Sci. Technol.* **23** 105604

A simple high temperature resistant speckle manufacturing technology and a high temperature micro digital image correlation method were developed and applied to study the real time deformation of thermal barrier coatings' (TBCs) near-interface regions and surfaces during a thermal shock of 1100 °C. This method was used to measure the displacement and strain fields of TBCs and to analyze the strain evolution of TBCs at high temperature. During the thermal shock heating stage, tensile and shear strain concentrations were found in the ceramic coat near the ceramic coat/bond-coat interface, indicating that the inner regions of the ceramic coat near the interface are a weak link because of the tensile and shear stress concentrations here during the process of thermal shock cycles. Experimental results show that this method can be applied to strain distribution regularity investigation of TBCs' near-interface regions and surfaces in an 1100 °C thermal shock environment.

Measurement techniques for biological, medical and life science applications

In the 1970s, new technology was having a dramatic effect on measurement science. There were greater opportunities for experimental innovation interfaced with electronic feedback and control.

There were further opportunities arising from digital data and digital signal processing. Interest also grew with applications of measurement in the life sciences. These included this paper on electronic measurement of bacterial growth, along with techniques for the measurement of tissue impedance using a vector impedance meter, and on image recovery from nuclear magnetic resonance (NMR) imaging systems.

FROM THE ARCHIVES

Electronic measurement of bacterial growth

J C S Richards, A C Jason, G Hobbs, D M Gibson and R H Christie

1978 *J. Phys. E: Sci. Instrum.* **11** 560

The growth and multiplication of bacterial cells in a nutrient medium can be monitored by measuring changes in the AC conductivity at constant temperature produced by charged metabolites; the method is faster, more accurate and requires less labour than traditional viable counting. Two instruments are described; one presents conductance changes directly on a chart recorder; the other can handle up to 128 samples at a time, and normally feeds the data to a computer for processing. Methods of obtaining bacteriological parameters (mean generation time, lag time, inoculum number, etc.) from conductivity measurements are briefly described.

MEASUREMENT TECHNIQUES FOR BIOLOGICAL, MEDICAL AND LIFE SCIENCE APPLICATIONS

An interfacial stress sensor for biomechanical applications

K Sundara-Rajan, A Bestick, G I Rowe, G K Klute, W R Ledoux, H C Wang and A V Mamishev

2012 *Meas. Sci. Technol.* **23** 085701

This paper presents a capacitive sensor that measures interfacial forces in prostheses and is promising for other biomedical applications. These sensors can be integrated into prosthetic devices to measure both normal and shear stress simultaneously, allowing for the study of prosthetic limb fit, and ultimately for the ability to better adapt prosthetics to individual users. A sensing cell with a 1.0 cm^2 spatial resolution and a measurement range of 0–220 kPa of shear and 0–2 MPa of pressure was constructed. The cell was load tested and found to be capable of isolating the applied shear and pressure forces. This paper discusses the construction of the prototype, the mechanical and electrode design, fabrication and characterization. The work presented is aimed at creating a class of adaptive prosthetic interfaces using a capacitive sensor.

Active flexible concentric ring electrode for non-invasive surface bioelectrical recordings

G Prats-Boluda, Y Ye-Lin, E Garcia-Breijo, J Ibañez and J Garcia-Casado

2012 *Meas. Sci. Technol.* **23** 125703

Bioelectrical surface recordings are usually performed by unipolar or bipolar disc electrodes even though they entail the serious disadvantage of having poor spatial resolution. Concentric ring electrodes give improved spatial resolution, although this type of electrode has so far only been implemented in rigid substrates and as they are not adapted to the curvature of the recording surface may provide discomfort to the patient. Moreover, the signals recorded by these electrodes are usually lower in amplitude than conventional disc electrodes. The aim of this work was thus to develop and test a new modular active sensor made up of concentric ring electrodes printed on a flexible substrate by thick-film technology together with a reusable battery-powered signal-conditioning circuit. Simultaneous ECG recording with both flexible and rigid concentric ring electrodes was carried out on ten healthy volunteers at rest and in motion. The results show that flexible concentric ring electrodes not only present lower skin–electrode contact impedance and lower baseline wander than rigid electrodes but are also less sensitive to interference and motion artefacts. We believe these electrodes, which allow bioelectric signals to be acquired non-invasively with better spatial resolution than conventional disc electrodes, to be a step forward in the development of new monitoring systems based on Laplacian potential recordings.

Instrumentation for environmental and atmospheric measurements

Mackereth published the paper below in 1964, concerning an improved galvanic cell for the determination of oxygen concentrations in fluids. This subject is of interest for environmentalists wishing to measure the condition of river water and lakes. The paper was highly cited, and the author went on to publish a book entitled *Water Analysis: Some Revised Methods for Limnologists*.

FROM THE ARCHIVES

An improved galvanic cell for determination of oxygen concentrations in fluids

F J H Mackereth

1964 *J. Sci. Instrum.* **41** 38

An improved membrane protected galvanic cell oxygen-temperature probe is described. The device produces a high electrical output and displays great stability of sensitivity to oxygen over long periods of use. It is used to determine or record oxygen concentrations in liquids or gases.

Did you know?

The *Journal of Scientific Instruments* (the journal's predecessor, 1923–67) had a section called 'New Instruments and Tools', where manufacturers (both companies and individuals) could communicate their new or improved instrumentation and advertise their sale.

Examples included 1938's 'Laboratory pick-up tongs' (Griffin and Tatlock, London, threepence each), 1938's 'Spectacle magnifier' (Newbold and Bulford, Ltd, London, two pounds five shillings each) and 1940's 'An electrical calculator' (Ionic Laboratories, Bucks., four shillings and sixpence each).

INSTRUMENTATION FOR ENVIRONMENTAL AND ATMOSPHERIC MEASUREMENTS

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Onboard calibration and monitoring for the SWIFT instrument

P Rahnama, W Gault, I McDade and G Shepherd

2012 *Meas. Sci. Technol.* **23** 105801

The SWIFT (Stratospheric Wind Interferometer for Transport studies) instrument is a proposed space-based field-widened Doppler Michelson interferometer designed to measure stratospheric winds and ozone densities using a passive optical technique called Doppler Michelson imaging interferometry. The onboard calibration and monitoring procedures for the SWIFT instrument are described in this paper. Sample results of the simulations of onboard calibration measurements are presented and discussed. This paper also discusses the results of the derivation of the calibrations and monitoring requirements for the SWIFT instrument. SWIFT's measurement technique and viewing geometry are briefly described. The reference phase calibration and filter monitoring for the SWIFT instrument are two of the main critical design issues. In this paper it is shown that in order to meet SWIFT's science requirements, Michelson interferometer optical path difference monitoring corresponding to a phase calibration accuracy of $\sim 10^{-3}$ radians, filter passband monitoring corresponding to phase accuracy of $\sim 5 \times 10^{-3}$ radians and a thermal stability of 10^{-3} K s^{-1} are required.

K S Paulson
University of Hull

The measurement of rain kinetic energy and rain intensity using an acoustic disdrometer

P Winder and K S Paulson

2012 *Meas. Sci. Technol.* **23** 015801

Microwave engineers and geomorphologists require rainfall data with a much greater temporal resolution and a better representation of the numbers of large raindrops than is available from current commercial instruments. This paper describes an acoustic instrument that determines rain parameters from the sound of raindrops falling into a tank of water. There is a direct relationship between the kinetic energy (KE) of a raindrop and the acoustic energy that it creates upon impact. Rain KE flux density is estimated from measurements of the sound field in the tank, and these have been compared to measurements from a co-sited commercial disdrometer. Eight months of data have been collected in the eastern UK. Comparisons of rain KE estimated by the two instruments are presented and links between the KE and rainfall intensity are discussed. The sampling errors of the two instruments are analysed to show that the acoustic instrument can produce rain KE measurements with a 1 s integration time with sampling uncertainty of the same size as commercial instruments using a 1 min integration time.

Novel instrumentation

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TransMIT Centre for Adaptive Cryotechnology and Sensors, Giessen

A new Ultra Precision Interferometer for absolute length measurements down to cryogenic temperatures

R Schödel, A Walkov, M Zenker, G Bartl, R Meeß, D Hagedorn, C Gaiser, G Thummes and S Heltzel

2012 *Meas. Sci. Technol.* **23** 094004

A new Ultra Precision Interferometer (UPI) was built at PTB. It was designed for highly precise absolute length measurements of prismatic bodies, e.g. gauge blocks, under well-defined temperature conditions and pressure, making use of phase stepping imaging interferometry. The UPI enables some enhanced features, e.g. it is designed for a much better lateral resolution and better temperature stability. In addition to the original concept, the UPI is equipped with an external measurement pathway (EMP) in which a prismatic body can be placed alternatively. The temperature of the EMP can be controlled in a much wider range than the interferometerís main chamber. An appropriate cryostat system, a precision temperature measurement system and improved imaging interferometry were established to permit absolute length measurements down to cryogenic temperature, demonstrated for the first time ever. Results of such measurements are important for studying thermal expansion of materials from room temperature towards <10 K.

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A microwave resonance dew-point hygrometer

R J Underwood, R Cuccaro, S Bell, R M Gavioso, D Madonna Ripa, M Stevens and M de Podesta

2012 *Meas. Sci. Technol.* **23** 085905

We report the first measurements of a quasi-spherical microwave resonator used as a dew-point hygrometer. Conventionally, the condensation of water from humid gas flowing over a mirror is detected optically, and the mirror surface is temperature-controlled to yield a stable condensed layer. In our experiments we flowed moist air from a humidity generator through a quasi-spherical resonator and detected the onset of condensation by measuring the frequency ratio of selected microwave modes. We verified basic operation over the dew-point range 9.5–13.5 °C by comparison with calibrated chilled-mirror hygrometers. These tests indicate that the microwave method may allow a quantitative estimation of the volume and thickness of the water layer condensed on the inner surface of the resonator. The experiments reported here are preliminary due to the limited time available, but show the potential of the method for detecting not only water but a variety of other liquid or solid condensates. The robust all-metal construction should make the device appropriate for use in industrial applications over a wide range of temperatures and pressures.

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