XI' AN JIAOTONG UNIVERSITY

HARBIN INSTITUTE OF TECHNOLOGY

HEFEI UNIVERSITY OF TECHNOLOGY

ISMTII 2017

Metrology - Master Global Challenges

22-25 September 2017

Xi'an, China

The 13th International Symposium
on Measurement Technology and Intelligent Instruments

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ISMTII 2017 Final Program

22 September	
14:00-20:00	Registration (Empark Grand Hotel)
19:00-21:00	ICMI Meeting (Empark Grand Hotel)

23 September			
7:30-8:00	Registration (Empark Grand Hotel)		
8:00-8:30	Opening Ceremony (Banquet Hall) / Group photo		
8:30-9:15	**Plenary Keynote Session 1** (Banquet Hall) Prof. Dame Jane Jiang, University of Huddersfield **Topic: Manufacturing infratechnology** Chair: Prof. Kuang-Chao Fan		
9:15-10:00	**Plenary Keynote Session 2** (Banquet Hall) Prof. Hans Nørgaard Hansen, Technical University of Denmark **Topic: Quality assurance in micro manufacturing** Chair: Prof. Wei Gao		
10:00-10:20	Coffee Break		
10:20-11:05	**Plenary Keynote Session 3** (Banquet Hall) Prof. Wei Gao, Tohoku University **Topic: Precision manufacturing metrology based on scanning probe systems** Chairs: Prof. Hans Nørgaard Hansen		
11:05-11:50	**Plenary Keynote Session 4** (Banquet Hall) Prof. Shulian Zhang, Tsinghua University **Topic: Recent development for precision measurement based on laser oscillatingtechnology** Chair: Prof. Dame Jane Jiang		
12:00-13:30	Lunch (Coffee House)		
	International Hall	Conference Room No.7	Conference Room No.10
14:00-14:30	**Invited Talk 1** Prof. B.C.F. Cheung, Hong Kong Polytechnic University **Topic:** Autostereoscopic metrology for precision measurement of 3D microstructured surfaces Chairs: Prof. Haihua Cui, Prof. Liandong Yu	**Invited Talk 2** Prof. S. Takahashi, University of Tokyo **Topic:** High sensitive and super resolution optical inspection of nanodefects on Si wafer surface using infrared standing evanescent wave Chairs: Prof. Lingbao Kong, Dr. Mingjun Ren	**InvitedTalk 3** Prof. A. Abou-Zeid, Physical technical federal institute **Topic:** Laser interferometric length measurements Chairs: Prof. Xiangchao Zhang, Dr. Jiarui Lin
14:30-15:50	**Session 1** Optical Metrology (I) (Paper ID: 44, 46, 48, 53) Chairs: Prof.Haihua Cui, Prof. Liandong Yu	**Session 2** Sensors and Actuators (I) (Paper ID: 18,76, 87, 114) Chairs: Prof. Lingbao Kong, Dr. Mingjun Ren	**Session 3** Machine Vision and Image Processing (I) (Paper ID:16, 33, 61, 66) Chairs: Prof. Xiangchao

			Zhang, Dr. Jiarui Lin
15:50-16:10	Coffee Break		
16:10-17:30	**Session 4** Optical Metrology (II) (Paper ID: 65, 70, 72, 80) Chairs: Prof. Haihua Cui, Prof. Liandong Yu	**Session 5** Sensors and Actuators (II) (Paper ID: 140, 172, 185, 224) Chairs: Prof. Lingbao Kong, Dr. Mingjun Ren	**Session 6** Machine Vision and Image Processing (II) (Paper ID: 88, 118, 138, 201) Chairs: Prof. Xiangchao Zhang, Dr. Jiarui Lin
17:30-18:30	**Poster Session 1** (Jindian Hall) Paper ID: 79, 237, 238, 183, 197, 209, 217, 229, 20, 34, 54, 60, 129, 21, 81, 99, 141, 40, 51, 97, 115, 116, 130, 135, 226, 236, 239,122, 306		
19:00-21:00	Welcome Reception (Coffee house)		

24 September			
8:00-8:45	**Plenary Keynote Session 5** (Banquet Hall) Professor HaraldBosse, Physical technical federal institute **Topic: Metrology and precision engineering: yesterday-today-tomorrow** Chair: Prof. Shulian Zhang		
8:45-9:30	**Plenary Keynote Session 6** (Banquet Hall) Prof. Martin Booth, University of Oxford **Topic: Dynamic optics for microscopy and photonic engineering** Chair: Prof. Harald Bosse		
9:30-9:50	Coffee Break		
9:50-10:35	**Plenary Keynote Session 7** (Banquet Hall) Prof. Richard Leach, University of Nottingham **Topic: Information-rich metrology: changing the game** Chair: Prof. Seung-Woo Kim		
	International Hall	Conference room No.7	Conference room No.10
10:35-11:50	**Session 7** Optical Metrology (III) (Paper ID: 82, 83, 101, 102) Chair: Dr. Fang Cheng	**Session 8** Sensors and Actuators (III) (Paper ID: 225, 251, 252, 253) Chair: Prof. Satoru Takahashi	**Session 9** Machine Vision and Image Processing (III) (Paper ID: 255, 307, 316, 339) Chair: Dr. Lina Fei
12:00-13:30	Lunch (Coffee house)		
14:00-14:30	**Invited Talk 4** Prof. Liandong Yu, Hefei University of Technology **Topic:** Techniques of fringe projection profilometry for complicated surface measurement Chairs: Prof. Benny Chi-Fai Cheung, Prof.Yongmeng	**Invited Talk 5** Dr. Jiarui Lin , Tianjin University **Topic:** Coordinate measurement accuracy ana lysis of large-scaleheteroge neous network Chairs: Prof. Ping Cai, Dr. Ian Forbes	**Invited Talk 6** Dr. Lina Fei, Zeiss Industrial Metrology **Topic:** Future of manufacturing metrology in industry 4.0 Chairs: Prof. Ahmed Abou-Zeid, Prof. Jian Liu

	Liu		
14:30-15:50	**Session 10** Optical Metrology (IV) (Paper ID: 107, 110, 128, 137) Chairs: Prof. Benny Chi-Fai Cheung, Prof.Yongmeng Liu	**Session 11** Sensors and Actuators (IV) (Paper ID: 260, 250, 263, 265) Chairs: Prof. Ping Cai, Dr. Ian Forbes	**Session 12** Micro and Nano Metrology (I) (Paper ID: 23, 84, 91, 94) Chairs: Prof. Ahmed Abou-Zeid, Prof. Jian Liu
15:50-16:10	Coffee Break		
16:10-17:30	**Session 13** Optical Metrology (V) (Paper ID: 175, 194, 198, 207) Chairs:Prof. Benny Chi-Fai Cheung, Prof.Yongmeng Liu	**Session 14** Sensors and Actuators (V) & Calibration and Machine Tool Performance (I) (Paper ID: 268, 328, 50, 149) Chairs: Prof. Ping Cai, Dr. Ian Forbes	**Session 15** Micro and Nano Metrology (II) (Paper ID: 155, 159, 165, 196) Chairs:Prof. Ahmed Abou-Zeid, Prof. Jian Liu
17:30-18:30	**Poster Session 2** (Jindian Hall) Paper ID: 279, 289, 308, 205,295, 241, 266, 273, 67, 154, 164, 89,52, 142, 171,232, 247, 151,158, 166, 177, 186,203,261, 262, 264, 271, 315, 333, 353		
19:00-21:00	Conference Banquet / Award ceremony (Banquet Hall)		

25 September			
8:30-9:15	**Plenary Keynote Session 8** (Banquet Hall) Prof. Seung-Woo Kim, Korea Advanced Institute of Science & Technology **Topic: Ultrafast photonics for precision measurement and instrumentation** Chair: Prof. Liang-Chia Chen		
9:15-10:00	**Plenary Keynote Session 9** (Banquet Hall) Prof. Liang-Chia Chen, National Taiwan University Topic: **Evolution and advance of microscopic confocal profilometryforin-situ automated optical inspection** Chair: Prof. Martin Booth		
10:00-10:20	Coffee Break		
	International Hall	Conference room No.7	Conference room No.10
10:20-11:50	**Session 16** Optical Metrology (VI) (Paper ID: 216, 233, 243, 282) Chair: Dr. Fang Cheng	**Session 17** Calibration and Machine Tool Performance (II) (Paper ID: 150,189,199, 240) Chair: Prof. Ping Cai	**Session 18** Micro and Nano Metrology (III) & Surface Metrology (I) (Paper ID: 200, 259, 63, 113) Chair: Prof. Satoru Takahashi
11:50-13:00	Lunch (Coffee house)		
13:00-14:30	Laboratory visit		

14:30-15:00	**Invited Talk 7** Dr. Fang Cheng, Advanced Remanufacturing and Technology Centre **Topic:** Enhanced industrial measurement assisted by augmented reality Chairs: Prof. Yongsheng Gao, Dr. Lina Fei	**Invited Talk 8** Dr. Hao. Jiang, Huazhong University of Science and Technology **Topic:** Latest research progress on Mueller matrix ellipsometry for anometrology Chairs: Prof. Zonghua Zhang, Prof.Haihua Cui	**Invited Talk 9** Dr. Ian Forbes，Institute of Physics Publishing **Topic:** How to get published Chairs: Prof. Jie Lin, Dr. Feng Gao
15:00-16:20	**Session 19** Optical Metrology (VII) & In-Process and Online Metrology (I) (Paper ID: 288, 340, 17, 181) Chairs: Prof. Yongsheng Gao, Dr. Lina Fei	**Session 20** Intelligent Instruments for Automation (I) (Paper ID: 85, 86, 109, 152) Chairs: Prof. Zonghua Zhang, Prof.Haihua Cui	**Session 21** Surface Metrology (II) (Paper ID: 133, 285, 297, 338) Chairs: Prof. Jie Lin, Dr. Feng Gao
16:20-16:40	Coffee Break		
16:40-18:00	**Session 22** In-Process and Online Metrology (II) (Paper ID: 206,222,231,300) Chairs: Prof. Yongsheng Gao, Dr. Lina Fei	**Session 23** Intelligent Instruments for Automation (II) & Management of Measurement Processes (Paper ID: 168, 213, 275, 210) Chairs: Prof. Zonghua Zhang, Prof. Haihua Cui	**Session 24** Surface Metrology (III) & Material Characterization (Paper ID: 345, 31, 281, 283) Chairs: Prof. Jie Lin, Dr. Feng Gao
18:00-19:00	Poster Session 3 (Jindian Hall) Paper ID: 326, 358, 337, 280, 376, 364, 375, 96, 117, 119, 256, 335, 351,356, 234, 248, 272, 284, 322, 277, 299, 352, 355, 363, 367, 368, 370,93		
19:00-21:00	Close Remark		

26 - 27 September
Technical Tours

Conference Chair

Prof. Zhuangde Jiang, Xi'an Jiaotong University, China

Professor Zhuangde Jiang is a distinguished professor in the field of MEMS and nanotechnology. He is an academician of Chinese Academy of Engineering and a professor of Xi'an Jiaotong University (XJTU). He is also the Honorary Professor of University of Birmingham in UK, a visiting professor of The University of New South Wales in Austria, and the Adjunct Professor of Shanghai Jiaotong University. He was the former vice president of XJTU from 2004 to 2014 and is the vice director of Science and Technology Committee of Ministry of Education since 2014. In addition, Professor Jiang is affiliated with a number of committeesat national levels. He is the director of Strategic Steering Committee under the State Council, the Head of mechanical discipline assessment of National Science and Technology Award Committee, vice chairman of Chinese Society of Micro-Nano Technology, and President of Shaanxi Provincial Association of Science and Technology.

Professor Jiang has engaged in a long-term research in micro-nano manufacturing, precision measurement and precision machining technology and equipment. He has made outstanding contributions to the mechanical scientific and technological fields of high temperature pressure sensor, MEMS devices, and digital precision measurement technology and equipment. He has also carried on creative researches in relative theories of micro-nano technology.

Prof. Jiang has won many prizes and awards, including the National Award of Technological Innovation, one National Award of Science and Technology Progress, and eight provincial and ministerial level awards. He is also the recipient of the Prize for Scientific and Technological Progress of Ho Leung Ho Lee Foundation. Prof. Jiang has authored or co-authored more than300publications indexed by SCI and EI,edited 2 books, and obtained and100 Chinese patents, 1 USA patent and 15 software copyrights. He also got one Excellence Award of Chinese Patent. He has chaired more than 20 important international and national academic conferences, and has delivered more than 20 Plenary and Keynote talks in the international conferences.

Plenary Keynote Sessions

Plenary Keynote Session 1 (Banquet hall)

Day 2, Sep. 23, 8:30-9:15 am

Prof. Dame Jane Jiang

University of Huddersfield

Biography:

Professor Dame Jane Jiang holds a UK Royal Academy of Engineering/Renishaw Chair in Precision Metrology and is the Director of the EPSRC National Centre for Innovative Manufacturing in Advanced Metrology. She obtained her PhD in measurement science in 1995, a Professorial Chair in 2003, a DSc for precision engineering in 2007. More recently she received a Damehood in the 2017 Queen's Birthday Honours for services to manufacturing and engineering. Jane is leading the creation of the concept of the 'Factory on the Machine' and 'Manufacturing Infratechnology' for future Manufacturing. Jane is an internationally respected research leader in advanced metrology, involves two major aspects: mathematical models and algorithms for geometrical products specification and metrology, including geometric shape, tolerancing, and surface texture analysis, filtration and parametric characterisation; and optical interferometry technology for embedded measurement, including wavelength/frequency scanning interferometry and optical chip interferometry.Jane is a Fellow of the Royal Academy of Engineering (FREng), a Fellow of the International Academy of Production Research / Collège International pour la RechercheenProductique (FCIRP) and the Institute of Engineering Technology (FIET). Jane is an editor for Natural Group Journal: Light Science and Applications and a principle member of ISO TC/213 GPS committee. She has published more than 400 paper; was awarded a Royal Society Wolfson Research Merit Award in 2006 and the Sir Harold Hartley Medal in 2014.

Talk Title: Manufacturing infratechnology

Abstract:

This talk is will discuss the essential scientific foundations for the future manufacturing of high valued products. Manufacturing is going through a 'disruptive revolution', from traditional, through innovation to future breakthrough factories that are fully intelligent and digitalised, allowing autonomous, cloud and distributed manufacturing during 2025-2050. This demands the creation of completely new technologies and methodologies to make design, production and quality control of complex products intelligently and automatically and thereby suitable for future production.However, current scientific understanding of high value manufacturing is far behind the autonomous target; it is much slower than the development of scientific computing technology which can be ready to support the 'Internet of Things' in time. This is a consequence of the lack of science fundaments, knowledge and enabling technologies.The talk will concentrate on how to create infratechnology for future manufacturing of high valued products and establish scientific fundamentals and revolutionary technology to accelerate a transformation in high value manufacturing. These include fundamentals for imaginative product design and metrology, embedded sensors/instrumentation and breakthroughs in-process quality control.

Plenary Keynote Session 2 (Banquet hall)
Day 2, Sep. 23, 9:15-10:00 am

Prof. Hans Nørgaard Hansen

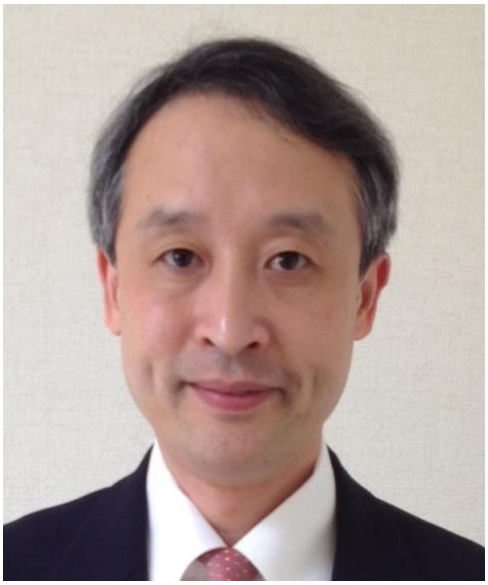
Technical University of Denmark

Biography:
Professor Hans Nørgaard Hansen is professor of Micro Manufacuring at the Department of Mechanical Engineering of which he is also the head. He obtained his PhD in geometrical metrology in 1997 and became professor in 2002.Hans's main research area is micro manufacturing. This includes the entire value chain from design of micro mechanical systems over manufacturing process chains to quality assurance and metrology. Processes included are for example tooling technologies for micro injection moulding and micro metal forming, mass production methods (micro injection moulding and micro metal forming) and material removal processes (micro machining, micro EDM, micro laser machining). The integration of single processes into coherent process chains and production systems including the necessary quality assurance activities is the ultimate goal of the research. Hans is a Fellow of the International Academy of Production Research (CIRP), The International Society for Nanomanufacturing and the Danish Academy of Technical Sciences. He is member of the European Society for Precision Engineering and nanotechnology (euspen) and he acted as president for euspen 2015-2017.

Talk Title: Quality assurance in micro manufacturing

Abstract:
The talk will address the topic of metrology and quality assurance in manufacturing of components and products with characteristic length scales in the sub-mm area. In this dimensional area metrology plays a major role both in terms of component validation and as a major tool in understanding and optimizing processes and process chains. The combination of both a product and process perspective is essential in finding viable solutions. When dimensions are scaled down, tolerances are typically not scaled down at the same rate, and this results in increased demands to metrology in terms of traceability and measurement uncertainty. The talk will present examples of these challenges and possible solutions.

Plenary Keynote Session 3 (Banquet hall)
Day 2, Sep. 23, 10:20-11:05 am



Prof. Wei Gao

Tohoku University

Biography:
Wei Gao received his Bachelor of Precision Instrumentation from Shanghai Jiao Tong University, China, in 1986, followed by MSc and Ph. D from Tohoku University, Japan, in 1991 and 1994, respectively. He is currently a professor and the director of Research Center for Precision Nanosystems, Department of Finemechanics of Tohoku University. He research interests lie primarily in the field of precision engineering, specialized in precision metrology and micro/nano-metrology. He and his group have developed a number of surface form measurement systems as well as a couple of optical sensor technologies for precision measurement and nanometrology. He is a fellow of the International Academy for Production Engineering (CIRP), the International Society for Nanomanufacturing (ISNM), and the Japan Society for Precision Engineering (JSPE). He serves as the Chairman of The Scientific Technical Committee Precision Engineering and Metrology of CIRP and also served as a Vice President of JSPE in 2015. He is working/ has worked as editor/editorial board member for several major international journals in the field of precision engineering and metrology such as Precision Engineering and IEEE Transactions on Instrumentation and Measurement. He is the author of the book "Precision Nanometrology" (Springer). He and his group have won five Paper Awards from JSPE.

Talk Title: Precision manufacturing metrology based on scanning probe systems

Abstract:
When manufacturing a precision workpiece, it is a common operation to measure the manufactured workpiece for quality control and feedback manufacturing. It is effective to make the precision manufacturing metrology in a place and at a time as close as possible to the manufacturing process for assurance of accuracy and efficiency of the measurement operation as well as the manufacturing process. Precision manufacturing metrology technologies can be classified into in-situ, in-line, on-machine or in-process metrology, based on the where and how the metrology is carried out. In many cases, precision manufacturing cannot be accomplished without a proper precision manufacturing metrology technology. Very large surface fabrication, ultra-precision surface machining, complicated freeform surface fabrication, ultra-fast laser processing, 3D Additive manufacturing, micro-structured surface stitching, extremely high reliability part manufacturing are some of the examples. In this keynote, the definitions of precision manufacturing metrology technologies will first be made clearly. Then the needs, benefits and limitations, as well as the specifications required for the related technologies will be specified, together with an overview of the state-of-the-art scanning probe systems that have been developed in the past decade.

Plenary Keynote Session 4 (Banquet hall)
Day 2, Sep. 23, 11:05-11:50 am

Prof. Shulian Zhang

Tsinghua University

Biography:
Professor, TsinghuaUniversity. Bachelor degree and master degree of Tsinghua University, The former director of The Key Lab of Precision Measurement Technology and Instruments at Tsinghua University from Feb.1997 to Apr. 2008 and the director of Optic-Electrical Engineering Institute of Tsinghua University from Aug. 1993 to Apr. 2004. Member of OSA, OSC, SPIE, Vice director of the Optic-electrical Technology Society. Formeror present visiting Professor of several universities: Kassel University, Engineering School ENSEEIHT of Toulouse, Beijing Jiaotong University, Huanan Normal University, Zhejiang Science and Tech. University. So far, He has taughtmore than 60 PHD and Master Students. More than 300 papers; More than 60Patents; Book: Monograph: "Fundamental of Orthogonally Polarized Lasers", Tsinghua University Press, 2005; themonograph"Orthogonal Polarization in Lasers: physical phenomena and Applications", Wiley andTsinghua University Press, 2013. Two Second-Class National awards for technological invention, 2007 and 2010;twoFirst-Class Science and Technology Awardsof National Education Ministry, 1994 and 2006; one First-Class Science and Technology Award of Electrical Society of China; three Second-class Science and Technology Award by Beijing and Electrical Society of China.

Talk Title: Recentdevelopment for precision measurement based on laser oscillating-technology

Abstract:
The presentation introduces the progress of precision measurement technology basedon Laser oscillating technology, which measure target displacement and opticalbirefringent through optical oscillating in laserinside. The technology was of high precisionand great progress and has great development potential. And it should be known and utilizedwidely. The presentation includes duel frequency lasers with high precision, high power, and high/stable frequency difference and little non-linearity; measurement instruments of birefringence and wave plates as the standard and in-site; the self-mixing solid laser feedback interferometers with Nanometer resolution and small drift; and other instrumentswith new principle. These instruments have been opening new ways for precisionmeasurement.

Plenary Keynote Session 5 (Banquet hall)
Day 3, Sep. 24, 8:00-8:45 am

Prof. HaraldBoss

Physikalisch-technischeBundesanstalt

Biography:
Professor Harald Bosse, head of Physikalisch-Technische Bundesanstalt (PTB) Division 5 "Precision Engineering" and consulting professor in Harbin Institute of Technology, works on Surface Metrology, Dimensional Nanometrology, Coordinate Metrology, Interferometry on Material Measures and Scientific Instrumentation since 2009. Bosse is author or co-author of more than 150 peer-reviewed papers. His research interests are in the area of Precision Engineering, Dimensional Metrology and Nanometrology .

Talk Title: Metrology and precision engineering: yesterday - today - tomorrow

Abstract:
The development of the system of units has always been linked to the increasing requirements from science, society and industry on the one hand and the opportunities offered by new technological developments on the other hand. In this contribution, this interdependence will be discussed with a focus on the redefinition of the International System of Units, the SI, which is foreseen to be accepted in 2018 and to be put into force on the World Metrology Day on the 20th of May, 2019. Examples of the contributions from Precision Engineering to the revised SI will be discussed: precision manufacturing and dimensional metrology enabled high accuracy determinations of a set of natural constants, whose numerical values will be fixed in the revised SI system namely, h, k, e and NA. This approach follows the route which was taken in 1983 when the unit of length, the metre, was defined by fixing the numerical value of the speed of light in vacuum. In addition to the progress related to the redefined SI, the contribution will also discuss results from recently finished projects in dimensional metrology, which were coordinated within the European Metrology Research Programme of EURAMET. These projects addressed several open issues in different technical fields ranging from nanometrology over microsystems metrology and metrology for advanced manufacturing to long distance metrology. These projects will not be explained in detail, however, their major research results will be identified along with their impact on the further development of dimensional metrology and precision engineering. The analysis of the project results will also be taken into account for a discussion of the future requirements on dimensional metrology to be applied in a distributed manufacturing infrastructure discussed in concepts such as industry 4.0.

Plenary Keynote Session 6 (Banquet hall)
Day 3, Sep. 24, 8:45-9:30 am

Prof. Martin Booth

University of Oxford

Biography:
Prof Booth is Professor of Engineering Science at the University of Oxford. His research group is based jointly in the Department of Engineering Science and the Centre for Neural Circuits and Behaviour. His research involves the development and application of adaptive optical methods in microscopy, laser-based materials processing and neuroscience. He was appointed Professor of Engineering Science in 2014. In 2012 Prof Booth was awarded the "Young Researcher Award in Optical Technologies" from the Erlangen School of Advanced Optical Technologies at the University of Erlangen-Nürnberg, Germany, and a visiting professorship at the university. In 2014 he was awarded the International Commission for Optics Prize. He has over ninety publications in peer-reviewed journals. He is Editor-in-Chief of the journal of Optics Communications and Chair of the Institute of Physics Photon conference.

Talk Title: Dynamic optics for microscopy and photonic engineering

Abstract:
The capabilities of high-resolution optical systems are considerably enhanced through the use of dynamic optical elements, such as deformable mirrors or liquid crystal spatial light modulators. These elements can be used to perform adaptive optical correction of aberrations or dynamic beam shaping. I explain how these methods are being used in microscopy to overcome the problems of specimen-induced aberrations, extending the effective imaging depth of a range of microscopes. Further developments are extending this approach into super-resolution microscopies, such as stimulated emission depletion (STED), single molecule localisation and structured illumination microscopes. Another area of application of dynamic optics is in laser micro and nano-fabrication. I will show a number of methods through which such methods are improved by dynamic optics, including aberration correction and parallelization for three-dimensional structuring of materials. These methods are being developed for the manufacture of photonic devices, such as waveguides, and the precision machining of various materials. Particular applications include waveguide circuits for quantum optics, laser writing of colourcentres in diamond, novel polymer/liquid crystal structures and diamond-based radiation detectors.

Plenary Keynote Session 7 (Banquet hall)
Day 3, Sep. 24, 9:50-10:35 am

Prof. Richard Leach

University of Nottingham

Biography:
Professor Richard Leach, Chair in Metrology at The University of Nottingham, is an internationally recognised expert in engineering nanometrology, surface topography measurement, traceability and optical instrument design. Formerly a principal research scientist at the UK National Physical Laboratory, Richard has made extensive contributions to the theoretical advancement and practical use of dimensional metrology systems, including Fizeau, Michelson, Twyman-Green, homodyne and low coherence interferometers, scatterometers, fringe projection, photogrammetry, and contact stylus systems and probes. He is a leader in several professional societies, a prolific author of technical papers, books and book chapters, and a visiting professor at Loughborough University and the Harbin Institute of Technology.

Talk Title: Information-rich metrology: changing the game

Abstract:
Often when we manufacture something, and especially when we use precision or additive manufacturing, we have a large amount of information about the object being manufactured, for example, the CAD data gives us the nominal form, and we have usually characterised the surface texture to a high degree of confidence. Information-rich metrology (IRM) is the combination of accurate modelling of the interaction of the measurement system with the object being measured with the a priori information that is available in manufacturing. In many cases, the a priori information allows us to solve the complex mathematical problems we encounter when trying to model he interaction with the object being measured (inverse problems), in many case employing tools from computer science. IRM can allow us to minimise the measurement time and increase the spatial bandwidth in which we measure (for example, by allowing us to measure high slope angles using multiple reflections). Specific examples discussed are an all-optical CMM for precision components and, form, texture, internal geometry and in-process measurements for additive components.

Plenary Keynote Session 8 (Banquet hall)
Day 4, Sep. 25, 8:30-9:15 am

Prof. Seung-Woo Kim

Korea Advanced Institute of Science&Technology

Biography:
Professor Seung-Woo Kim's professional interests are precision optical technology with specialty on optical-mechanics system synthesis for precision machines design, optical interferometry for 3-D surface and thin-film metrology, and ultrafast photonics for nano-scale fabrication and ultra-precision measurements.During last three decades he has published ~150 technical papers in peer-reviewed journals, ~240 presentations in conferences, and ~50 patents. He has been working as principal investigator for numerous national and industrial research projects and currently involved in an important national creative research initiative project for the development of next generation precision engineering key technologies using femtosecond pulse lasers. He has also actively been involved in international academic societies for organizing on-time conferences for leading-edge precision engineering optical technologies. He was president of the Korea Society of Precision Engineering (KSPE) during the term of 2011 and is currently a member of OSA (Optical Society of America), SPIE (International Society of Optical Engineering), CIRP (International Academy for Production Engineering), and euspen (European Society Precision Engineering).

Talk Title: Ultrafast photonics for precision measurement and instrumentation

Abstract:
Precision measurement and instrumentation is essential for most of strategically important technologies including IT, BT, NT and aerospace engineering. With ever-increasing demands on precision, various laser sources have been used to attain sub-wavelength precision in many fields of measurements and instrumentation. The precision-directed laser photonics will continue to advance to the direction of ultra-precision to achieve better resolutions, larger functional ranges, higher throughputs, and more improved stability. Particularly, the light sources available today are limited in the wavelength bandwidth, photon energy, spatial and temporal coherence, and peak power, which consequently hinders breakthroughs toward the realm of ultra-precision. Ultrafast photonics is to investigate the technological possibilities of femtosecond lasers with the aim of establishing the new foundation for ultra-precision that will cover the fundamental physical quantities of time, frequency, length and distance over extensive ranges as demanded in the next generation of precision engineering. To the end, a systematic approach will be pursued to generate noble coherent light sources covering the broad optical spectrum spanning from THz waves, infrared, visible to extreme violet light radiation by making the most of ultrafast femtosecond laser pulses.

Plenary Keynote Session 9 (Banquet hall)

Day 4, Sep. 25, 9:15-10:00 am

Prof. Liang-Chia Chen

National Taiwan University

Biography:

Prof. Liang-Chia Chen is currently working as a distinguished professor in the Department of Mechanical Engineering of National Taiwan University (NTU) in Taiwan. Prior to embarking on his teaching career in Taiwan, he worked as a full-time research engineer in Gerard Industries in Australia from 1997-2001 and Institute of nuclear energy research (INER) in Taiwan from 1991-1994. Before joining NTU, he worked as a distinguished professor in National Taipei University of Technology. He was the winner of the outstanding research award from the Ministry of Science and Technology (MOST) of Taiwan in 2016, Taiwanese national year-invention gold awards consecutively in 2013 & 2014 and the 2014 outstanding award on technology transfer from MOST of Taiwan. His major research fields are in precision metrology and manufacturing, automated optical inspection (AOI), opto-mechatronics instrumentation, and 3-D machine vision and algorithms for automation. To date, he has published one textbook, two book chapters, more than 100 referred journal papers and more than 60 invention patents internationally. He is currently served as the president of the international committee of measurement and instrumentation (ICMI). He is a member of SPIE, the society of Taiwan precision engineering, the Institution of Engineers of Australia (IEA), SME and Chinese Institute of Engineers.

Talk Title: Evolution andadvance of microscopic confocal profilometry forin-situautomated optical inspection

Abstract:

The application of automated optical inspection (AOI) to advanced manufacturing processes with tight tact time and specifications is critical in winning today's global competition. In the past decades, great effort had been devoted to developing novel solutions for in-line optical inspection of surfaces and the dynamic characteristics of tested components or devices. Conventional approaches to micro-scale 3D profilometry have adopted novel optics or concepts in confocal microscopy for measuring 3D surface characteristics with high speed and precision. One-shot measurement capability is demanded to minimize measured uncertainty from environmental vibration or system instability. Nevertheless, extremely high-speed microscopic 3D profilometric methodologies for 100 % full-field inspection are yet to be developed. This talk intends to review the technical evolution and development trend of confocal surface profilometry in overcoming bottlenecks and developing feasible solutions. For the next significant move in 3D profilometry, obviously, the lateral resolution of the measurement currently impeded by the diffraction limit should be enhanced. Novel manufacturing technologies, such as roll-to-roll nano-imprinting or nano-scale semiconductor lithography processes, require accurate reconstruction of surfaces with a lateral resolution of less than 100 nm, which is ten times better than what can be achieved by current microscopic technologies. Therefore, innovative far-field optical measurement methods for solving the detection limit are not only of academic interest, but of great significance to industrial innovation.

Invited Talk Session 1 (International Hall)
Day 2, Sep. 23, 14:00-14:30 pm

Prof. Benny Chi-Fai Cheung

Hong Kong Polytechnic University

Biography:
Benny Chi-Fai Cheungis Professor and an Associate Head of the Partner State Key Laboratory of Ultra-precision Machining Technology in the Department of Industrial and Systems Engineering of The Hong Kong Polytechnic University. His research interests include ultra-precision machining, advanced optics manufacturing, modelling and simulation of nano-surface generation, precision metrology, etc. Up to now, he has authored and co-authored over 200 research papers in various refereed journals and more than 140 of them are published in various Science Citation Indexed (SCI) journals. He has been actively involved in organizing a number of international conferences and has been invited to deliver keynote speeches and invited talks at various international conferences, seminars, and forums. Currently, he holds various honorary positions including Adjunct Professorship of Changchun University of Science and Technology, Board Membership of the Asian Society for Precision Engineering and Nanotechnology (ASPEN), etc. He has received many research prizes and awards including the "First Runner Up" award in the category of "Engineering and Technology" at the 2008 ASAIHL-Scopus Young Scientist Awards in 2008, Joseph Whitworth Prize 2010 by the Manufacturing Industrial Division of The Institution of Mechanical Engineers (IMechE), UK in 2011, 2, a Gold medal in the 44th International Exhibition Inventions New Techniques & Products in Geneva in 2016, etc.

Title: Autosteroscopic metrology for precision measurement of 3Dmicrostructured surfaces

Abstract: Three dimensional (3D) microstructured surfaces such as pyramids, microlens array and V-grooves are widely used in the development of a wide range of products to realize specially designed optical and mechanical functions. The geometry of these surfaces has to be precise to ensure their functional performance. However, the complexity of 3D-structured surfaces creates considerable difficulty for the control of the manufacturing process and quality assessment. Autostereoscopic metrology is an emerging technology which provides a new perspective for the measurement of 3D microstructured surfaces through single image capturing of one camera, and the extraction of the three dimensional information can be accomplished by stereo matching process. It not only provides a compact system setup but is also capable of fast data acquisition and high accuracy in 3D reconstruction of the surfaces under a shop floor environment. In this presentation, the development of a disparity pattern-based autostereoscopic metrology system for precision measurement of 3D surfaces is presented. The system makes use of a micro lens array (MLA) to capture raw 3D information of the measured surface in a single snapshot through a CCD camera. Hence, a 3D digital model of the target surface with the measuring data is generated through a system-associated direct extraction of disparity information (DEDI) method. Experimental results show that the proposed system is capable of measuring precision surfaces with sub-micrometer measuring repeatability.

Invited Talk Session 2 (Conference room No.7)
Day 2, Sep. 23, 14:00-14:30 pm

Prof. Satoru Takahashi

University of Tokyo

Biography:
Satoru Takahashi, born 1969, received his bachelor's and master's degrees in the Mechanical Engineering for Industrial Machinery and Systems from Osaka University, Japan in 1993 and 1995, respectively. He received his doctor degree from Osaka University in 2002. He is currently working as a full professor of the University of Tokyo (UTokyo), Japan, and leads the Photon based dvanced Manufacturing Science Division of the Research Center for Advanced Science and Technology (RCAST) of UTokyo. His research interests include the nano-in-process measurement, nano-scale-metrology, and nano/micro microfabrication using the advanced optics based on not only far-field optics but also localized photon energy such as evanescent light, near-field light, and so on. In parallel, he worked at the University of Toronto, Canada in 2011,as a visiting professor. He is a member of the ASPE, euspen, JSPE, JSME, and CIRP andhas been awarded various prizes from national academic communities, including three JSPE Best Awards, four JSPE Best Paper Awards, two JSPE Numata Memorial Prize, and has also received various international awards of euspen Recommended Poster (2007), IMEKO Award Certification of Merit for the Paper (2007), ASPEN Best Paper Award (2009), Outstanding Paper Award of ISMQC (2010), and Certificate of Merit forOutstanding Presentation of LEM (2013 and 2015).

Title: High sensitive and super resolution optical inspection of nanodefects on Si wafer surface using infrared standing evanescent wave

Abstract:
In this talk, I would like to present a novel optical measurement technique that enables the sensitive evaluation of microdefects on a Si semiconductor wafer surface beyond the diffraction limit even under far-field conditions, which implies that time-consuming processes such as a probe approaching and scanning is not needed. The proposed measurement technique is based on a hybrid method combining a super-resolution measurement method using a structured illumination and a highly sensitive dark-field inspection method using an infrared evanescent illumination.Theoretical and experimental analyses suggest that the proposed method has the potential to evaluate Si wafer surface defects including subsurface defects with a spatialresolution less than 100 nm even with the highly sensitive dark-field detection under TIR conditions using infrared laser beams.

Invited Talk Session 3 (Conference room No.10)
Day 2, Sep. 23, 14:00-14:30 pm

Prof. A. Abou-Zeid

Physikalisch-Technische Bundesanstalt (PTB)

Biography:
Prof. A. Abou-Zeidwas born in El-Minia, Egypt. He received his B.Sc. in Physics from Assuit Univ. in Egypt, and Diploma inPhysics and Ph.D. in Solid State Physics from the Technical University of Braunschweig in 1969 and 1974, respectively.Since 1979 he was the employee of the Physikalisch-Technische Bundesanstalt (PTB), and his R&D in the field of diode laser application in the length measuring technology (Frequency and Wavelength Stabilization of Diode Lasers, Lambda-Meter for Calilbration of Wavelengths, Diode Laser Interferometer for Length Measurements). Since 1995 he was the head of the Laboratory “Length Measuring Equipment”: he was focus onthe Calibration and Certification of Length Measuring Equipment, and his R&D in the field of Diode Laser Application in the Length Measuring Technology (Frequency stabilization of Diode Lasers on Absorption Lines(Rb, J2), DiodeLaser Interferometry for Measurement of Surface Topography, Diode Laser Refractometer, Absolute Interferometry, Refractive of Index compensating Interferometry). Since 2003, he became the head of the department "Length Measures and Measuring Equipment" and since 2007 “Interferometry on Material Measures”, respectively.

Title: Laser interferometric length measurements

Abstract:
Interferometers are alreadyknown since 1881 by Michelson. However, the importance of interferometers for practical length measurements is since the discovery of laser (1960) due to its extraordinary optical properties as mononchromacity, coherence, beam divergence, polarization and frequency stability. Today laser interferometers has a variety of applications as contactless precise length instruments: mechanical engineering, machine tools, coordinate measuring machines etc. The relative measurement length uncertainty dl/l can vary depending on the application between 10−5 and 10−10.The invited speech gives an overview on length measurements using laser interferometry. After a short description on laser types used (He-Ne gas laser, Nd:YAG solid state laser, diode laser and femtosecond laser) the refractive index of air as an important factor forachieving an accurate length and other length error sources are discussed. Lastly investigation activities of author’s researcher groups at the PTB, the National Metrology Institute of Germany, for developing, testing and application of multi-wavelength interferometry, absoluteinterferometry and phase shift interferometry as well as the modified two colour method to be used in refractive index compensating nterferometry are reported in details.

Invited Talk Session 4 (International Hall)
Day 3, Sep. 24, 14:00-14:30 pm

Prof. Liandong Yu

Hefei University of Technology

Biography:

Prof. Dr. Liandong Yu studied precision instrumentation at Hefei University of Technology in 1993. And he received his Ph.D. in Precision Engineering in 2003. In 2009 he got his appointment as full professor of HFUT. Now he is the Dean of School of Instrument Science andOptoelectronic Engineering. From 2001.9-2002.9 he was invited by Physikalisch-Technische Bundesanstalt (PTB, in Braunschweig, Germany) as guest scientist. He has been invited by TU-Ilmenau in Germany and also invited as visit scholar by University of New South Wales. He ismember of China Metrology Society and member of the national optical standards committee. His research interests are polar coordinate measuring machine, nanometer measurement system. He has published over 50 publications and supervised 50 postgraduate students

Title: Techniques of fringe projection profilometry for complicated surface measurement

Abstract:
Fringe projection profilometry (FPP) is an optical 3D scanning technology and suitable for complicated surface measurement due to rapid measurement, high spatial resolution and high point density. In practical applications, the measurement accuracy of FPP system will be influenced by many complex factors, such as lens distortion in camera and projector and harmonic wave error in phase map. There,after carefully researching these factors, many novel calibration and compensation methods are proposed to improve the measurement accuracy of FPP system. Firstly, a novel method is presented to reduce the nonlinear response of digital phase-shifting profilometry (PSP). In order to improve the accuracy of projector calibration, a methodis then proposed based on the cross-ratio invariability. A new method to analyze the significance of each polynomial term and simplify the high order polynomial calibration model is presented. As a result, the high order model can be simplified with significant improvement of computation stability and little loss of reconstruction accuracy. Finally, to automatically identify and remove invalid points in constructed results, we propose a method to adaptively determine the segmentation thresholds. Experimental results are shown to validate of the proposed methods.

Invited Talk Session 5 (Conference room No.7)
Day 3, Sep. 24, 14:00-14:30 pm

Dr. Jiarui Lin

Tianjin University

Biography:

Dr. Jiarui Lin received his B.E. and Ph.D. degree in instrument science and technology from Tianjin University, China, in 2006 and 2012, respectively. After that, he started to work as a lecturer in State Key Laboratory of Precision Measuring Technology and Instruments, Tianjin University. In 2016,he went to the University of Bathas an academic visitor. In addition, He was selected into the Young Elite Peiyang Scholar Program in 2014 and the Young Elite Scientists Sponsorship Program by CAST in 2016. And he is a member of China Instrument and Control Society and Chinese Optical Society. His current research interests include laser and photoelectric measurement, vision measurement and large-scale metrology.

Title: Coordinate measurement accuracy analysis of large-scale heterogeneous network

Abstract:
With the increasing of the scale in mechanical manufacturing, large equipments' manufacturing and assembling are in urgent need of efficient, integrated digital measurement methods. The networking measurement method based on multi-instrument heterogeneous platform is an important developing direction. However, the lack of systematic and effective theory results in the limitation on applications of heterogeneous network measurement. This talk will introduce a coordinate uncertainty analysis method in large-scale measurement, which makes the evolution law of spatial error as the breakthrough point, combining with the precision measurement and engineering surveying theory. Then the method and performance of networking measurement in the multi-instrument heterogeneous platform will be discussed. The research includes several specific aspects: the distribution and expression of spatial non-uniform error based on multi-observation intersection; the method for establishing the high-accuracy measurement control network based on multiple geometric constraints; the coordinate transformation uncertainty analysis in the heterogeneous measurement network. This research provides a method of accuracy estimation and control for large-scale coordinate measurement of industrial manufacturing, and also provides the theoretical and technical support for the heterogeneous network measurement.

Invited Talk Session 6 (Conference room No.10)
Day 3, Sep. 24, 14:00-14:30 pm

Dr. Lina Fei

Zeiss Industrial Metrology

Biography:

Dr. Lina Fei, born 1981, Technical Representative of Zeiss Industrial Metrology China. Works on Coordinate Metrology, Dimensional Metrology, Dimensional Quality data, Mechanical Engineering since 2006. Her research interests are in the area of Dimensional Quality data, Closed-loop control of Manufacturing. Published the book “Geometry Coordinate Metrology Technology and Application”.

Title: Future of manufacturing metrology in industrie 4.0

Abstract:
Strategic considerations and publications dealing with the future of industrial production are significantly influenced these days by the concept of “Industrie 4.0”. For this reason the field of measurement technology for industrial production must also tackle this concept when thinking about future trends and challenges in metrology. To this end, the Manufacturing Metrology Roadmap 2020 of the VDI/VDE Society for Measurement and Automatic Control (GMA) was published in 2011 (VDI/VDE-GMA, 2011; Imkamp et al., 2012). The content of thisroadmap is reviewed and extended during the forum, covering new developments in the field of the Industrie 4.0 concept and presented with expanded and updated content.

Invited Talk Session 7 (International Hall)
Day 4, Sep. 25, 14:00-14:30 pm

Dr. Fang Cheng

Advanced Remanufacturing and Technology

Centre, Singapore

Biography:
Dr. Cheng Fang received his PhD from Hefei University of Technology in 2010. From 2010 to 2013, He worked as post-doc research fellow in National Taiwan University and Nanyang Technological University (Singapore). Before 2013 his research work wasfocusing on metrology, optical instrumentation and precision engineering Currently he is working as Technical Lead in Advanced Remanufacturing and Technology Centre, Singapore. His research interests include surface metrology, in-situ inspection, machine vision and Augmented Reality. His research team is working on both industrial solutions on vision inspection and academic research on surface metrology, covering Technical Readiness Level from 3 to 7.

Title: Enhanced industrial measurement assisted by augmented reality

Abstract:
Industry 4.0 has higher requirements on automation and data exchange than ever before.It brings new challenges to industrial measurement and inspection, including in-situ measurement, real-time data transfer, physical transport minimization and on-site decision making. In this report, new technologies forin-situ measurement / inspection are discussed, including automated surface adaptive scanning, dynamic image capturing and processing, fast scanning path generation for reverse engineering and remote assistance for on-site decision making.The proposed measurement / inspection process can be performed in a same cyber-physical manufacturing system. Augmented Reality (AR) also plays an important role in such cyber-physical system. By integrating logic object with physical world, AR visualize processing results on site and help the operator to take further action immediately. Three case studies are included in this report, demonstrating how enhanced industrial measurement improves the process reliability, reduces the cost and shorten the cycle time.

Invited Talk Session 8 (Conference room No.7)
Day 4, Sep. 25, 14:00-14:30 pm

Dr. Hao Jiang

Huazhong University of Science and Technology

Biography:
Dr. Hao Jiang is an associate professor of Huazhong University of Science and Technology. He received his B.E. degrees in Mechanical Engineering and Financial Management from Huazhong university of Science and Technology in 2000, and received his MS degree in Mechanical Engineering from Huazhong university of Science and Technology in 2004. In 2011, he earned his PhD in Mechanical Engineering at Florida Institute of Technology. From 2004 to 2001, he worked as Software System Engineer and Senior Software Engineer at Shanghai Micro-Electronics Equipment Ltd. and Asian Design Center of TRANE Air Conditioning Company, respectively, being engaged in the software development for high precision movement control system and large commercial air conditioning control system. After receiving his ultimate degree at Florida Tech, he worked as a postdoctoral research fellow and adjunct instructor at the University of Texas at Arlington until he started his appointment of Associate Professor with Huazhong University of Science and Technology in 2014. He is interested in the research topics of the principle and instrumentation for ultra-fast dynamics metrology, polarization optics based multi-parameter measurement, Micro/Nano scale mechanical variable measurement, and metrological traceability.

Title: Latest research progress on mueller matrix ellipsometry for anometrology

Abstract:
Compared with conventional ellipsometric scatterometry, which can only change two measurement conditions, such as wavelength and incident angle, and canat most obtain two ellipsometric angles under each condition, Mueller matrix ellipsometry (MME) offers an additional configuration condition of azimuthal angle and can provide all 16 elements of the 4×4 Mueller matrix in each measurement, and consequently, MME-based scatterometry can acquire much more useful information about the sample and thereby show many advantages in nondestructive, precise characterization of complex nanostructured thin films.Latest progress achieved on the instrumentation and application of novel Mueller matrix ellipsometers will be discussed in this talk. At first, a brief introduction of the fundamental principle of MME will be given, followed by a series of novel case studies using self-developed high precision broadband MME including the metrology of holography process, the metrology of oxide layer on silicon sphere surface, characterization of asymmetric nanostructures, etc. These examples show that MME is suitable for nondestructive, precise characterization of thin films, especially suitable for the metrology of anisotropic structured thin films. After that, aiming at the drawbacks of MME such as the low lateral resolution and limitations on aperiodic structure characterization, our efforts on the principle study, optical design, instrumentation as well as application of two novel instruments, i.e. Mueller matrix imaging ellipsometer (MMIE) and Tomographic Mueller-Matrix Scatterometry (TMS), will be introduced. In the end, the potential applications of MME will be evaluated according to these latest progresses.

Invited Talk Session 9 (Conference room No.10)

Day 4, Sep. 25, 14:00-14:30 pm

Dr. Ian Forbes

Institute of Physics Publishing

Biography:

Dr Ian Forbes received his PhD from Heriot-Watt University (Edinburgh, Scotland) in 2003, investigating diamond thin film growth and analysis. He subsequently performed postdoctoral work on probe microscopy at Edinburgh University before joining IOP Publishing (then Institute of Physics Publishing) in 2005. He has been a Publisher since 2004, Publisher of Measurement Science and Technology since 2013, and has been responsible for IOP's entire Measurement and Instrumentation journals portfolio since 2016.

Title: How to get Published

Abstract:

Publishing in academic journals is increasingly important, not only as a way of sharing information with other researchers in your field, but also as a means of validating your research and to help build your reputation and your career. This talk will look at how to choose the most suitable journal for publishing your research in, how to prepare your paper to fit the specific requirements of that journal, and what you can do to maximise your chances of acceptance. It will look at the structure and presentation of your paper, and the specifics of the peer review process, as well as what happens after acceptance and publication.

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Traffic Information

Airport Information:

Xi'an Xianyang International Airport (XIY) is about 45Km to Empark Grand Hotel.

XIY to Empark Grand Hotel (Conference Venue)

Plan 1: By Taxi:

Taxis between XIY and Empark Grand Hotel are readily available

Service Hours: Taxis are available at XIY Airport 24 hours a day.

Trip Duration: About 70 minutes

Charge: About 120RMB (18 dollars) . Please note that taxi doesn't accept dollars and credit cards.

Plan 2: By Public Transport :

Step 1: Airport bus Jianguo Hotel lineto Jianguo Hotel Station.

XIA Airport provides airport bus service between the airport and Jianguo Hotel Station, providing comfortable, convent, low-cost and practical transportation for travelers.

Step 2: Jianguo Hotel Station to Empark Grand Hotel (Conference Venue)

Taxi to Empark Grand Hotel (Conference Venue)

Trip Duration: About 15 minutes

Charge: About 10RMB (1.6 dollars)

High Speed Railway Station information:

Xi'anbei railway station is located at the north part of Xi'an，it's about 22Km to Empark Grand Hotel (Conference Venue).

Plan 1: By Taxi

Trip Duration: About 1 hour

Charge: About 60 RMB (9 dollars)

Plan 2: By Public Transport

Take Metro Line 2 from Beikezhan Station to Xiaozhai Station

Transfer at Xiaozhai Station

Take Metro Line 3 to YanxingmenStation

Get off and walk east alone Jiangong Road about 1.3km to the Empark Grand Hotel (Conference Venue)

Oral Session 1: Optical Metrology (I)

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Paper No. 44: Single-spot two-dimensionaldisplacement measurement with non-destruction, non-contact and high sensitivity

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Keywords: Laser sensor; Self-mixing interferometry; In-plane and out-of-plane displacement measurement; Nondestructive testing;Heterodyne detection.

Abstract:A novel method for single-spot two-dimensional (2D) displacement measurement based on the frequency shifting and multiplexing feedback effect is proposed. The in-plane and out-of-plane single-spot measurements are realized in this system simultaneously and independently. The system has advantages as non-contact, non-destruction, nanometer-scale resolution and high sensitivity. The performance of the system is testified in displacement measurement of an aluminum target with rough surface. 2D movement with different parameters of Lissajous figures are measured by the system. The resolutions of the two dimensions are all better than 5nm. The method revealed is promising to be applied in 2D deformation test of materials, 2D positioning of particles, thermal expansion coefficient measurement and other applications.

Paper No. 46: Experimental verification of a novel in-process depth measurements of diffraction limited micro-groove based on near-field optical response

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Keywords: Optical measurement, diffraction limited structures, super-resolution technology, Linnik interferometer method, phase shift method.

Abstract: The importance of micro-fabricated devices has been a valuable research topic, hampered in part by the quality control. One of the inspection factors for evaluating the quality is depth measurement, especially for diffraction limited micro-structures. A novel optical inspection method has been proposed for the in-process depth measurement for diffraction limited micro-grooves, which is characterized by non-destructive and high-resolution. In this paper, the fundamental experiments are conducted for further verification. The experimental setup based on the Linnik

interferometer method, which has the advantages of high resolution and high magnification, is built to measure the grating micro-groove structure with the size of 300nm×110nm (width×depth). This experimental system is mainly constituted by a continuous wave (CW) plane laser, a beam splitter cube generating two coherent laser beams capable of interference, two same infinity-corrected optical microscope objective lens,a 12-bit highly sensitive charge-coupled device (CCD) area sensor, and a computer that controls the piezoelectric stage for nano-scale shift. Indicated from the 27 repeated experiments, the standard deviation and maximal deviation of calculated depths are 3.35nm and 14.26nm, respectively.

Paper No. 48: The new NIM angular comparator

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Keywords: angular standard, angular calibration, divided circle, polygon, autocollimator, angularinterferometer, metrology.

Abstract: A multi-function and highly accurate angular comparator was developed at nationalinstitute of metrology, China (NIM). This angular comparator consists of an interferential scanningangular encoder with 4 scanning heads, a vacuum preloading air bearing and a piezo-ceramic motor.The equal-division-average (EDA) method was used as 1st step of deviation restraining,and aninverting compensation function was calculated and used as 2nd step of deviation restraining. Themeasuring uncertainty was estimated as U=0.05″ (k=2). The experiments of cross measurement andcomparison with angular interferometer were carried out to test and verify the angular comparator onboth of division deviation and interpolation deviation. This angular comparator can be used tocalibrate the angular measuring instruments such as polygon, autocollimator, angular interferometer,and angular encoder with measuring range of (0~360)° and minimal measuring step of 0.1″.

Paper No. 53: Light field measurement based on the single-lens coherent diffraction imaging

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Keywords: light field measurement, phase retrieval, extended fractional Fourier transform.

Abstract: Plenoptic camera and holography are popular light field measurement techniques. However, the low resolution or the complex apparatus hinders their widespread application. In this paper, we put forward a new light field measurement scheme. The lens is introduced into coherent diffraction imaging to operate a special optical transform, extended fractional Fourier transform. Combined with the multi-image phase retrieval algorithm, it is proved to hold several advantages. Our scheme gets rid of the support requirement and is much easier to implement while keeping a high resolution by making full use of the detector plane. Also, it is verified that our scheme has a superiority over the direct lens focusing imaging in amplitude measurement accuracy and phase retrieval ability.

Oral Session 2: Sensors and Actuators (I)

Location: Conference room No.7 **Chairs: Prof. Lingbao Kong, Dr. Mingjun Ren**
18 A New Capacitive Long-range Displacement Nanometer Sensor withDifferential Sensing StructureBased on Time-grating
76 Rectangular closed double magnetic circuit for ultra-low-frequency vibration calibration
87 Bias Electric Field Distribution Analysis for a Non-Contact Nano-Probe Based on Tunneling Effect
114 Research on measuring method of rotation angle and clearance in intelligent spherical hinge

Paper No. 18: A new capacitive long-range displacement nanometer sensor with differential sensing structure based on time-grating

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Keywords: Nanometer measurement, Capacitivedisplacement sensor, Long-range, Time-grating, Differentialsensing structure

Abstract: High-precision displacement sensors, which can measure large displacements with nanometer resolution and accuracy, are key components in many ultra-precision fabrication machines. In this paper, a new capacitive nanometer sensor with differential sensing structure is proposed for long-range linear displacement measurements based on an approach denoted as time grating. Theoretical models are established using electric field coupling theory and an area integral method, which indicate that the common-mode interference will result in a first harmonic error in measurement results. Therefore, a differential sensing structure, which adopts another group of induction electrodes placed relative to the initial group by a half pitch width, is employed to eliminate the common-mode interference. The experiment results demonstrate that the measurement accuracy, the anti-interference ability and the stability of the sensor have been further improved after adopting the differential sensing structure. Finally, the prototype sensor achieves a value of ±200 nm measurement accuracy within 200 mm measuring range.

Paper No. 76: Rectangular closed double magnetic circuit for ultra-low-frequency vibration calibration

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Keywords: Closed double magnetic circuit, vibration calibration, ultra-low frequency, magnetic flux density, fringing effect.

Abstract: The main problems that occur during extending the stroke of vibration exciters are discussed through reviewing the state of art of low frequency vibration exciters, a rectangular closed double magnetic circuit (CDMC) is proposed through a comparative analysis of three configurations on their advantages in obtaining ultra-long strokes. Analyses are performed from the viewpoint of distribution of the MFD to evaluate the stroke potential, taking into account key factors of material differences in permanent magnet (PM) pairs, and assembling errors in PM arrays. The structure with PMs assembled at the ends of the center yoke has proven advantageous over the other two schemes in

obtaining ultra-long strokes. A preliminary prototype of vibration exciter based on the proposed CDMC with an air gap length of 200 mm is designed, manufactured, and tested. Experimental results indicate that an MFD of up to 233.5 mT and MFD non-uniformity of 0.2% in the LAG are achieved.

Paper No. 87: Bias electric field distribution analysis for a non-contact nano-probe based on tunneling effect

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Keywords: bias electric field, non-contact nano-probe, tunneling effect, non-uniform grid, finite difference method

Abstract: During proposal and development of a new non-contact nano-probe based on tunneling effect, analysis of the bias electric field (BEF) distribution is a key step for modeling and characterization of the probe. However, the BEF between the spherical electrode serving as the probing ball and the surface to be measured has combined features of macro- and micro- dimensions simultaneously, which makes the modeling of it a far tricky problem. In this paper, a modeling method based on non-uniform grid generation according to the structural features of the BEF is proposed, and the field distribution is solved with high accuracy. The maximum relative calculation error is within 15% compared with calculation results for a bias electric field with regular boundary with analytical electric image method.

Paper No. 114: Research on measuring method of rotation angle and clearance in intelligent spherical hinge

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Keywords: Ball hinge Measurement accuracy Resolution Measurement Clearance error

Abstract: Precision ball hinges are widely applied in parallel mechanisms, robotics and other area, but its rotation orientation and angle can not be known in its passive motion. At the same time, the clearance error in its motion can not be achieved too. The paper proposed a intelligent ball hinge(IBH) which can detect its rotation angle and moving clearance based on our previous research results. The measuring model has been optimized to promote measurement accuracy and resolution, and the optimal design of IBH structure has been finished. The experimental data showed that the measurement accuracy and resolution of the modified scheme are improved. In the range of ±10 °, the average error of uniaxial measurement is 0.29°, and the average error is 0.42 ° in the range of ± 20°. The resolution of the measurement can be achieved at 15″. The source of measurement errors is analyzed through theory and experimental data, several key error sources have been determined, and a point capacitance model for measuring clearance error is proposed, which will not only be helpful to compensate the angle measurement error but also realize motion clearance of IBH on real-time in the near future.

Oral Session 3: Machine Vision and Image Processing (I)

Location: Conference room No.10 **Chairs: Prof. Xiangchao Zhang, Dr. Jiarui. Lin**
16 Calibration of a Vision-Based Location system with Hybrid Genetic- Newton Method
33 An Image Processing System for Extension Measurement
61 Simple method to achieve full-field metric reconstruction using a movable stereo rig
66 An Algorithm Based on regional separation for Extracting Grain Boundaries automatically by Improved Mean Shift Method

Paper No. 16: Calibration of a vision-based location system with hybrid genetic- newton method

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Keywords: Camera calibration; non-contact measurement; micro-motion platform; location accuracy; genetic algorithm; Newton iteration

Abstract: To correct the uncertainty of the vision-based location system, a Hybrid Genetic-Newton Method (HGNM) is presented to calibrate its camera model. This method can minimize the uncertainty of the camera model by fusing the Genetic Algorithm (GA) and Newton method together. First, the camera model of the vision-based location system is built according to the image-forming rule and space geometry transformation principle of its visual measuring device. Second, the initial camera parameters generated by genetic process are iterated by Newton method until it meets the required accuracy. Otherwise, new populations will be generated again by GA and reiterated by Newton method. Third, a novel vision-based location system is designed to illustrate the application advantages of the modeling framework. The experimental result shows that the absolute error range of HGNM is [-1.1, 1.0] mm and the relative error range is [-9.49%, 0.11%]. It reveals that the accuracy of HGNM is about four times higher than LM method and up to six times higher than Newton method. In all, the HGNM is superior to traditional method when it comes to camera model calibration of the vision-based location system.

Paper No. 33: An image processing system for extension measurement

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Keywords: Image processing, Target, Sub-pixel, Extension measurement

Abstract: In material testing, video extensometer has the advantages of no influence on the test specimen, no problems with knife-edge slippage, etc. In this paper, an extension vision based measurement system using image processing techniques is developed. By attaching two targets on the specimen under tensile testing, a sub-pixel image processing scheme was developed to measure the distance between two targets automatically. The influence of image interpolation, target size, and field of view on the accuracy of the measurement was investigated. Test of the system on rubber was done. Inverse distorted calibration and bilinear shape function calibration methods are considered and compared. The experiment results show that an error of 1.5% can be achieved with proper size of target, smaller field of view, and calibration.

Paper No. 61: Simple method to achieve full-field metric reconstruction using a movable stereo rig

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Keywords: stereo rig, 3D reconstruction, real scale, image sequences, transferable features

Abstract: This paper introduces a simple method to achieve full-field metric reconstruction using a movable binocular vision system (MBVS). The MBVS is composed of two cameras,one is called the tracking camera, and the other is called the working camera. The tracking camera is used for tracking the positions of the MBVS and the working camera is used for 3D reconstruction task. The MBVS has several advantages compared with a single moving camera or multi-cameras network. Firstly, the MBVS could recover the real-scale-depth-information from the captured image sequences without using auxiliary objects whose geometry or motion should be precisely known. Secondly, the removability of the system could guarantee appropriate baselines to supply more robust point correspondences. Additionally, using one camera could avoid the drawback exists in multi-camera networks, that variability of cameras' parameters and performance can significantly affect the accuracy and robustness of feature extraction and stereo matching. The proposed framework consists of local measurement and initial pose estimation of the MBVS based on transferable features, followed by overall optimization and accurate integration of multi-view 3D measurement data. The whole process requires no information other than the input images. The framework has been verified with real data, and very good results have been obtained.

Paper No. 66: An algorithm based on regional separation for extracting grain boundaries automatically by improved mean shift method

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Keywords: grain size, metallographic images, image processing, mean shift

Abstract: By using the metallographic microscope, we can observe that the vast majority of the metal material is composed of many small grains, and the grain size of the metal material has a decisive impact on the tensile strength, toughness, plasticity and other mechanical properties. In order to quantitatively evaluate the grain size of the metal material, we need to extract grain boundaries in the metallographic image. According to the phenomenon of grain boundaries blurred or disconnected in metallographic images, this paper shows an algorithm based on regional separation for extracting grain boundaries automatically by an improved mean shift method. The experimental results show that grain boundaries obtained by the proposed algorithm are highly complete and accurate than other algorithms. This paper has practical value because the proposed algorithm is suitable for grain boundaries extraction of most metallographic images.

Oral Session 4: Optical Metrology (II)

Location: International Hall **Chairs: Prof. Haihua Cui, Prof. Liandong Yu**	
65	A High Resolution and Response Speed Interrogation Method for FBGs-based Sensors
70	Iodine frequency stabilizing laser diode and displacement measuring Mach-Zehnder interferometer based on sinusoidal phase modulation
72	A calibration method for non-overlapping cameras based on mirrored phase target
80	Two dimensional ellipsometer by ghost imaging technique

Paper No. 65: A high resolution and response speed interrogation method for FBGs-based sensors

Hong Dang[1, a],Kunpeng Feng[1, b], Haoran Zhang[1, c], Dong Jiang[1, d], Xun Sun[1, e], Weidong Wu[1, f], Yuanhang Zhang[1, g], Jiwen Cui[1, h, #] and Jiubin Tan[1,i]

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Keywords: Optical communication; Optical metrology; Fiber Bragg gratings

Abstract: Fiber Bragg gratings (FBGs) and their applications have played significant roles in a variety of fields where the accuracy and dynamic characteristics of these applications are directly dependent on the spectral resolutions and response speed of their interrogation method. In order to exploit a FBG interrogation method with higher spectral resolution and higher response speed, this paper detailedly investigated a FBG interrogation method based on reflective-matched FBGs scheme. To ensure theFBG interrogation method match an accurate and robust initial condition, a mathematical-physical model was established through Taylor expand, and a preload mechanical adjustment was then employed to modify the initial central wavelength of the reference FBG. Finally, experiments on the performance of the interrogation method were carried out, and the experimental results showed the wavelength resolution and response speed were 0.34 pm and 500 kHz, respectively.

Paper No. 70: Iodine frequency stabilizing laser diode and displacement measuringMach-Zehnder interferometer based on sinusoidal phase modulation

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Keywords: Frequency stabilization, Laser diode, Interferometer, Mach-Zehnder, Displacement measurement

Abstract: In this paper, we propose a combined method that includes an I_2 frequency stabilized LD and a displacement measuring Mach-Zehnder interferometer, both based on the sinusoidal phase modulation technique with an electro-optic modulator (EOM). The frequency of an external cavity laser diode (ECLD) is locked to a hyperfine absorption line of P(33) transition of the I_2 molecular near 633nm using both the sinusoidal phase modulation and the frequency modulation spectroscopy (FMS) with the stability of 10^{-11} order. Then the ECLD is employed as the light source for the displacement measuring Mach-Zehnder interferometer. The displacement of the target mirror of the interferometr can be determined from the Lissajous diagram drawn by the 2nd and 3rd harmonics of the interference

signal. The displacement measurement result is compared with that measured by a capacitive sensor. Finally, we discuss the possibility to improve the accuracy of the displacement measurement to nm order.

Paper No. 72: A calibration method for non-overlapping cameras based on mirrored phase target

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Keywords: Camera calibration, Non-overlapping cameras, Phase target
Abstract: A novel calibration method for non-overlapping cameras is proposed in this paper. A LCD screen is used as a phase target to display two groups of orthogonal phase-shifted sinusoidal patterns during the calibration process. Through a mirror reflection, the phase target is captured by the cameras respectively. The relations between each camera and the phase target can be obtained according the proposed algorithm. Then the relation between the cameras can be calculated by treating the phase target as an intermediate value. The proposed method is more flexible than conventional mirror-based approach, because it do not require the common identification points and is robust to out-of-focus images. Both simulation work and experimental results show the proposed calibration method has a good result in calibrating a non-overlapping cameras system.

Paper No. 80: Two dimensional ellipsometer by ghost imaging technique

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Keywords: Ghost imaging, ellipsometry, single pixel imaging
Abstract: 2D measurement method for an phase-modulated ellipsometry (PME) was developed by applying the computational ghost imaging (CGI). The PME was useful method for detecting elliptical parameters preciously. However there is a problem for detecting the 2D distribution because of using high frequency modulated signals. To overcome the problem, we focused on the CGI which can be constructed by single pixel detector. DMD projector was used as a light source in the proposed PME optical setup. As a results, we have succeeded to detect correlation signals and 2D distribution of the elliptical parameters of silicon wafer and Au thin film.

Oral Session 5: Sensors and Actuators (II)

Location: Conference Room No.7 **Chairs: Prof. Lingbao Kong, Dr. Mingjun Ren**	
140	Iterative Learning Identification of Linear Motor Cogging Force in the Presence of Measurement Noise
172	Design, Simulation and Fabrication of Micro Gas Chromatography Column for Breath Analysis
185	Wireless and passive temperature sensor based on microwave slot radiation patch
224	Design of optical fiber Fabry-Perot micropressure sensor based on beam-membrane structure

Paper No. 140: Iterative learning identification of linear motor cogging force in the presence of measurement noise

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Keywords: Iterative learning identification, cogging force, linear motor, measurement noise, normal optimal, orthogonal projection.

Abstract: For structural simplicity, permanent-magnet linear synchronous motors (PMLSMs) are receiving increasingly attentions in high velocity and high precision applications. The cogging force, as a space-periodic disturbance, however, will deteriorate the achievable dynamic performance. Conventional identification schemes always use all the error signals to update the parameters in the cogging force. However, the error resulting from measurement noise is noneffective for the cogging force's identification, and even deteriorates the identification process. This paper proposes a novel iterative learning method to identify the cogging force. Firstly, the error caused by the cogging force is extracted by projecting the overall error signal to a subspace spanned by some basis functions based on the physical model of the PMLSM as well as the sinusoidal model of the cogging force. Then, a norm-optimal approach is proposed to design the learning gain. It balances the tradeoff between convergence speed and robustness against noise and disturbance. Experiments are finally provided to validate the proposed method and confirm its feasibility and effectiveness.

Paper No. 172: Design, simulation and fabrication of micro gas chromatography column for Breath Analysis

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Keywords: Micro column; Gas chromatography; MEMS; Breath analysis

Abstract: Theseparation and detection of human breath play significant role in early and noninvasive disease diagnosis. Gas chromatography (GC) is a common way of the breathing volatile organic compounds (VOCs) analysis. In this paper, several kinds of micro columns with embedded pillars were developed for micro gas chromatography (μGC). The flow patterns of different pillar configurations in the columns were simulated and optimized. Micro electro mechanical system (MEMS) fabrication methods were applied to fabricate the column chips. The etched chip was sealed by anodic bonding. Static coating method was applied to coat the stationary phase. The separating properties of the column would be tested by some typical kinds of gases in the metabolic liver disease. The proposed micro column will be used as the crucial component for future portable breath analysis device.

Paper No. 185: Wireless and passive temperature sensor based on microwave slot radiation patch

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Keywords: temperature sensor, microwave, slot radiation, interrogation antenna, half-wavelength, resonant frequency

Abstract: A wireless and passive temperature sensor operating up to 800 °C is proposed. The sensor is based on the principle of microwave slot radiation. Such planar structure and simple working principle make it easy to be realized for high temperature application. In this paper, the proposed high temperature sensor was designed, fabricated and characterized. Here 99% alumina ceramic with a dimension of 40 mm×40 mm×1 mm was prepared in micromechanics for fabrication of the sensor substrate. And the metalization of the slot patch was realized in magnetron sputtering slot width 2 mm, slot length 32 mm. The measured resonant frequency of the sensor at 29 °C is 2.37 GHz. It can be concluded that the resonant frequency decreases with the increase of the temperature in range of 29-800 °C. It was shown that the average sensor sensitivity is 94.21 kHz/°C.

Paper No. 224: Design of optical fiber Fabry-Perot micropressure sensor based on beam-membrane structure

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Keywords:micro pressure; optical fiber sensor; FP interferometric cavity; MEMS; phase demodulation; beam-membrane structure

Abstract: In this paper, the design of optical fiber FP (Fabry-Perot) micro pressure sensor based on beam-membrane structure is proposed. The FP interferometric cavity is composed of an end face of the incident optical fiber and a sensitive diaphragm. The sensitive diaphragm creatively utilizes a square beam-membrane structure which is fabricated by MEMS(Micro-Electro-Mechanical System) technology. Compared with round membrane structure and square membrane structure, FEM(Finite Element Method) simulation results show that the square beam-membrane structure can achieve higher sensitivity and better linearity. Phase demodulation method is employed to demodulate the cavity length signal from the spectrum. Compared with the piezoresistive or piezoelectric micro pressure sensor, optical fiber FP micro pressure sensor based on phase demodulation method can achieve higher accuracy and higher resolution. The sensor performance test platform is built by ASE wide spectrum light source, optical spectrum analyzer, micro pressure gas source and so on. The optical fiber FP micro pressure sensor based on beam-membrane structure has high sensitivity, good linearity, high accuracy and high resolution. The measure range of the sensor is 0~10KPa, and the sensitivity can reach to 320nm/KPa.

Oral Session 6: Machine Vision and Image Processing (II)

Location: Conference room No.10 **Chairs: Prof. Xiangchao Zhang, Dr. Jiarui Lin**
88 Abnormal Detection of Two-dimensional Attitude for Small-sized Objects in Complex Scene118 A multi-scale seed point selection algorithm for registration
138 Improvement of High Temperature Deformation Measurement Accuracy Based on ImageRestoration Method
201 Design of Surface Defect Detection System for Reversing Radar Probe

Paper No. 88: Abnormal detection of two-dimensional attitude for small-sized objects in complex scene

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Keywords: structural background model,the hierarchical detection framework,small-sized objects,Abnormal detection

Abstract: Attitude recognition is one of the most important tasks in computer vision. Two-dimensional attitude recognition (also known as deflection state detection) is the more common research content in attitude recognition. In this paper, we propose a structured background model to reduce the redundant information in the image and form the sparse representation of the image data by using the census transformation feature descriptor for small objects in complex scenes. At the same time, there is a strong texture noise in the surrounding area of the object, and the hierarchical detection framework is constructed based on the principle of structural significance. On the basis of this, the abnormal detection of two-dimensional attitude is realized by two stages. Experiments show that our method can detect the two-dimensional attitude of small-sized objects with high efficiency and reliability. It has good real - time, robustness and accuracy.

Paper No. 118: A multi-scale seed point selection algorithm for registration

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Keywords: Seed point; Multi-scale; Pyramid decomposition; Point cloud; Registration

Abstract: A novel seed point selection algorithm based on pyramid decomposition is proposed for point cloud registration purposes. Firstly, the three-dimensional (3D) points in each point cloud are localized by the Hotelling Transformation[1], and the Z-coordinates of the 3D points are normalized, through which each point cloud is converted into a two-dimensional (2D) gray scale image. Secondly, the 2D gray scale image is decomposed into multi-level down sampled Gaussian pyramid images. Afterwards, the multi-level Gaussian pyramid images are converted into multi-level Laplacian pyramid images through an expansion procedure. And the important feature information is retained in the Laplace pyramid images. Finally, according to the demand of point cloud matching, the effective points in different level Laplacian pyramid image are selected as the 2D feature seed point, and the effective points in the Gaussian pyramid image are selected as the 2D non-feature seed point. The 2D feature seed points and non-feature seed points in the selected image are thereby mapped into the 3D point cloud, and the corresponding 3D points are employed to replace the original point cloud for matching. Experimental results demonstrate the superiority of the new

algorithm.

Paper No. 138: Improvement of high temperature deformation measurement accuracy based on image restoration method

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Keywords: Digital Image Correlation, heat flow disturbance, image restoration, measurement accuracy, image inverse filter

Abstract: Digital Image Correlation (DIC) is a full-field and non-contact technique based on white-light illumination for displacement and strain measurement. It can be used to measure the mechanical properties of materials at high temperature because of its advantages compared to other measurement methods. However, there are still many matters urgent to be solved by using DIC method such as the heat flow disturbance. These matters can warp the images acquired in high temperature and cause the tiny move of the images acquired at the same temperature even make the gray value of the images changed. The results of the measurement will not be guaranteed. This paper proposes a method to diminish even eliminate these influences and improve the measurement accuracy of high temperature measurement results. Degraded images can be processed by using the image inverse filter method. Then the filtered images can be used to calculate the displacement and strain of materials. The experimental results show that using image inverse filter method to process images can get smaller RMS errors and more stable results than the value calculated from the original images with no processing. Using this method can improve the measurement accuracy in high temperature measurement.

Paper No. 201: Design of surface defect detection system for reversing radar probe

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Keywords: Defect detection; Reversing radar probe; Machine vision; Ring lighting; Least square circle fitting

Abstract: An automatic defect detection system for reversing radar probe is developed to improve the detection precision and efficiency. The system is based on computer vision. In this paper, an effective lighting method of high angle (bathing) ring lighting is illustrated. A series of methods are designed to highlight the useful information in the image. Initially, edge scan and the least square circle fitting algorithm are used to remove the boundary aperture. Then, the Ostu algorithm is introduced in threshold modularization. Additionally, the closed operation is selected to eliminate the noise pixels after image segmentation and smooth the boundary. Finally, a corresponding defect judgment criterion is proposed, and two kinds of defects are classified and identified. In addition, 100 workpieces with 15mm diameter are selected as detection samples for the experiments. The detection rate of particle defects is 94% while fracture is 86%. The inspection speed of the system can achieve 40 pieces per minute. In conclusion, the system can detect surface defects on reversing radar probe accurately, rapidly, and it has important significance in control of diseases and pests.

Oral Session 7: Optical Metrology (III)

Location: International Hall	
Chair: Dr. Fang Cheng	
82	Super-resolution Scanning Microscopy with Virtually Structured Illumination
83	A New Method for Measuring the Glass Thickness and Refractive Index using Optical Frequency Comb
101	Error Analysis of Spectral Phase Shifting Digital Holographic Microscopy
102	High-precision lateral distortion correction in 2D and 3D optical imaging systemusing an arbitrary surface

Paper No. 82: Super-resolution scanning microscopy with virtually structured illumination

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Keywords: Super-resolution, Structured illumination, Multiphoton processes, Scanning microscopy, Virtually structured illumination, Three-dimensional optical sectioning

Abstract: The resolution of optical microscopy fundamentally limited by diffraction is at best 200 nm. Super-resolution structured illumination microscopy (SR-SIM) provides an elegant way of overcoming the diffraction limit in conventional wide-field microscope by superimposing a grid pattern generated through interference of diffraction orders on the specimen while capturing images. The use of non-uniform illumination field “shift” high specimen frequencies which are out-of-band into the pass-band of the microscope through spatial frequency mixing with the illumination field. Therefore the effective bandwidth of SR-SIM is approximately twice as conventional microscopy, corresponding to a 2-fold resolution enhancement, if the difference between excitation and emission wavelength is ignored. However, such a wide-field scheme typically can only image optically thin samples and is incompatible with multiphoton processes. In this paper, we propose a Super-resolution scanning scheme with virtually structured illumination, utilizes detection sensitivity modulation on line by programming or off line by numerical processing together with temporally cumulative imaging, the excitation intensity is constant while capturing images. In this case a nondescanned array detector such as CCD camera is needed. When combined with multiphoton excitation, this scheme can image thick samples with three-dimensional optical sectioning and much improved resolution.

Paper No. 83: A new method for measuring the glass thickness and refractive index using optical frequency comb

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Keywords: Optical frequency comb, OSCAT, Glass thickness, Glass refractive index
Abstract: In this paper, we introduce a new method to obtain the glass thickness and refractive index of high accuracy using optical frequency comb by the method of optical sampling by cavity tuning. Through the four cross-correlation patterns corresponding to the front and rear surface of the specimen and the co-operation mirror generated by tuning the repetition frequency of the comb, both the geometrical thickness and the optical thickness of the specimen can be measured, and the quotient of them is refractive index. Depend on the comparison with the value provided by National Institute of Metrology, it shows an agreement within 1.3 μm for the thickness measurement and within 5×10^{-4} for the refractive index measurement.

Paper No. 101: Error analysis of spectral phase shifting digital holographic microscopy

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Keywords: spectral phase shifting; digital holographic microscopy; interferometry; wavelength calibration; aberration;
Abstract: Digital holographic microscopy is an attractive technology of precision measurement. Phase shifting is required to correctly reconstruct the measured surfaces from interferograms. Spectral phase shifting schemes, as an alternative approach of PZT phase shifting, has drawn intensive attention in recent years. In this paper, an optical system based on spectral phase shifting digital holographic microscopy is built. The generalized phase shift algorithm is adopted to make the phase shifting more flexible. A calibration method is developed for the acoustic optic tunable filter. The two significant factors that affects the lateral size of the measured sample is analyzed. The proposed method is validated by measuring several MEMS elements and compare the result with those of confocal microscope and white light interferometer.

Paper No. 102: High-precision lateral distortion correction in 2D and 3D optical imaging systems using an arbitrary surface

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Keywords: High precision, optical distortion, self-calibration, microscopy, optical imaging
Abstract: Lateral optical distortion may cause field-dependent systematic errors in the measurement of surface topography or lateral dimensions of an object. These errors become critical when high-precision surfaces, e.g. precision optics, are measured. Current correction methods for distortion require some form of calibration artefact that has a smooth local surface and a grid of calibrated features. The manufacturing and calibration processes for calibration artefacts are usually expensive and complex. Our current research shows that it is possible to correct the lateral optical distortion in an optical imaging system by using an arbitrary surface that contains some deviations from flat and has some features (possibly just contamination), such that feature detection is possible. By using image processing and a self-calibration technique, a precision of a few nanometres is achieved for the distortion correction. The result of the new method is compared with that of a traditional distortion correction method, and the advantage in terms of precision and flexibility is pronounced.

Oral Session 8: Sensors and Actuators (III)

Location: Conference room No.7 **Chair: Prof. Satoru Takahashi**	
225	A Differential Accelerometer Composed of Quartz Resonator and Silicon Substrate with digital output signal
251	Multi-finger metal-graphene-metal photodetector based on CVD monolayer graphene
252	Voice coil based actuator with scanning range of 25 mm using built-in interferometric sub-nanometre position feedback
253	Multichannel Sub-millikelvin Temperature Logger for Thermocouple and Resistive Temperature Sensors

Paper No. 225: A differential accelerometer composed of quartz resonator and silicon substrate with digital output signal

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Keywords: Accelerometer; Quartz Resonator; Digital Output;IntegratedPackage

Abstract: This paper presents a novel micro-machined resonant accelerometer realized by a combination of a differential silicon substrate and double quartz DETF (double-ended tuning fork) resonators, which can output digital signals and improve the anti-interference ability. On the top side of the silicon substrate, four grooves are designed to guarantee that two quartz resonators are symmetrical and parallel, which can reduce the common mode errors in the sensor, such as temperature drift, cross-interference and nonlinearity. Utilizing a special epoxy-phenolic adhesive (M-Bond 610), the quartz DETF resonators are bonded to the silicon substrate through flip chip bonding technology. When the acceleration is applied along the sensing axis, the proof mass will transfer force to resonators, which causes an opposite variation in their resonant frequencies. To improve the electromagnetic shielding ability of the sensor, the sensor chip and PCBs (printed circuit boards) are sealed in a steel shell together which is filled with protective gas. Benefiting from the novel differential structure, the accelerometer characteristics such as temperature drift, cross-interface and non-linearity are improved, effectively. The experiment results demonstrate that the sensitivity is 18.45 Hz/g, which is in good agreement with analytical calculations and FEM simulations.

Paper No. 251: Multi-finger metal-graphene-metal photodetector based on CVD monolayer graphene

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Keywords: Graphene, photodetector, multi-finger, metal-graphene-metal

Abstract: Graphene, a single layer of carbon atoms with high carrier mobility and constant light absorption, has attracted wide attention for potential application in electronics and photonics. Here we report on the synthesis of monolayer graphene by CVD and fabrication of multi-finger metal-graphene-metal photodetector based on transferred graphene. Raman spectrum and scanning electron microscope (SEM) results showed that the graphene was continuous, clean, monolayer thin film and presented good quality. Lithography, metal sputtering and lift-off processing were employed to define electrode pattern, deposit metal layer (100nm Au) and finally fabricate metal electrode on transferred graphene. In metal-graphene-metal junction, the built-in electric field is symmetric with zero bias and the photocurrents rising from neighboring junctions offset each other. The bias voltage can break the symmetric built-in electric field and lead to the increase of photocurrent. The room temperature current–voltage (I–V) measurement of as-prepared graphene photodetector indicatedthat the photocurrent would increase linearly with bias voltage. The responsivity of the detector is 4mA/W at 532nm with a bias voltage of 3V.

Paper No. 252: Voice coil based actuator with scanning range of 25 mm using built-in interferometric sub-nanometre position feedback

Gabor Molnar[1,a,#], Sebastian Bütefisch[1,b], Christian Werner[1,c], Rudolf Meeß[1,d], Hans-Ulrich Danzebrink[1,e] and Jens Flügge[1,f]

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Keywords: voice coil actuator, positioning stage, 2D CMOS sensor, interferometry, Twyman-Green interferometer, Field Programmable Gate Array (FPGA).

Abstract: Quantitative determination of dimensional properties like length, diameter, height, etc. is essential in research, development and in production process control. In measurement equipment like micro coordinate measuring machines (µCMM) - in addition to the probing system - the positioning stage is a key component, since the characteristics of the position acquisition and control directly influence the achievable accuracy of the complete measurement system. Below a newly developed positioning system is presented, consisting of voice coil based actuators and an integrated interferometric measurement system. In contrast to a standard interferometer the presented system utilizes a 2D CMOS image sensor to capture the measurement signal [1]. To drive the stage, a commercial voice coil actuator is used: the scanning range of the introduced system covers about 25 mm (1 inch), and can be easily extended.

Paper No. 253: Multichannel sub-millikelvin temperature logger for thermocouple and resistive temperature sensors

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Keywords: Temperature logger; sub-millikelvin; multichannel; thermocouple; thermoelectric effect

Abstract: The requirements on high-end production machines and measurement equipment are continually rising. All processes and measurement techniques are affected by the environment properties such as humidity, air pressure and

especially temperature. Temperature effects like time-dependent drifts and thermal gradients are serious limitations of the achievable system performance [1]. While many temperature measurement systems are available for resistance thermometers like platinum resistance thermometers and thermistors, thermocouple measurement electronics is mainly targeting high temperature applications and lacks appropriate resolution for precision engineering.

Oral Session 9: Machine Vision and Image Processing (III)

Location: Conference room No.10	
Chair: Dr. Lina Fei	
255	An innovative error compensation method of circular grating based on the visualsystem
307	Designing index to recognize roughness based on color distribution statistical matrix
316	Bayesian inference based multi-scale optimization of stereo matching
339	Deep learning based fast object detection in light field imaging

Paper No. 255: An innovative error compensation method of circular grating based on the visual system

Huakun Jia[1, a],Yuan Wang[1,b] ,Liandong Yu[1,c,#] ,Wenhui Bao[1,d] and Huining Zhao[1,e]

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Keywords: circular grating; error compensation method; eccentricity; articulated arm coordinate measuring machine; CCD camera

Abstract: The articulated arm coordinate measuring machine is a kind of instrument in tandem type. The measurement accuracy is mainly influenced by angle measurement accuracy. An innovative method is proposed to compensate the angle measurement error of circular grating derived from the eccentricity of installing the circular grating. First, the paper analyzes the relationship between angle measurement accuracy and eccentricity. When circular grating works in ideal condition, the optical radius shall be a constant. However, the optical radius changes when there is an eccentricity of the circular grating. The compensation model of angle measurement error of grating derived from the eccentricity of installing the circular grating is built by integrating the difference value of optical radiuses when circular grating works in actual condition and ideal condition.Then, the visual system is built to measure the eccentricity of installing the circular grating. We use image processing technology to get the eccentricity value and eccentricity direction. Finally, we test the compensation effect of this innovative compensation method by comparing the angle measurement errors before and after the compensation. The experiment shows that the angle measurement accuracy is improved greatly by using the proposed method.

Paper No. 307: Designing index to recognize roughness based on color distribution statistical matrix

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Keywords: surface roughness; machine vision; color image; index design; index evaluation

Abstract: At present, the roughness measurement methods based on machine vision are mainly based on the grayscale images to design indices but ignore the advantages of multidimensional information of color images, making the indices algorithm complex and poor-accuracy. At the same time, the performance evaluation methods of the image-based characteristic indices correlated to roughness mainly focus on the prediction accuracy, ignoring the monotonicity, stability and efficiency of the indices. To address these problems, this paper proposes a color image-based index design and evaluation method to recognize surface roughness. A color distribution statistical matrix (CDSM) is proposed to characterize the aliasing of virtual images formed by color block on rough surfaces. Based on the CDSM, a specific indexS_{CY} is designed. Then, for developing a roughness measuring instrument, we propose a

scientific performance evaluation method to evaluate image-based indices. The experimental results show that the S_{CY} performs better than those indices based on grayscale images. Additionally, the index performance evaluation method can quantitatively and comprehensively characterize the performance of different indices.

Paper No. 316: Bayesian inference based multi-scale optimization of stereo matching

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Keywords: 3D vision, stereo matching, multi-scale optimization, real-time, Bayes inference.
Abstract: Most of the existing stereo matching methods have a trade-off between the matching accuracy and the cost for the computation, and are difficult to realize high reliable stereo matching with video level frame rate. This paper presents a generic Bayesian inference based multi-scale optimization method which can be used to improve the matching accuracy of arbitrary local stereo matching while maintaining the real-time performance. The method utilizes the rapidity of the local methods to obtain multiple disparity maps with scale information by different supporting window sizes, and then uses Bayesian reasoning to optimize the disparity on multiple scales to find the best disparity distribution. It is verified from a series of comparison experiments that, with the use of only three disparity maps with scale information, the simplest block matching algorithm can be optimized to reach both the accuracy and efficiency better than several the most state-of-the-art real time stereo matching methods.

Paper No. 339: Deep learning based fast object detection in light field imaging

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Keywords: Light field imaging, deep leaning, object detection, focal stacks, stereo matching
Abstract: Although 4D light field imaging has many advantages over traditional 2D imaging, its high computation cost often hinders the application in many fields, such as object detection and tracking. This paper presents a hybrid method to accelerate the object detection in light field imaging by integrating the deep learning with the depth estimation algorithm. The method takes full advantage of the computation imaging of light field to generate an all-in-focus image and focal stacks at the same time, and region on convolutional neural network and defocusing are sequently used to perform initial detection of the objects in 3D space. The estimated depths of the detected objects are further optimized based on multi-baseline superresolution stereo matching while the efficiency is maintained as well by compressing the searching space of the disparity. Experimental studies are conducted to demostrate the effectiveness of the proposed method.

Oral Session 10: Optical Metrology (IV)

Location:International Hall **Chairs: Prof. Benny Chi-Fai Cheung, Prof.Yongmeng Liu**
107 Light filed-based 3D reconstruction technique for micro-structure measurement
110 Resolution analyzing method of cell imaging based on transmittance digital holographic microscopy
128 Intracavity Laser Spectroscopy of Waveguide Structures
137 Study on adaptive Kalman filtering for laser Doppler velocimetry

Paper No. 107: Light filed-based 3D reconstruction technique for micro-structure measurement

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Keywords: micro-structure, light field, Fourier ptychography, high resolution, 3D reconstruction

Abstract: Probe-based measuring techniques are the mainstream approach for the measurement of micro-structure surface topography. But all these techniques have strong dependence on the precision mechanical movement of the translation stage, which will increase the measurement cost covertly. In this paper, we propose a novel microscopy approach, combining light field techniques and the Fourier ptychographic (FP) algorithm to achieve a high resolution 3D reconstruction of complex surface without sample movement. In our approach, two LED arrays are invoked as the light source for epi-illumination and transmitting illumination respectively, which can illuminate the sample from different angles. A microlens array is inserted in the microscopy optical system. Through the light field techniques, a tomography-liked dataset of optical slice for the sample is obtained. Meanwhile, we could get a resolution approximately twice that of conventional wide FOV microscopy through the FP algorithm. A prototype microscopy system is experimentally verified through a series of measurement experiments with different metallic micro-structure embossed molds. Both the simulation and experiment results show that our microscopy provides a strong potential for measurement of micro-structured surfaces.

Paper No. 110: Resolution analyzing method of cell imaging based on transmittance digital holographic microscopy

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Keywords: digital hologram microscopy; image process; modulation transfer function; resolution; quantification

Abstract: Digital holographic microscopy (DHM) is a potent method of measurement to perform three-dimensional imaging and tracking in micro/nanometer technology. It has been widely used in the field of life science and biomedical engineering for the advantage of high precision, noncontact and so on. Higher requirements of resolution are put forward in digital holographic microscopy for the development of micro/nanometer manufacturing and measurement. It is of great importance to improve the ability in the micrometer and nanometer scales resolution nowadays. Thus, it is necessary to develop an assessment means to improve the motivation of enhancing resolution. Accordingly, we devised a method to evaluate the resolution of hologram where we use to compare various digital

holographic microscope systems frequently. In this paper, we present the schematic of off-axis digital holographic microscope, the original hologram and phase image. The modulation transfer function curve images were obtained by dealing with holograms using the algorithm we invented. Since the measuring requirements of smaller scale and higher accuracy are more and more demanded, there is plenty of room to progress in measuring solution and novel solution evaluating methods.

Paper No. 128: Intracavity laser spectroscopy of waveguide structures

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Keywords: Intracavity laser spectroscopy, waveguide spectroscopy, Brewster prism coupler, thin films, *m*-line, weak coupling, planar waveguide.
Abstract: A new technique of intracavity waveguide spectroscopy for investigating planar waveguide was proposed. It's based on recording and processing angular spectrum of a light beam reflected from a prism coupler in case of exciting a guided mode in thin-film structure by the intracavity radiation of low-gain laser using a parallelepiped coupling prism in which the intracavity radiation enters the input faces of the prism at the Brewster angles and undergoes double internal reflection in the prism. It was demonstrated that the excitation of guided modes can be performed at the weak coupling. It was shown that the proposed technique can be used for measuring the optical parameters of low-loss planar waveguides.

Paper No. 137: Study on adaptive kalman filtering for laser doppler velocimetry

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Keywords: laser Doppler velocimetry; Kalman filtering; velocity; CSM
Abstract: Kalman filtering for laser Doppler velocimetry(LDV) is important to improve the velocity measurement accuracy. In this work, current statistical model (CSM) is used to build the state-space model. In order to make the algorithm adaptive and robust, an adaptive strategy is adopted. The acceleration variance is adaptively adjusted by using the difference of predictive observation and measured observation, and the measured noise variance is calculated or adjusted according to the existence of outliers. The laboratory rotating table experiments show that the adaptive Kalman filter would greatly reduce the rms error from 0.59cm/s to 0.22cm/s and have eliminated all the outliers. The field tests validate the conclusion that the adaptive Kalman filter is suitable for LDV signal processing.

Oral Session 11: Sensors and Actuators (IV)

Location:Conference room No.7 **Chairs: Prof. Ping Cai, Dr. Ian Forbes**
260 Novel annular-circular coupled piezoelectric micromachined ultrasonic transducers
250Fabrication of a ZnO Nanowire CO Sensor by a Simple Combing ProcessandIts Property Measurement
263 A New Functionalization Method for CMUTs-BasedResonant Biochemical Sensors
265 A temperature compensation method in fluid density measurement using MEMS resonant sensor

Paper No. 260: Novel annular-circular coupled piezoelectric micromachined ultrasonic transducers

TingzhongXu[1, 2,a], Zhixia Qiao[3, b],Libo Zhao[1, c, #],Zhiming Zhao[1, d],Jiuhong Wang[1, e],Jie Li[1, f],Zhikang Li[1, g],Yihe Zhao[1, h] and Zhuangde Jiang[1, i]

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Keywords: Annular-circular coupled structure, PMUTs, ultrasonic transmission sensitivity, multi-mode-merging, harmonic performance

Abstract: This paper presents the concept, optimization process and fabrication of a novel annular-circular coupled piezoelectric micromachined ultrasonic transducers (ACC-PMUTs) element with high ultrasonic transmission sensitivity and working frequency. Also, the annular-circular coupled structure presented a multi-mode-merging method to broaden the bandwidth of the ACC-PMUTs. Key performance parameters, including mechanical mode shape, resonant frequency, dynamic response, and displacement, with respect to the curvature and size of annular-circular coupled structure had been investigated. Based on mechanical coupling between two diaphragm structures, the proposed ACC-PMUTs achieved a transmission sensitivity increased by 39% compared with the traditional unimorph PMUTs and shown a better broadband and harmonic performance.

Paper No. 250: Fabrication of a ZnO nanowire CO sensor by a simple combing process and its property measurement

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Keywords: Nanowire Assembly; Combing; Carbon monoxide Sensor; ZnO nanowire

Abstract: Arranging ZnO nanowires with high alignment ratio are meaningful for high sensitivity andfast respone of gas sensors. In this paper, a novel method is developed to assemble ZnO nanowirearrays via a simple combing process

with a makeup brush. It is shown that ZnO nanowires can beassembled uniformly in large-scale area. The ratio of directional assembly within ±20° is up to 80%.Device fabricated with the assembled ZnO nanowire arrays has stable electrical characteristics. Suchdevice was used as gas sensor to detect CO. The current of the device shows a five-fold increase whenthe concentration of CO increases from 0 to 2000ppm, showing high gas sensitivity. Such simplemethod is possible to assemble almost all the one-dimensional nano-materials to fabricate gas sensors.Especially, it can be used to fabricate gas sensor in mass production because the density of assemblednanowire can be controlled by adjusting the comb times and density of nanowire suspension.Soit is anovel and useful method for assembling one-dimensional nano-materials.

Paper No. 263: A new functionalization method for CMUTs-based resonant biochemical sensors

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Keywords: CMUTs, Functionalization, Electrospinning, Resonant biochemical sensors.

Abstract: Capacitive micromachined ultrasonic transducers (CMUTs) can be used as a resonant biochemical sensor after coating biochemical-sensitive materials on their membranes. The coating method, that is the functionalization method, plays a highly important role in CMUTs-based resonant biochemical sensors, which has a significant impact on the performance such as the volume sensitivity. In this paper, the electrospinning technique is firstly proposed as an innovative functionalization method for CMUTs-based resonant biochemical sensor, which enables the biochemical-sensitive membrane coated with electrospinning fibers to form a nano reticular structure and have a strong adsorption capacity to detect biochemical objects. Ethylenedinitrilotetraethanol (EDT) was chosen as the sensitive material for detecting sulfur dioxide (SO2), and diameters of the coated fibers are 100 nm~500 nm. Experimental results showed that the CMUTs had the volume sensitivity over 127 ppb/Hz with an *Allan* deviation of 5.53×10-8 MHz2. The aforementioned results reveal that electrospinning technique has extremely great potential for the coating of CMUTs-based resonant biochemical sensor.

Paper No. 265: A temperature compensation method in fluid density measurement using MEMS resonant sensor

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Keywords: MEMS resonant sensors, fluid density measurement, temperature compensation, micro-cantilever

Abstract: Based on the Micro Electromechanical Systems (MEMS) resonant sensor with micro-cantilever structure, a temperature compensation method is put forwarded in this study according to the change of elastic modulus. Through the relationship function between elastic modulus and temperature, the working equation of measured fluid density is obtained to eliminate the effect of temperature on the measuring accuracy. The measurement experiments of several fluids with different densities were carried out by the MEMS micro-cantilever resonant sensor under different temperatures. The results of experiment showed that the deviation of resonant frequency value under the temperature influence was larger when the experimental temperature range is increased. Through the proposed temperature compensation method, the accuracy of density measurement by the sensor was increased by more than 50%, which demonstrated that the temperature compensation method can effectively improve the accuracy of fluid density measurement.

Oral Session 12: Micro and Nano Metrology (I)

Location: Conference room No.10 **Chairs: Prof. Ahmed Abou-Zeid, Prof. Jian Liu**	
23	Displacement measurement with high/low resolutions based on multiple gratings
84	Non-contact detection of surface defects by using a micro thermal sensor
91	Ultra-precision temperature control of circulating cooling waterbased on fuzzy-PID algorithm
94	Uncertainty analysis in the evaluation of pitch deviation and out-of-flatness of a planar scale grating by Fizeauinterferometry

Paper No. 23: Displacement measurement with high/low resolutions based on multiple gratings

Jie Lin[1, a, #], Hang Chen[1,b], Peng Jin[1, c], and Jiubin Tan[1,d]

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Keywords: Grating encoder, High/low displacement resolutions, Heterodyne light beam

Abstract: Here, we achieved a novel grating encoder, which can get low/high resoluitions for displacement at the same time. The proposed grating encoder includes a heterodyne light source, multiple holographic gratings and lock-in amplifier for phase measurement. The experimental results show that our system has good ability in long and small range displacement measurement. The low displacement resolution path can get 1.2488 *m* displacement error with 1000 *m* displacement and 0.4694 *m* displacement error with 100 *m* displacement. The high displacement resolution path has the sensitivity of 0.28 nm. Hence, our system can be widely used in modern precise systems such as precise displacement system and accurate position system.

Paper No. 84: Non-contact detection of surface defects by using a micro thermal sensor

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Keywords: micro thermal sensor, heat flow, measurement, simulation

Abstract: This paper presents a study on a new method for surface defect detection, in which surface defects will be detected by monitoring a change in heat flow between a micro thermal sensor and a measurement surface such as a magnetic disk or a silicon wafer. Since the change in heat flow across the gap is utilized, the method is expected to find out both the convex and concave surface defects. A theoretical analysis based on a simple heat transfer model is carried out to search for the possibility of the non-contact surface defect detection by the developed micro thermal sensor, as well as some basic experiments with the developed micro thermal sensor.

Paper No. 91: Ultra-precision temperature control of circulating cooling water based on fuzzy-PID algorithm

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Keywords: Circulating cooling water, ultra-precision temperature control, fuzzy-PID, thermal pollution

Abstract: Thermal pollution is one of the most urgent issues in the fields of ultra-precision measurement and manufacturing, which presents the demand of producing ultra-precision circulating cooling water (CCW) with the temperature stability up to millikelvin level and response time at hundred-second level. In this paper, an ultra-precision CCW producing method based on model identification and fuzzy-PID control is proposed and illustrated. A structure of circulating water loop with ultra-precision temperature control is proposed. A cooling module using of thermoelectric cooling device arrays as refrigerator and a heating module using electrical heating-tubes as heater are employed.A control algorithm based on fuzzy-PID is designed, and a variety of model identification experiments has been carried out to extract key parameters of the modules. Experimental results show that a temperature stability up to ±3mK is achieved, the temperature control resolution is better than 5mK, and the adjusting time of 1K step is 128s, satisfying the urgent need of ultra-precision measurement and manufacturing.

Paper No. 94: Uncertainty analysis in the evaluation of pitch deviation and out-of-flatness of a planar scale grating by Fizeau interferometry

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Keywords: scale grating, interferometry, optical encoder, pitch deviation, out-of-flatness, uncertainty, measurement
Abstract: The planar scale grating is a key component in an optical encoder. The pitch deviation and out-of-flatness of the planar scale grating used in an optical encoder determine the final measurement precision of the encoder, which are required to be evaluated for high precision applications. In this work, an improved evaluation method is proposed to evaluate the quality of a planar scale grating based on a Fizeau interferometer by taking account of the possible error factors in measurement. Theoretical equations are derived to evaluate the final uncertainties in the measured out-of-flatness and pitch deviation of a planar scale grating. Experiments are finally performed for a planar scale grating by a commercial Fizeau interferometer to show the implementation of the proposed evaluation method.

Oral Session 13: Optical Metrology (V)

Location:International Hall	
Chairs: Prof. Benny Chi-Fai Cheung, Prof. Yongmeng Liu	
175	Low-coherence Interference Wide-field Optical Microscopy with Improved Axial Measurement Range
194	Innovative full-field chromatic confocal microscopy using multispectral sensors
198	Three-dimensional deformation measurement technique combining DSPI and DIC
207	Recent development of next generation of laser interferometer at Harbin Institute of Technology

Paper No. 175: Low-coherence interference wide-field optical microscopy with improved axial measurement range

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Keywords: three dimensional measurement, low-coherence interference, object scanning, opticalmicroscopy, image processing

Abstract: One of the critical drawbacks of the low-coherence interference wide-field microscopy is its axial measurement range typically limited by the depth of field which is determined by a numerical aperture of the objective lens and the central wavelength of a light source. If a low-coherent interference fringe is out-of-range far from the depth of field, the measurement accuracy is decreased no matter how a reference mirror is well adjusted. In order to solve this problem, an object scanning measurement scheme is employed in the Linnik interferometer to improve the axial measurement range of the low-coherence interference wide-field microscopy. As a calibration of the system, the post-image-processing for a well-conditioned state is performed to make sure that a low-coherent interference fringe is generated within the depth of field, then a three dimensional object with high aspect ratio structure can be scanned along the axial direction. During object scanning, this state is always monitored and corrected by adjusting the reference mirror. By using this method, the axial measurement range is improved up to the working distance of the objective lens without compromising the measurement accuracy. A typical working distance is longer than 10mm, while the microscope depth of field is around 0.01mm though it depends on the imaging system. In this study, an experimental setup of the object scanning low-coherence interference wide-field microscopy was developed, then an experimental verification was carried out.

Paper No. 194: Innovative full-field chromatic confocal microscopy using multispectral sensors

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Keywords: chromatic confocal microscopy, multispectral sensor, optical metrology, digital micromirror device, automated optical inspection (AOI).

Abstract: A full-field chromatic confocal microscopy using a multispectral sensor was developed for quasi-one-shot microscopic 3D surface measurement. An innovative optical configuration employs a digital micromirror device (DMD) and a multispectral sensor is used to realize chromatic confocal microscopy with full-field area scanning. In the optical design, an area-scan type chromatic dispersive objective is specially designed to achieve measuring specification. Based on an 8x chromatic dispersive objective, the FOV for one shot measurement can be reached to 1.8mm*1.3mm which is immersive to microscopic profilometry. The spectral image captured by the multispectral sensor at each pinhole position has a unique spectrum pattern corresponding to its conjugate measured depth. A normalized cross-correlation (NCC) algorithm is developed to establish a spectrum-depth response curve with its corresponding spectrum pattern sets for accurate reconstruction of the tested 3D surface profile. With real test on standard targets, the measurement repeatability for a single surface depth is less than 0.6 micrometer.

Paper No. 198: Three-dimensional deformation measurement technique combining DSPI and DIC

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Keywords: digital speckle pattern interferometry, digital image correlation, out-of-plane deformation, in-plane deformation, three-dimensional deformation measurement.

Abstract: A technique combining digital speckle pattern interferometry (DSPI) and 2D digital image correlation (DIC) for three-dimensional deformation measurement is presented.The existing DSPI-based 3D deformation measurement technique needs three sets of DSPI setups, which makes the measurement system complex. We developed a measurement system combining DSPI and 2D DIC to obtain 3D deformation data. In our system, an out-of-plane DSPI optical setup is developed, in which an additional CCD cameras is arranged for digital speckle photography. Three dimensional deformation can be recorded. By analyzing the DSPI interferograms before and after deformation, out-of-plane deformations are obtained, which utilizes the Fourier transform method to extract the phase due to out-of-plane deformation. Meanwhile, in-plane deformations are worked out by applying 2D DIC algorithm on the speckle patterns. Preliminary experiments were conducted, in which the 3D deformations of a specimen were obtained. This approach suggests a possibility of non-contact, full-field, simple operation and comprehensive measurement.

Paper No. 207: Recent development of next generation of laser interferometer atharbin institute of technology

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Keywords: Pico-meter laser interferometer, Frequency stability, Periodic nonlinearity errors, Signal processing, Precision machining and manufacturing.

Abstract: The next generation of laser interferometer is generally supposed to achieve a target uncertainty of several ten pico-meters with measuring speed of several meters per second along with the rapid progress of industry. Over the past few years, our research group has conducted in-depth study on pico-meter laser interferometer, especially in these three aspects of laser frequency stability, periodic nonlinearity errors and interference signal processing technology. To enhance the frequency stabilization, a water-cooling offset frequency locking method is proposed. The experimental results indicate that the frequency stability of the water cooling stabilized He-Ne laser is better than 4.2×10−10. To

eliminate the periodic nonlinearity errors, a spatially separated beams heterodyne interferometer is constructed. The residual periodic nonlinearity errors of this interferometer reduced to tens of pico-meter, by avoiding the double-frequency mixing. To achieves both high speed and high precision signal acquisition, the process of signal processing is optimized. The resolution of the interference signal processing system is better than 27 pm, and the static standard deviation is 4.8 pm, the dynamic standard deviation is 18 pm under the measuring speed of 1.5 m/s.

Oral Session 14: Calibration and Machine Tool Performance(I)& Sensors and Actuators (V)

Location: Conference room No.7	
Chairs: Prof. Ping Cai, Dr. Ian Forbes	
268	Annealing-pressure-influenced ultraviolet photodetecting performance of ZnO film fabricated by electrospinning
328	Study on Novel Temperature Sensor based on Amorphous Carbon Film
50	Evaluation of Self-calibratable rotary encoder (SelfA) to detect shaft runout
149	Two Dimensional Abbe Error Analysis and Modeling of CNC Machine Tool XY Worktable

Paper No. 268: Annealing-pressure-influenced ultraviolet photodetecting performance of ZnO film fabricated byelectrospinning

Yong Xia[1,a],Rahman•hebibul[2, b], LiboZhao[1,c, #],Lei Li[1,d], ZhikangLi[1, e],Wendi Gao[1, f], GuoxiLuo[1,g], XudongFang[1,h], JiuhongWang[1, i], ZhuangdeJiang[1, j]

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Keywords: Ultraviolet photodetectors; ZnO film; Annealing pressure; Electrospinning

Abstract: ZnOfilm was fabricated viasequential coupling of electrospinning and high temperature annealing process. To investigate the influence of annealing pressure on the photodetecting performance of ZnO film, the annealing pressure was set as -0.09, -0.05, 0, 0.01 MPa compared with standard atmospheric pressure. All of the devices showed fast response and recovery property of less than 0.5 s which was attributed to Schottky barrier (SB) contact between ZnO film and sputtered Au electrodes.In addition, the results showed that photodetecting responsivity and response of the devices decreased with the increase of annealing pressure. It isbecause thelarge annealing pressure may produce amorphous carbon in ZnO film that limited the photodetecting performance.

Paper No. 328: Study on novel temperature sensor based on amorphous carbon film

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Keywords: Amorphous carbon film, Thermistor, Temperature sensor, Temperature resistance characterization, Temperature coefficient of resistance

Abstract: In this study, a new type of thermistor temperature sensor was developed. The sensing materials was amorphous carbon (a-C) film prepared using electron cyclotron resonance (ECR) plasma processing system under low energy electron irradiation sputtering. The nanostructure of a-C film was observed by transmission electron microscope (TEM), the atomic bonding and carbon hybridization condition was analyzedby Raman spectra and X-ray photoelectron spectroscopy (XPS) respectively. The linearity of temperature-resistance curve of this kind of a-C film was very good in certain temperature range, with high temperature coefficient of resistance (*TCR*). The a-C film by 50 eV electron irradiation can measure larger temperature range from -75 ℃ to 155 ℃, with good repeatability. The working temperature range of a-C film by 100 eV electron irradiation was much smaller, but *TCR* absolute value of this film was higher. It can be concluded that the lower sp^2 / sp^3, the better linearity of temperature-resistance curve, the lower *TCR* absolute value in certain working temperature range. The research shows that this kind of a-C film temperature sensor has good linearity and repeatability,also it can be integrated with other MEMS sensor simply.

Paper No. 50: Evaluation of the self-calibratable rotary encoder (SelfA) to detect the shaft run-out

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Keywords: Rotary encoder, Run-out, Self-Calibration, Measurement instrument, Angle
Abstract: We evaluated how much a shaft runout can be detected by the SelfA (Self-Calibratable Angle Device) developed by National Institute of Advanced Science and Technology (AIST) in Japan. SelfA is a rotary encoder with the angular self-calibration function that can realize the accuracy less than 0.1 [arcsec] correcting the angle error factor, and it has the function to detect the shaft runout which is one of failure factors of machine tools. This function is called “SelfA+”. Therefore it is expected that SelfA will be used not only as a high accurate angle measurement device but also as a sensor to predict the failure of machine tools. In our previous study, we evaluated the shaft runout using the mechanism to move the axis directly. However this mechanism had the problems that it was difficult to freely change the amount and the cycle of the shaft runout. Therefore, the new mechanism to generate the pseudo shaft runout by moving the encoder housing on the sensor side is proposed. In this paper, the new mechanism is investigated and it is evaluated how much shaft runout the SelfA+ can detect using new one.

Paper No. 149:Two - dimensional abbe error analysis and modeling in unidirectional motion of CNC machine tool XY worktable

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Key words: CNC machine tools; Stacked worktable; two-dimensional Abbe error; correlation; error modeling
Abstract: guideway system errors of XY worktable with stacking structure is an important part of geometry error of CNC machine tools, which affected by the temperature and cutting force. There exist error correlation among error components, which must be fully compensated to improve the machining accuracy. In this paper, the correlation between the line error and the angular motion error of one way movement of XY worktable and the variation of the two-dimensional Abbe error of the X -direction guideway system were analyzed under the combined effect of temperature and force. The calculation model of Abbe error between X -axis guideway system and Y -axis guideway system was established, which could lay a solid foundation for real time error compensating and machining precision improving of CNC machine tool and for measurement accuracy improving of machine measurement system.

Oral Session 15: Micro and Nano Metrology (II)

Location:Conference room No.10	
Chairs: Prof. Ahmed Abou-Zeid, Prof. Jian Liu	
155	Development of multi-spectral tomographic Mueller matrix microscopyfor the characterization of two-dimensional materials
159	Precision Measurement of Microoptics with Double Steep Sidewalls by an Atomic Force Microscopy with a Linear-Rotary Scanning Strategy
165	Study on the arc discharging parameters for fabricating the micro ball tips
196	Study for the adhesion force of a microprobing system with the shear-mode detection

Paper No. 155: Development of multi-spectral tomographic Mueller matrix microscopy for the characterization of two-dimensionalmaterials

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Keywords: Ellipsometry; Mueller-matrix microscope; Scattering field; High lateral resolution; Two-dimensional material

Abstract: In this work, we present the development of a multi-spectral tomographic Mueller-matrix microscope (TMM) which combines optical microscope and ellipsometry for the characterization of two-dimensional (2D) materials. TMM adopts a dual rotating-compensator configuration to obtain the complete 4 4 Mueller matrix of a sample. Fast measurement is realized over a range of incidence angle (0–65°), wavelength (400–700nm), and azimuth angle (0–360°). In the experimental setup, we use a high numerical (NA) objective lens (NA=0.95) to achieve a high lateral resolution about 0.625μm at 633nm. To show the performance of TMM, we measure homogeneous and inhomogeneous layered graphene. The fitting result of the measured and calculated best-fit Mueller matrices of the sample show reasonable agreement with the theoretical prediction. It is expected that the developed instrument would gain wide applications in the characterization of other 2D materials, especially for anisotropic 2D materials such as black phosphorous.

Paper No. 159: Precision measurement of microoptics with double steep sidewalls by an atomic force microscopy with a linear-rotary scanning strategy

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Keywords: Microoptics, Double steep sidewall, Atomic force microscope, Tilt probe, Rotary stage

Abstract: Microoptics components are widely used in a variety of fields such as optical communications, semiconductor industries and biomedicine. Some of the microoptics components have double sidewall structures near 90o and large amplitudes. For realizing precision measurement of microoptics with double steep sidewalls, this paper presents a linear-rotary scanning strategy associated with a self-developed atomic force microscope (AFM) measuring system. A linear-rotary scanning mechanisms, which consists of an ultra-precision air bearing scanning stage and a rotary stage, has been employed as the sample holder. A microoptics sample with double steep sidewall structures is mounted on the rotary stage and a tilt probe is controlled to scan the sample for measurement of one side (Side 1) of

the structure. Then, the sample is rotated 180o and then scanned along the same path for measurement of another side (Side 2) of the structure. By combining the two measurement results, the entire surface profile of the double steep sidewall microstructure can be accurately imaged by the AFM. Experiments by measuring a Fresnel lens have been performed to demonstrate the feasibility of the proposed measurement strategy.

Paper No. 165: Study on the arc discharging parameters for fabricating the micro ball tips

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Keywords: Micro ball tip, Monolithic tungsten probe, Arc discharge, Discharge parameters, Micro/Nano CMMs
Abstract: The micro geometric dimensions with high aspect ratio, such as deep holes and lateral-walls can not be measured by conventiuonal optical measuring instruments and contact measuring instruments. Micro/nano coordinate measuring machines(CMMs) with a high precision ball-ended stylus tip can be used to overcome this technical problem. The performance of the CMMs is decided by the diameter and roundness of the ball tip to a great degree. The method to fabricate micro monolithic tungsten ball tip, based on the principle of arc discharge and the surface tension phenomenon has been proposed by our group several years ago[1,2,3]. Meanwhile, the success rate to fabricate a good ball tip is still low because the ball tip's quality is subject to many process paratementers, such as the impulse voltage, the pulse frequency, the electric dischargeduration, the diameter of the raw tungsten and so on. Many experiments have been conducted to explore the rules between the fabricating parameters and the ball tip's quality. A micro tungstenball tip of 43μm in diameter and 1μm in roundess error was abtained using a 100 μm diameter tungsten. The micro ball tips can be applied for micro/nano CMMs. It will be possile to achieve more accurate measurement resolution and extend the capability.

Paper No. 196: Study for the adhesion force of a microprobing system with the shear-mode detection

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Keywords: Probing system, Micro-CMM, Adhesion force, Shear-mode detection, Microprobe
Abstract: A tactile probing consisting of a tip ball with micrometric diameter, which is often called as a micro-probing system, has been utilized for micro-coordinate measuring machine. Since the dimensional measurement of the workpiece is conducted by the detection of the contact between the tip ball and the workpiece, high-sensitive probing sensors are usually employed to reduce the measuring force. However, in the case of the micro tactile probing system, the adsorption of the tip ball due to the adhesion force on the surface often causes the probing errors and the enlarging of the measuring time. A shear-mode detection micro-probing system enables high-sensitivity of the probing detection by the positively applying the interaction force including the adhesion force at the surface. In this study, the intensity of the interaction force applied to the tip ball during the probing is investigated by the simplified dynamic model of the shear-mode microprobe.

Oral Session 16: Optical Metrology (VI)

Location: International Hall	
Chair: Dr. Fang Cheng	
216	Dual-comb absolute distance measurement in 70 m range with micrometer precision
233	Characterizing a Fabry-Perot cavity with Mirror Absorption and Scattering Loss
243	Development of nanoparticle detection method based on a new principle combining volatile liquidand optical observation method: Study of highly sensitive optical detection system
282	Measurement configuration optimization of Stokes-vector polarimeter for dynamicmetrology

Paper No. 216: Dual-comb absolute distance measurement in 70 m range with micrometer precision

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Keywords: femtosecond laser; frequency comb; absolute ranging; asynchronous optical sampling; long range.

Abstract: We demonstrate an absolute distance measurement system based on free-running dual-comb asynchronous optical sampling method and test its performance at long distance. The system is composed of two free-running all polarization maintained fiber Er-femtosecond lasers and an optical cross-correlation detection module. The update rate of ranging system is ~ 2 kHz, corresponding to the repetition rates difference of the two femtosecond lasers. The ultrafast ranging pulses reflected by target and reference mirrors are sampled by a local oscillator (LO) pulses and down converted to electric-detectable slow signals through asynchronous optical sampling. The distance is calculated with the information of the pulse timing and the real time repetition rate of the ranging laser. The air refractive index is corrected according to Ciddor equation. We compare the system with the He-Ne laser interferometer in an optical tunnel with a step of 4 m and the differences are within 6 μm over 70 m distance, corresponding to 9×10^{-8} in relative. To our knowledge, this is the first testify for the long ranging performance of dual-comb ranging system, which can promote further industrial applications.

Paper No. 233: Characterizing a fabry-perot cavity with mirror absorption and scattering loss

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Keywords: Mirror absorption, scattering loss, Fabry-Perot cavity, transmitted intensity, reflected intensity, impedance-matched cavity.
Abstract: The light intensity transmitted through and reflected by a Fabry-Perot cavity is derived based on the electric field, while the influence of mirror absorption and scattering loss is sufficiently taken into account. Fabry-Perot cavity finesse is determined only by mirror reflectance, but the magnitude of transmitted and reflected intensity is essentially determined by the ratio between residual transmittance and optical loss. As mirror reflectance, transmittance, absorption and scattering loss are coupled with each other, the residual transmittance factor *K* is proposed to describe the mirror performance. Simulation results based on the derived equations show the influence and sensitivity of factor *K* on a Fabry-Perot cavity with respect to transmitted and reflected intensity. The determination and characterizers of an impedance-matched cavity with different mirror performance are also illustrated based on factor *K*. The work in this paper provides a reference of observed light intensity to help design a Fabry-Perot cavity and check the alignment or even the mirror performance.

Paper No. 243: Development of nanoparticle detection method based on a new principle combining volatile liquid and optical observation method: Study of highly sensitive optical detection system

Kazuki Tachibana[1, a], Shohei Asai[1, b], Masaki Michihata[1, c], Kiyoshi Takamasu[2, d], Satoru Takahashi[1, e, #]

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Keywords: Surface inspection, Defect inspection, Optical measurement, Nanoscale particulate defects, Phase contrast microscopy
Abstract: In recent years, with the progress of microfabrication technology on a substrate, the necessity of detecting minute defects existing on the substrate surface is increasing. In particular, the existence of nanoscale particulate defects affect the manufacturing yield, so that a nanoscale particle detection method having characteristics applicable to manufacturing processes is strongly required. Then we have proposed a detection method based on a new principle combining volatile liquid and optical observation method. When a volatile liquid is dropped onto a substrate, the liquid interface behavior during evaporation is disturbed by the existence of particulate defects, and forms a liquid thin film widely spreading around the particulate defects. At this time, the existence of a particulate defect is detected by optically detecting the presence of a liquid thin film centered on a particulate defect. In this report, we report the results of the verification of the effectiveness of phase based optical system by theoretical analysis, and the construction of detection device using epi-illumination type phase based optical system.

Paper No. 282: Measurement configuration optimization of stokes-vector polarimetry for dynamic metrology

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Keywords: Stokes-vector polarimeter; Measurement condition configuration; Optimization; Uncertainty propagation; Dynamic metrology
Abstract: Dynamic loading experiment such as shock compression test usually has the characteristics of short duration, unrepeatability, and high cost, which put forward high temporal resolution and accurate requirement of the measurement. Due to the high temporal resolution up to ten-nanosecond-scale, Stokes-vector polarimeter has been used to capture such instantaneous changes in optical properties. In this paper, we proposed a method to optimize the

measurement configuration based on the uncertainty propagation for a house-developed Stokes-vector polarimeter with three parallel analyzer branches. Simulations and static measurement experiments on SiO2 film have been carried out for demonstration. The measured error distribution curves are in good agreement with the predictions given in our simulations. At the incident angle of 45°, the experiment result shows that the accuracy of measured thickness of SiO2 thin film using the optimal measurement configuration can be significantly improved, whose relative error can be compressed from 7% to 1%. The result demonstrates the validity and feasibility of the proposed measurement configuration optimization method.

Oral Session 17: Calibration and Machine Tool Performance (II)

Location: Conference room No.7	
Chair: Prof. Ping Cai	
150	Coordinate measuring machine verification using an optical-comb probe with ball-lens targets
189	Analysis of Angle Indexing Error Caused by Coaxial Deviation of Double Centers in Gear Measuring Machine
199	Evaluation of high accuracy gear-type magnetic rotary encoder
240	A novel approach to calibrate the galvanometric laser scanning system

Paper No. 150: Coordinate measuring machine verification using an optical comb probe with ball-lens targets

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Keywords: Optical frequency comb, Pulsed interferometer, Length measurement, Coordinate measuring machine, CMM verification, Ball-lens

Abstract: This paper describes a new method of coordinate measuring machine (CMM) verification. We propose a novel method of CMM verification using an optical frequency comb (optical comb) probe with ball-lens targets on the CMM's table. In the new system, the CMM verification is performed by measuring the displacement length from the optical comb probe attached on CMM's probing system to the ball-lenses target on the CMM's table. By using this configuration, the measuring axis can be easily changed by rotating the probe head and the ball-lenses target on the CMM's table can be easily adjusted to be in the same axis with the optical comb beam emitted from the optical comb probe. The preliminary experiment result of CMM verification is reported using the new system.

Paper No. 189: Analysis of angle indexing error caused by coaxial deviation of double centers in gear measuring machine

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Keywords: angle indexing error, coaxial deviation, double centers, gear pitch, measurement

Abstract: Double centers are common positioning device in machines. The machined part or measured part are installed by the axis and positioned by the double centers in machines, and the axis is driven to rotate by rotary table. Many researchers paid attention to rotation errors of rotary table, and developed many analysis methods of indexing errors, but few people cared deviation of double centers. Liu analyzed influence of the alignment angle error of a gear axis on gears' measurement, and a method was proposed to compensate measurement errors of pitch deviation. But the research only analyzed the influence of measuring point's position on the tooth profile. If coaxial error exists between the double centers, the angle indexing deviation will occur and affect accuracy of manufacture or measurement. A gear measuring machine was taken as a example, and relation of rotation angle between the shaft and working table was

analyzed when the double centers have coaxial deviation. The principle of angle indexing deviation was obtained. When the coaxial deviations were 5μm and 3μm, angle indexing deviations were 9.7" and 5.2" respectively. A angle indexing measuring experiment was carried out to test principle of angle indexing deviation. If the lower center has tilt error or radial error when rotary table rotating, the coaxial errors between the two centers will change when the rotary table is on different position, and the indexing deviation will change relative to no rotation errors. Indexing errors model caused by rotation error of lower centre was also analyzed in the paper.

Paper No. 199: Evaluation of high accuracy gear-type magnetic rotary encoder

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Keywords: Rotary encoder, Self-Calibration, Gear wheel, Magnetoresistive sensor, Measurement instrument, Angle

Abstract:A gear-type magnetic rotary encoder is an inexpensive rotary encoder using a magnetoresistance effect that has resolution of 64-512 gear teeth number, and can provide further high resolution from 256 to 16,384 times by using an electric interpolation. However, even though this rotary encoder has a high resolution, the angular position indexing accuracy is about ± 100”, which is not suitable for highly accurate angular control.In this study, we have realized a gear-type magnetic rotary encoder with high precision of ± 10” by adding a self-calibration function capable of detecting angular error using several magnetoresistive sensors. The gear-type magnetic rotary encoder with the self-calibration function can carry out self-calibration analysis after being installed into a machine tool, and correct the angular error. Therefore, it is possible to contribute to high precision of angle control of the motor spindle in a machine tool used under a harsh environment.

Paper No. 240: A novel approach to calibrate the galvanometric laser scanning system

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Keywords: Galvanometer; Laser scanner; System calibration; Triangulation; Planar target

Abstract: Traditional 3D laser scanners often involve mechanical scanning platforms to realize the function of the scanning, which make the structure of the system huge and complicated. The emergence of the galvanometric laser scanner solves the problem by using a galvanometer to perform object scanning. The employment of the galvanometer can improve the speed of scanning and simplify the structure of the system. However, there arefewapproaches available to calibrate the whole system. In this paper, a high precision calibration method is proposed to calibrate the system. A precision motorized linear stage and a planar target are applied in this method. The planar target is used to calibrate the camera based on Zhang’s method and the precision motorized linear stage is used to calibrate the laser plane. The calibration process is simple and rapid. A calibration accuracy of 0.2956mm can be achieved using the proposed method. The experiments conducted suggest that this method is robust and suitablefor the calibration of the galvanometric laser scanning system.

Oral Session 18: Micro and Nano Metrology (III) & Surface Metrology (I)

Location: Conference room No.10

Chair: Prof. Satoru Takahashi

200	Design and construction of an ultra-precision instrument for nanoindentation of single point diamond cutting tool
259	Development of an Abbe Error Free 3D Wafer Inspection Stage
63	Development of chromatic dispersion for chromatic confocal microscope
113	Defect Classification and Evaluation System

Paper No. 200: Design and construction of an ultra-precision instrument fornanoindentation of single point diamond cutting tool

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Keywords: Instrument, Nanoindentation, Single point diamond cutting tool, Capacitive sensor,Force, Displacement

Abstract: This paper presents an ultra-precision instrument that is designed and constructed for conducting nanoindentation experiments by using a single point diamond cutting tool as an indenter. This instrument is primarily consisted of an ultra-precision cutting tool indentation unit and a cantilever deformation detection unit. The indentation depth can be accurately obtained from the displacement of a diamond cutting tool and the deflection of an aluminum cantilever at the indent point, which are detected by inside and outside capacitive sensors. The indentation force can be accurately evaluated from the deflection of the aluminum cantilever at the indent point and the spring constant of the aluminum cantilever. After introduced the principle of the designed ultra-precision instrument, the nanoindentation experiments are performed by bringing a single point diamond tool with a nose radius of 2.0 mm to indent into a copper workpiece with a roughness of 1.58 nm under variour PZT driving voltages to demonstrate the feasibility and the resolution of the designed instrument.

Paper No. 259: Development of an abbe error free 3D wafer inspection stage

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Keywords: Co-planar stage, Abbe error free, wafer inspection, nanopositioning and nanomeasuring machine

Abstract: This paper presents the development of a new Abbe free 12-inch wafer inspection stage. The wafer inspection stage consists of a granite frame, an xyz stage and a vertical probe positioning stage. The granite frame consists of a granite base for mounting the xyz stage and a granite gantry for mounting the vertical probe positioning stage. The xyz stage is designed with the conventional box-in-box concept and co-planar concepts. These two concepts make three elevations of the wafer surface, y-stage guide surface and x-stage guide surface on the same z-plane. The movement of each stage is sensed by an individual laser interferometer, and the intersection point of three axes of laser interferometers is located on the top of the wafer surface. In addition, the focus point of the vertical optical probe

coincides with this intersection point. Therefore, the measuring system of the developed 3D wafer inspection stage fulfills the Abbe principle in 3 directions, and is an Abbe error free measuring system. The measuring range of this wafer inspection stage is 300mm x 300mm x 5mm, which fits the dimension of 12-inch wafers.

Paper No. 63: Development of chromatic dispersion for chromatic confocal microscope

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Keywords: chromatic dispersion lens, tube lens, axial chromatic dispersion, highly linear, variable range.
Abstract: Chromatic confocal microscopy (CCM) has been widely used in industry, medicine and other research areas. CCM focus on the relationship between displacement along the optical axis and wavelength of light source.Due to the various focal lengths according to wavelength, a series of focus points are formed along the optical axis at the object space. The height of the sample can be measured by analyzing the peak wavelength. Unfortunately, the relationship of the axial chromatic dispersion versus the wavelength is not linear, and the chromatic dispersion range is fixed in generally.

In this paper, a novel chromatic dispersion lens, which is named tube lens (TL), was designed to solve the problems mentioned above. The function of TL was to generate a large and linear chromatic dispersion along the optical axis; and a replaceable objective was added to control the chromatic dispersion range. The simulation results indicated that the chromatic dispersion range was 294mm in the visible light range, which was enough for displacement measurement; and the nonlinearity of chromatic dispersion curve could reach at 0.1% from 425nm to 700nm of wavelength. Numerous experiments by different convex lens or objective were carried out. As the experiment results shown, the larger value of NA of convex lens or objective, the smaller linear chromatic dispersion range and wavelength range; while almost all the linearity of these curves of chromatic dispersion versus wavelength stayed around 99%. The author combined an objective of magnification with 10× and NA of 0.35 in the experiment device; and the experiment results indicated that the chromatic dispersion range was about 175μm and the practical axial resolution was better than 0.4μm. Two height differences produced by three gauge blocks with 1.24mm, 1.25mm and 1.26mm of height were set as measured objects, and the measuring results were 21.83μm and 11.22μm, respectively. Thus, the designed TL is suitable for the surface topography measurement of engineering materials, and it could be fit to versatile measuring demands.

Paper No. 113: Defect Classification and evaluation system

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Keywords: AOI, Defect Inspection, Defect Classification, Deep Learning, Evaluation System
Abstract: Automated optical inspection (AOI) equipment has been widely used for real-time detection of defects and quality control of products on the production line. However, it still lacks the ability in providing an effective advice from the inspected information to improve the manufacturing process and upgrade the production yield. In order to evaluate and feedback the performance of a manufacturing process, a fast and intelligent defect classification and evaluation system is developed in this study.Defect imagesfrom an AOI instrument are first trained utilizing a deep learning approach. The features of defects in the detected images can then be characterized with the developed system.

A GPU card was used to build the parallel computing architecture for fast data computation both in training and classification process. Experimental results show that an automated defect evaluation catalogue integrated to an optical inspection result for improvement of manufacturing operation can be expected with the proposed method.

Oral Session 19: Optical Metrology (VI) & In-Process and Online Metrology (I)

Location: International Hall **Chairs: Prof. Yongsheng Gao, Dr. Lina Fei**
288 A Method of Laser Drift Measurement for Compensation
340 A fast three-dimensional profile recovery algorithm in white-light scanning interferometry
17 In-process measurement on the thickness of photosensitiveresin inevanescent wave-based nano-stereolithography
181 Use of Multiple Air Beams for In-Process Form Error Measurement

Paper No. 288: A method of laser drift measurement for compensation

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Keywords: Laser Micrometer, Micrometer Measure, Laser Drift, Four-quadrant Detector
Abstract: A new low-cost method is proposed to compensate the linear and angular drifts of laser micrometer. The laser beam emitted by the semiconductor laser is divided into three beams by two beam splitters. One beam is used as measure beam, while the other two beams are used for compensation. The compensation beams are irradiated to two feedback four-quadrant position detectors respectively. The angular drift can be reflected in different coordinate values of two feedback four-quadrant detectors. One of the coordinate values subtracts the value of angular drift can reflect linear drift. The linear and angular drifts are compensated in the measurement four-quadrant position detector. By applying these techniques, the measure precision and efficiency are improved and experimental results show that the measure precision of the module is in accordance with measurement requirement of medium machine tools.

Paper No. 340: A fast three-dimensional profile recovery algorithm in white-light scanning interferometry

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Keywords: White-light scanning interferometry; Recovery; Least square fitting; Phase-shifting
Abstract: White-light scanning interferometry (WLSI) has been widely used to measure the surface of objects over the past several decades. Due to the continuous spectrum obtained by white-light source, the phase ambiguity problem can be avoided. Thus, samples with discrete surface can be measured accurately by WLSI. In this paper, a fast and novel three-dimensional profile recovery algorithm based on WLSI is proposed, in which improved gravity center method is adopted to obtain the coarse results. Least square fitting and phase-shifting methods are used to correct the above results. Compared with traditional spatial domain algorithms, it can improve processing precision; compared with frequency domain algorithms, such as Fourier transform and Morlet Wavelet transform, it can enhance measurement efficiency. Simulations and experiments are conducted to demonstrate its validity.

Paper No. 17: In-process measurement on the thickness of photosensitive resin in evanescent wave-based nano-stereolithography

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Keywords: Photosensitive resin; Nano-stereolithography; Evanescent light; Refractometer; Critical angle; In-process measurement;

Abstract Stereolithography is one of most powerful ways that fabricate complex three-dimensional polymeric-based structure layer-by-layer in high speed. Nano-stereolithography using the ultra-thin field distribution of evanecnet wave can provide a sub-micrometer horizontal resolution. A measurement method that utilizes the variation of resin's refractive index after polymerization and its large influence on reflectivity at the critical angle has been proposed to meet the strong demand for in-process measurement in evanescent-wave based nano-stereolithography. Single-layer resin solidified by evanescent light will be monitored by this proposed method from the bottom of the substrate with p-polarized light launched at the critical angle. By this way, an in-process measurement on each layer of cured resin has been achieved. This method has been experimentally confirmed by using both bulk and nanometer-size samples. In addition, the feasibility of thickness measurement has been proved by measuring the photosensitive resin simultaneously with the curing process.

Paper No. 181: Use of multiple air beams for in-process form error measurement

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Keywords: In-Process Optical Measurement, Coolant, Opaque Barrier, Applicator, Multiple Air Beams

Abstract: In-process measurement can provide feedback for control of workpiece precision in terms of size, roughness and, in particular, mid-spatial frequency form error. The optical measurement methods are of the non-contact type and possess high precision, which should be used for in-process form error measurement. In precision machining, coolant is commonly used to reduce the heat generation and thermal deformation on workpiece surface. However, the use of coolant will induce opaque coolant barrier problem if optical measurement methods are used. In this paper, the multiple air beam approach is proposed. The new proposed approach permits displacement of coolant from any direction with large thickness. The model, the working principle, and the key features of the new approach are presented. Based on the proposed approach, a new in-process form error optical measurement system is developed. The coolant removal capability of multiple air beam approach is tested. The test results show that the measurement can be conducted coolant thickness of 15mm and the measurement error is 0.2μm.

Oral Session 20: Intelligent Instruments for Automation (I)

Location: Conference room No.7 **Chairs: Prof. Zonghua Zhang, Prof.Haihua Cui**	
85	Experimental Research on Online Dynamic Balancing System of Grinding Machine
86	Automatic Monitoring of Baby’s State of Health Using Optic and Acoustic Methods
109	Non-Contact Method of an Absolute Length Measurement Between Two Ball-Lenses Using a Tandem Low-Coherence Interferometer
152	Wearable Plantar Pressure Mapping System and Its Application towards Gait Phase Segmentation

Paper No. 85: Experimental research on online dynamic balancing system of grinding machine

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Keywords: Grinder spindle ,On-line balancing ,Vibration suppression, dynamic model

Abstract: Screw grinding is an important process to improve the accuracy of screw machining, but the machine tool vibration will affect the grinding accuracy of the screw. The vibration of the active suppression can effectively reduce the spindle vibration to improve the grinding quality and efficiency. The spindle on-line dynamic balancing technology can not only inhibit vibration to improve grinding accuracy, but also not interrupt the processing automation. In this paper, the dynamic model of the spindle of the grinding machine is established, and the vibration mechanism is researched and analyzed. The on-line dynamic balancing system of the spindle is developed. The validity of the system was verified in the laboratory and the machining experiment is done in the field. The results show that the vibration displacement amplitude decreases from 17.83μm to 7.686μm between before and after the balancing, and the amplitude decreases by 55%. The surface roughness of the screw raceway were measured by Taylor Hobson's PGI 3D aspherical measuring instrument. By comparing the surface quality of the ball screw between before and after balancing, it can be seen that the average roughness of the surface of the ball screw was reduced from 1.11μm to 0.82μm and the descending amplitude is as high as 25%, which indicated that the dynamic balance can effectively improve the ball screw grinding quality.

Paper No. 86: Automatic monitoring of baby’s state of health using optic and acoustic methods

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Keywords: smart healthcare, multidimensional quantities, facial expression, body gestures, baby's vocalizations, Internet of Things
Abstract: The paper deals with acoustic and 3D optic methods to organize automatic monitoring of health and safety of babies in medical facilities. Perspective trends of development of these methods are considered. Efficiency of their joint use is noted.

Paper No. 109: Non-contact method of an absolute length measurement between two ball-lenses using a tandem low-coherence interferometer

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Keywords: two ball lenses, length measurement, internal distance, tandem low-coherence interferometer.
Abstract: This paper will present a method of internal distance measurement between two ball-lenses by using a tandem low-coherence interferometer. The internal distance between two ball-lenses can be measured by arranging a beam splitter and a reference mirror in between them. As the result, the distance from the reference mirror to the ball lenses can be measured to determine the internal distance. The preliminary experiment to prove the concept was performed with a measurement repeatability about 40 nm.

Paper No. 152: Wearable plantar pressure mapping system and its application towards gait phase segmentation

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Keywords: wearable, plantar pressure, gait phase, gait event, podiatric evaluation.
Abstract: Detection of gait events and phase duration without inducing encumbrance to patients' natural ambulation is extremely in demand in clinic diagnosis. This research constructed a wearable measurement system of plantar pressure and motion direction of limb segments based on ultra-low power consumption microchip controller MSP430F5510 and integrated sensor. 40 fps of plantar pressure cloud image refresh speed at least has been achieved. The system enables to consecutively work about 20 hours if equipped with 850-mAh battery pack. The subarea pressure of five key anatomic sites of the foot are used for gait phase segmentation. Major foot-strike events are captured at the time of initiation, maximization, and termination of the numeric pressure values on said sites. With motion processing units (MPUs), kinematic parameters are obtained. Different from conventional gait analysis systems that restrict the data sampling in laboratory environment with spatial and mental limitation, this embodiment provides a more natural measurement experience.

Oral Session 21: Surface Metrology (II)

Location: Conference room No.10

Chairs: Prof. Jie Lin, Dr. Feng Gao

Paper No. 133: A method for inspecting double-sided high-sloped structured surfaces based on dual-probe wavelength scanning interferometer

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Keywords: surface metrology; V-groove; WSI (Wavelength Scanning Interferometry); calibration; 3D registration.

Abstract: Double-sided high-sloped structured surfaces such as V-groove surfaces and Fresnel lenses are widely used in optical fibre positioning, retro-reflection, grating, light guiding and light concentration for solar power installation. Both the surface finish as well as the dimensions of the structured surfaces play important roles in the quality of the final products. Numerous efforts have been put into the study of characterisation of these types of surfaces. However, only part of the parameters can be acquired and analyzed. It is still impossible to measure and generate the whole topography of these types of structured surfaces. This results in the manufacturing process suffering from high scrap rates. In this paper, an orthogonally placed dual probing system based on Wavelength Scanning Interferometry (WSI) aiming to measure the whole topography of the double-sided high-sloped structured surfaces simultaneously is presented. Each of the probes form an interferometer, and measures the facets of the double-sided high-sloped surfaces in one direction and acquires part of the topography. The whole topography is then stitched together using the two datasets based on the relationship between the coordinate systems of the two probes. The relationship between the two probes is acquired through the calibration of a specially designed 3D artefact. The artefact contains geometric features on each of the facets and is calibrated by a combination of several measurement methods to establish the space coordinates of the features. By matching the corresponding features on the measurement results acquired with each of the probes of the new setup to the reference topography using a 3D registration algorithm such as ICP (Iterative Closest Points) and its variants, the relationship between the coordinate system of each probe and the coordinate system of the reference topography can be calculated. Then the relationship between the coordinate systems of 2 probes can be determined, which can then be used to stitch the whole topography. The setup and the math model has been built and some initial results have been acquired.

Paper No. 285: A fast phase detection method based on multi-wavelength interferometry for point diffraction measuring system

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Keywords: phase detection; surface measurement; multi-wavelength; Chinese remainder theorem; interferometry.
Abstract: Point diffraction interferometry (PDI) provides a high accuracy measurement of spherical and aspherical surfaces. A new phase detection method based on multi-wavelength interferometry for PDI system is proposed in this paper. Laser beams with three different wavelengths are composited to generate diffraction wavefront. Three interferograms caused by the three wavelength lights interference respectively are captured by a 3CCD (multispectral CCD) simultaneously in one-shot acquisition so as to significantly reduce sensitivity to vibration. The multi-wavelength interferometry is modeled as a non-linear equation set. Initial values are required firstly when using iteration method to solve the non-linear equation set. Chinese remainder theorem (CRT) is used to robustly obtain initial value of distance. By this means, phase detection can be realized without special phase shifter, such as PZT (Piezo-electric transducer), and do not suffer from the measurement error resulting from the presence of vibration. Simulation experiments testified that the multi-wavelength method has a quick convergence and robust performance.

Paper No. 297: Method for cylindricity error evaluation using incremental algorithm

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Keywords: cylindricity; minimum circumscribed cylinder; maximum inscribed cylinder; SQP method; incremental algorithm
Abstract: Cylindricity error is an important quality index of the mechanical parts that affects performance of the precision products. A novel method for cylindricity error evaluation based on minimum circumscribed cylinder (MCC) and maximum inscribed cylinder (MIC) is proposed in this paper inspired by randomized incremental algorithm. The principle of the method is to construct a minimum circumscribed (maximum inscribed) cylinder for initial subset constituted by six points and add the point farthest (nearest) from the center axis of cylinder to the subset. The previous step repeats until all the measured points are in (out of) the minimum circumscribed (maximum inscribed) cylinder. The proposed method is tested in comparison with selected methods published and proposed method is shown to have excellent performance on computation time and precision.

Paper No. 338: A new method for integration of registered multiview point clouds

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Keywords: 3D Reconstruction; Data Fusion; Point Cloud Integration; Moving Least Squares Fitting
Abstract: Registration and integration of multi-view point clouds are primitive problems for the application of 3D scanning systems in industrial inspection and reverse engineering. Tremendous work has been carried out to transform multiview point clouds into a unique global coordinate system, but the registration result cannot guarantee to

be a single, seamless or coherent point-set surface due to measurement uncertainties. Therefore, integration algorithms are often utilized as a subsequent procedure to improve the quality of the reconstructed surface. In this paper, a novel data fusion method based on moving-least-squares-projection and energy function minimization was proposed to seamlessly integrate the registered point clouds within their overlapping area. A comparative study on synthetic surface data shows that the proposed algorithm can significantly reduce the registration error and desirably retain geometric details of 3D object surface of interest.

Oral Session 22: In-Process and Online (II)

Location: International Hall	
Chairs: Prof. Yongsheng Gao, Dr. Lina Fei	
206	In-Situ Geometric Parameters Measurement for Thin-Wall Rotary Body Based on Double Laser Sensors
222	Four-probe Error Separation Method for On-line Measuring Cylindricity
231	Modeling for Accuracy Prediction of Distribution Automation Test System by LS-SVM Method
300	A New MOV Online Monitoring System in Series Compensation Capacitor System

Paper No. 206: In-situ geometric parameters measurement for thin-wall rotary body based on double laser sensors

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Keywords: measurement; thickness; datum axis; rotary body; laser; relative position
Abstract: To estimate the geometric parameters of the thin-wall rotary body, an in-situ measurement method is introduced based on double laser displacement sensors. The mathematical model which links the measured values with the installation position of the rotary body is established by using computational geometry method, which can unify coordinate systems to connect the sensor coordinate system with the milling machine coordinate system. Then, an improved particle swarm optimize algorithm (IPSO) with the least squares initial value is applied to extract the datum axis vector and thickness of the measured work-piece from the original data. The simulation results show that it has the fast convergence speed and high precision of prediction. The repeatability of eccentricity and thickness is not more than 0.02mm and 0.05mm, respectively, which meets the detection precision requirements for the large sized hollow rotating parts.

Paper No. 222: Four-probe error separation method for on-line measuring cylindricity

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Keywords: On-line measurement; Reconstruction; Form error; Error separation technology; Multi-probe method.
Abstract: Four-probe error separation method implements synchronously two kinds of error separation calculations so as to realize the on-line measuring the large cylindrical profile. The three-probe roundness error separation is employed to extract the out-of-roundness and radial deviation of the cross-section profile, but not determine exactly the geometric center vector due to the harmonic suppression. The another probe at the next cross-section profile senses the radial mixed errors. We derived a formula to calculate the differential vector of the geometric center at adjacent two cross-sections by the outputs of four probes during one-circle measuring. The geometric center vector of each cross section profile is determined by the accumulation operation alike the two-probe straightness error separation method.

And then, the cylindrical profile is reconstructed based on a curving median line fitted by the geometric center vector of cross-section profile, supplemented by the out-of-roundness and radial deviation extracted by the three-probe error separation method. On this basis, the cylindricity can be evaluated easily. Theoretical analysis and numerical validation have proved that the method is immune to both the spindle radial run-outs and the linear slide error motions. Just so, the method makes it possible to lower requirements for the spindle motion precision and the linear slide motion precision, and save the manufacturing cost of on-line measurement equipment.

Paper No. 231: Modeling for accuracy prediction of distribution automation test system by LS-SVM method

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Keywords: distribution automation; accuracy; nonlinear modeling; LS-SVM; parameter optimization

Abstract: In order to on-line compensate the signal transmission error of the Distribution Automation Test System(DATS), a novel accuracy prediction model is built in this paper. The traditional accuracy prediction modeling method is generally applied to static measuring systems, which cannot be used for on-line measurement and compensation. Therefore, a novel accuracy modeling method of DATS is proposed based on least square support vector machine (LS-SVM). The generalization ability and predictive effect of the LS-SVM regression is influenced by the kernel parameter and the regularization parameter. The popular parameter optimization algorithms of LS-SVM include the grid search algorithm (GS), genetic algorithm (GA), and particle swarm optimization algorithm (PSO). To validate the advantage of our suggested method, it is applied to a DATS based on a four-layer structure. Different nonlinear models of the system with three characteristic variables are constructed. The model forecasting effects of these methods are compared. The results show that GA algorithm is more appropriate for DATS, the mean square error (MSE) of the optimum accuracy model is only 0.0005, and the relative error is less than 3%.

Paper No. 300: A new MOV online monitoring system in series compensation capacitor system

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Keywords: Metal Oxide Varistor, Online Monitoring, Series Compensation Capacitor,
Leakage Current, Fiber Transmission

Abstract: In this paper, an improving Metal oxide varistor (MOV) on-line monitoring and installation method is presented.The monitoring system includes data acquisition unit, optical fiber transmission unit and data processing unit.The leakage currents in MOV sets are measured by current sensors with range of 100 μA to 10 mA. Each current sensor is responsible for measuring two adjacent MOV sets. The leakage currents are acquired with 16-bit A/D converter. The sampling data are sent to the ground analysis unit with optical fiber. The harmonic current components are calculated with Fourier transform algorithm with Blackman-Harris window and harmonic analysis method are used to achieve the diagnosis and fault alarm. The system test are carried out in the laboratory. The results show that the system have high accuracy.

Oral Session 23: Intelligent Instruments for Automation (II)

Location: Conference room No.7

Chairs: Prof. Zonghua Zhang, Prof. Haihua Cui

Paper No. 168: Calculation and simulation of negative pressure at outlet of throttle orifice

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Key words: negative pressure; CFD simulation; pressure distribution; the bearing capacity.

Abstract: The stability of the air film on the floating platform is affected by bleed pressure and geometric parameters. According to the gas lubrication theory, establish the equation of pressure distribution at the outlet of throttle orifice. The state of the air flow is simulated by the software CFD (computational fluid dynamics). Explore the law of negative pressure at outlet of throttle orifice by the means of changing the pressure of air source, modifying the structural parameters of throttle orifice, and adding negative pressure boundary conditions. The simulation is consistent with theoretical results, which has great significance on improving the stability of air film.

Paper No. 213: Coaxiality detection method with non-adjustment for installation errors

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Keywords: Installation errors; Coaxiality; Non-adjustment; Automation; Detection method

Abstract: During the assembly of the engine casing, the coaxiality detection for the two assemblies are essential. And the modern manufacturing industry has put forward higher requirements for the coaxiality measurement with the development of the industrial technology. The existing coaxiality detection methods are mostly based on manual measurements. It takes long time to adjust the axes of assembly parts and turntable to coincide by the current measurement method, which greatly affects production efficiency. To solve the problem, this paper proposes a coaxiality detection method which can compensate assembly installation errors automatically. The coaxiality measurement method based on the position of the assembly is deduced by introducing the measurement mechanism of the coordinate measuring machine. The data processing uses coordinate transformation and least squares fitting method. Experimental verification shows that the method do not need to adjust the assembly part repeatedly, so measuring time is reduced greatly. The method simplifies the measurement steps, and provide supports of methods and techniques for automatic detect.

Paper No. 275: The method for laser drift restraining based on mirror control

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Keywords: laser collimation; beam drift; feedback control; moving average filter; PID

Abstract: In this paper, based on piezoelectric ceramics (PZT), a feedback control method of compensating for collimated beam drift is proposed. The angular drift of laser is detected and separated in the designed optical path. The influence of interference noise is suppressed by moving average filter, and then the drift of the beam drift is compensated through controlling mirror by PZT in result of suppressing its influence on the stability of collimation measurement of laser. The real-time control of PID (proportional-integral-derivative) is realized by using LabVIEW. The experimental results show that the angular drift of the laser compensated by this method is reduced by 1.5 to 6 times.

Paper No. 210: Whole gear outline scanning measurement of internal gear by using CNC gear measuring machine

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Keywords: gear measuring machine, internal gear, whole gear outline scanning measurement, 3D scanning probe

Abstract: We aim to develop a general-purpose and relatively inexpensive gear measuring machine (GMM). A 3D scanning probe has been installed on a GMM and the whole gear outline gear measurement is devised to perform scanning measurement with a single stroke without detaching a stylus tip from a gear surface. By this method, it is possible to evaluate the tooth root and bottom profiles with single measurement in addition to calculation of tooth profile deviations and pitch deviations. The measurement target is narrowed down to an internal spur and helical gears in this paper. The evaluation was conducted on the same cross-section of the external helical gear measurement and the variation of deviations along the axial direction were evaluated. The axial deviations were improved by controlling the stylus movement during scanning measurement.

Oral Session 24: Material Characterization & Management of Measurement Processes

Location: Conference room No.10 **Chairs: Prof. Jie Lin, Dr. Feng Gao**
345 3-D surface profiling of rough surfaces by coherence scanning interferometry using femtosecond pulsed laser
31 Analysis of vulnerable components in Automatic Brake Arm
281 Effect of ambient air flow on the resistivity uniformity of Ga-doped ZnO film deposited in open air
283 Three-dimensional parameter detection of defects for gas turbine blades based on digital radiography

Paper No. 345: 3-D surface profiling of rough surfaces by coherence scanning interferometry using femtosecond pulsed laser

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Keywords: Coherence scanning interferometry, femtosecond pulse laser, 3-D surface profile measurement, rough surface, large field of view

Abstract: We present a coherence scanning interferometer designed for large field-of-view surface profiling using an Er-doped femtosecond laser. The infrared light source interferometer scheme provides high spatial coherence and subsequently enhances the correlogram fringe contrast by increasing the specular reflectance from rough surfaces. And, an infrared camera operating in the C-band light range is used configured to facilitate direct measurement with high quantum efficiency. Experimental results acquired from gauge blocks, polished and ground SiC concave mirrors of 50 mm aperture size are discussed to verify the proposed interferometer.

Paper No. 31:Analysis of vulnerable components in Automatic Brake Arm

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Keywords： Automatic Brake Adjuster; Bench test; Simulation analysis; Fatigue life

Abstract： This paper studies the vulnerable components of the automatic adjusting arm(ABA) for automobile. Based on the SW part model of the ABA,the gear rack system and worm gear system of ABA are mainly analyzed. Especially, three kinds of vulnerable parts are researched. The worst situation of components is analyzed and simulated in ANSYS Workbench which could predict the fatigue life of components in a given condition. Thereby, the overall life of ABA could be evaluated, too.A fatigue life test bench is also provided in this paper, 25 ABA of the same model have been

tested，the experimental results show that the average fatigue life of ABA is 2.018×10^5 times, which is in agreement with the results of the finite element analysis in ANSYS Workbench.

Paper No. 281:Effect of ambient air flow on the resistivity uniformity of ga-doped ZnO film deposited in open air

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Keywords: Atmospheric pressure plasma jet (APPJ), transparent conductive oxide (TCO), gallium-doped zinc oxide (GZO), material characterization

Abstract: Transparent conductive thin films are usually grown by magnetron sputtering method which possessing a vacuum chamber which isolates the deposition process from surrounding's interrupt. However, in atmospheric pressure plasma jet method, it is hard to avoid being disturbed by surroundings because of no vacuum chamber. Here we prepared double-deposit Gallium-doped Zinc Oxide thin films on large area (185 mm × 117 mm × 0.5 mm) glass substrate (preheated to 180°C) by APPJ with open and close boundary. We found that the resistivity is higher at the position next to the open boundary, which the air can flow in with no obstacle, but in close boundary case, there is no significant difference between all of the position. The results can beattributed to the annealing effect.Annealing in oxygen sufficient ambient results in the decrease of oxygen vacancy concentration which is positive correlation to carrier concentration. Hence, the lower carrier concentration leads to the higher resistivity at the position next to the open boundary. This result can help us improve the APPJ system such as the isolation ability to the enclosure

Paper No. 283: Three-dimensional parameter detection of defects for gas turbine blades based on digital radiography

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Keywords: Gas turbine blades; Defects; Three-dimensional parameters; Digital radiography; Nondestructive testing

Abstract: During the process of manufacturing or service, various types of defects may be formed in the turbine blades, such as holes, cracks, porosity and inclusions. However, some limitations are faced by the existing nondestructive testing methods in the process of detecting defects. For instance, although the industrial computed tomography (CT) can detect and obtain the 3D geometric parameters of defects, the low efficiency and high cost cannot be avoided when applied to the detection of gas turbine blades. Moreover, the conventional film based radiographic testing (RT) can only obtain the 2D parameters of defect with the disadvantages of high cost and low efficiency as well. Aiming at this critical issue, a new method based on digital radiography (DR) is presented in this paper. In the proposed method, the material thickness along the irradiation direction was discretized based on the grey level of DR image. Combined with the 2D geometric parameters in the plane perpendicular to the transmission direction, the 3D geometric parameters of defects could be obtained. The experimental results showed that the proposed method could quickly and effectively detect the turbine blades and acquire the 3D geometric parameters of defects. It is particularly suitable for the practical application of offline detection for gas turbine blades with high efficiency and low cost.

Poster Session 1: Intelligent instruments for automation & machine vision and image processing

Poster ID	Paper ID	Paper Title
P1-06	209	An Temperature Compensation System for Quartz Differential Resonant Accelerometer Using FPGA and SOPC
P1-07	217	The Calibration and Analysis of Inertia Sensors for Unmanned Aerial Vehicle
P1-08	229	Design of Motion Controller in Flat-Panel Detection and Conveying Platform Based on STM32F4
P1-09	20	The Motion blurred image restoration based on Automatic guided vehicle
P1-10	34	Global Calibration Method and Apparatus for Multi-camera Measurement System
P1-11	54	First Exploration in Micro Inertial Navigation Typed Motion Capture System

Paper No. 209: Antemperature compensation system for quartz differential resonant accelerometer using FPGA and SOPC

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Keywords: Resonant accelerometer, Quartz DETF, Temperature compensation

Abstract: This paper presents a temperature compensation system for improving the accuracy of quartz differential resonant accelerometer (QDRA) interfered by the temperature. To begin with, the accelerometer's principle and structural features are illustrated, and the excitation circuit is made according to the equivalent circuit parameters of the quartz double-ended tuning fork (DETF) using two-door self-oscillator design. Then, in order to measure the frequency of the square wave which is outputted by the excitation circuit, the software and hardware are structured by Verilog and SOPC based on FPGA. A procedure on PC is programmed, which implements serial port communication, database storage, turntable control and calibration of the accelerometer. Finally, A temperature compensation method based on the procedure is put forward. The experimental results indicate that it can reduce the maximum root mean square error (RMSE) from 1.1559×10-2 kHz to 2.6031×10-4 kHz, and reduce the offset thermal drift from 3.440%FS/℃ to 0.179%FS/℃ in the range from -10℃ to 50℃.

Paper No. 217: The calibration and analysis of inertia sensors for unmanned aerial vehicle

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Keywords: Inertia Sensor, Unmanned aerial vehicle, Error compensation

Abstract: This paper reports on a method for calibration and analysis of inertia sensors which is widely used for the area of unmanned aerial vehicles. This study analyzes the static and dynamic characteristics of the adopted device. A system error model is built including accelerator and gyro. This static experiment of inertia sensor was carried on the

six directions platform for getting the parameters which is used for calibrating the bias, scale factor and sensitivity. The relative error model is established for explaining the rate performance of the inertia sensor. Compared the performances with different inertia sensors such as the shock, bias and chaos, the optimal system of inertia sensor for unmanned aerial vehicle was confirmed with low system errors.

Paper No. 229: Design of motion controller in flat-panel detection and conveying platform based on STM32F4

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Keywords: Motion controller, Cylinder synchronization, STM32F4, Flat-panel conveying platform
Abstract: There are many problems such as expensiveness and difficult maintenance in motion controller of flat-panel detector and delivery platform. For these, the design of flat-panel detection and conveying platform is presented based on STM32F4. The design uses a high-performance MCU to provide powerful computing resources and rich communication interfaces, and it provides a guarantee for precise control of the servo motor. Meanwhile, the rich microcontroller IO resources fully meet the multi-switch detection and control in the process of flat panel detection and control. The modular design is adopted for the power module, the core board module, communication module, encoder module, IO module, etc. This simplifies hardware structure of the control system, easy to maintain and upgrade later. Finally, the scheme of cylinder synchronization control is proposed and has been verified in matlab simulation. While achieving precise control, it effectively reduces the controller cost and size of the control system. In the industrial automation and networked application environment, the design has practical significance.

Paper No. 20: The motion blurred image restoration based on automatic guided vehicle

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Keywords: Automatic guided vehicle; Qt Creator; Image Restoration; motion-blurred images
Abstract: The Automatic guided vehicle (AGV) based on visual guidance is adopted CCD to collect of Line-tracking of AGV. Acquiring the paths and signs form the surface of the road. When the CCD sampled the image, that blurring image while the CCD and the object are in relative motion during the short time of exposure. This paper to The Restore of motion-blurred images by establishing Motion blur degradation model, and Restored image by the Improved Lucy-Richardson reconstruction algorithm, finally converted the algorithm into C plus programming in the Linux operating system by QT with OpenCV2.4.7 environment. The experimental results show that algorithm has a good effect on the restoration of motion-blurred images.

Paper No. 34: Global calibration method and apparatus for multi-camera measurement system

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Keywords: Multi-camera; Global Calibration; Attitude Measurement; Target Binding; Coordinates Unification

Abstract: Global calibration of multi-camera measurement system is an important process which has direct influence on system accuracy. Aiming at complexities of operation and maintenance existing in present methods and apparatuses for global calibration, a new method and its associated apparatus are proposed to improve the calibration with modified double planar targets. Operation is simplified because global measurement of apparatus part is unnecessary, transformation matrix of multi-camera is calculated based on the distance invariance of two bound points and the direction consistency of two rotation vectors. After the apparatus is designed and manufactured, calibration and measurement experiments are carried out accordingly; experimental results are consistent with factory calibration by means of standard components and prove that this proposal is advisable.

Paper No. 54: First exploration in micro inertial navigation typed motion capture system

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Keywords: Designplan,Magnetic force meter, MEMS, Acceleration meter,Gyroscope-free SINS system
Abstract: At present, making use of the Gyroscope-free Micro Inertial Navigation technology to achieve Motion Capture System is one of its development directions. On the whole, this paper have introduced the method adopting MEMS technology design, by that and testing the feasibility of this scheme.This paper has been listed the difficult points coming across in process, and carried out detailed explanation on difficult point. Finally, this paper has brought forward some views on systematic deficiencies.

Poster Session 1: Management of Measurement Processes & Micro and NanoMetrology

Poster ID	Paper ID	Paper Title
P1-12	60	On-line Monitoring of Mine Tunnel Deformation using Laser Radar
P1-13	129	Kernel Function Modeling of Spatial Measurement Error
P1-14	21	Probe Error Analysis of Articulated Arm Coordinate Measuring Machine
P1-15	81	Motion interactions of a 2-DOF linear piezoelectric impact drivemechanism with a single friction interface
P1-16	99	Creation of a long optical needle by a planar microstructure
P1-17	141	Numerical simulation of tomographic Mueller-matrix microscopy for nanoscale measurement

Paper No. 60: On-line monitoring of mine tunnel deformation using laser radar

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Keywords: Tunnel deformation; Laser radar; Zig Bee wireless communication; Processing; STM32

Abstract: Minetunnel deformation blocks underground coal mine traffic, or even cause serious securityincidents. Aiming at the problemof lack of monitoring method of tunnel deformation, this paper presents a method of tunnel deformation measurement based on laser-radar technology. The measurement method is anon-contact and on-line measurement method. The system is mainly composed of two parts, the host part is composed of computer,Zig Bee module and processing software system based on Processing, the slave part is composed of four-rotor craft,STM32 microprocessor,laser radar, Zig Bee wireless communication module and power supply module.The new tunnel deformation measurement method based on radar proposed in this paper has the advantage of smaller measurement data error, the data communication and processing speed is qualified and suitable for on-line monitoring.

Paper No. 129: Kernel function modeling of spatial measurement error

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Key words: Coordinate Measuring Machine; Error modeling;non-parametric regression; Kernel function

Abstract: Due to the complicated system constitution of three-dimensional measuring machine, it involves the multiple error components. So in the fast measurement, it is complicated to analyze spatial error characteristics in detail. In the experimental planning section, data are collected by measuring Gauge block in different length and different space positions. Then we use partial least square and kernel function to model and predict the experimental data. According to the result, the error of mean square in kernel function is 0.00542mmand the correlative coefficient is as high as 91.1373% while the mean square of partial least square is 0.3069mm.The experiment results indicate that the kernel function has a better imitative predictive effect than the partial least square and non-parametric modeling is more accurate than the parametric modeling in predicting spatial measurement error estimation of Coordinate

Measuring Machine.

Paper No. 21: Probe error analysis of articulated arm coordinate measuring machine

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Keywords: Articulated arm coordinate measuring machine; Diameter error; Contact force; Error compensation
Abstract: Researched on the probe's diameter error of the articulated arm coordinate measuring machine (AACMM) in the measuring process. Based on the analysis of the influence of the error source on the accuracy of the probe, the influence of the contact force on the measuring diameter of the probe was analyzed emphatically. It was proposed to use the coordinate measuring machine (CMM) to identify the probe diameter error of the AACMM and apply the least square method to compensate the probe diameter error. The results show: The research method has certain feasibility. The maximum error of the length measurement is reduced by about 47 um. The average error is reduced from 0.0315 mm to 0.0046 mm, which improved the measurement accuracy of the AACMM.

Paper No. 81: Motion interactions of a 2-DOF linear piezoelectric impact drive mechanism with a single friction interface

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Keywords: piezoelectric, impact drive mechanism, motion interaction, dynamic model
Abstract: A two-degree-of-freedom (2-DOF) linear piezoelectric impact drive mechanism (PIDM), which is actuated by two independent piezoelectric actuators (PAs), can move in the corresponding x-axis and y-axis with a single friction interface.While the two DOF motions are operated non-simultaneously, the relationships between the output displacements and input voltages are simple. However, while the two DOF motions are operated at the same time, there might be a different result due to the common friction interface. In this paper, motion interactions of the 2-DOF linear PIDM with a single friction interface are introduced and analyzed. A complete dynamic model of the PIDM is established with proper friction model considering the distribution of friction force in the two axes. With different relationships of the two sawtooth input voltages, the 2-DOF motions are investigated numerically by MATLAB/Simulink software. The mechanism and influences of the friction coupling on the PIDM performances are estimated and discussed.

Paper No. 99: Creation of a long optical needle by a planar microstructure

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Keywords: microstructure; diffraction; super-resolution; polarization; binary optics
Abstract: Based on the previous work, our method is extended to design a microstructure which comprised of multi-FZP(Fresnel zone plate)-fragments for getting a optical needle with random length. As an example, we designed a new microstructure which comprised of three planar FZP-fragments with different focal lengths f1, f2 and f3, then

form a longer light needle by delicate interference of coherent light beams diffracted from these three FZP-fragments. For a 74.34 m diameter microstructure illuminated with a linearly x-polarized beam, a 7.87λ-long uniform optical needle is produced at a distance of 12.31λ away from the mask surface. The transverse beam size are 0.97λ and 0.4λ in x and y directions, respectively. The vectorial angular spectrum(VAS) theory is used to describe the electric field of light behind themicrostructure. These far-field long optical needles can be used in the fields of nanolithography, high density data storage, optical trapping, and microscopypotentially.

Paper No. 141: Numerical simulation of tomographic Mueller-matrixmicroscopy for nanoscale measurement

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Keywords: tomographic Mueller-matrix microscopy; computational electromagnetics; polarization effects; vectorial imaging

Abstract: Accurate modeling of electromagnetic fields is highly desirable in the optical measurement of nanostructures as one need repeatedly evaluate the distribution of electromagnetic field under variations of the frequency, the incident angle of the incident wave, and the nanostructure geometric parameters. In this paper, a rigorous vector optical modeling which contains both near-field electromagnetic-filed modeling and far-field electromagnetic-field modeling for TomographicMueller-matrix microscopy (TMM) is proposed.This modeling applies a full treatment of polarization effects which such considerations have implications at all stages in the image formation process, namely, illumination, scattering from the sample, imaging. By applying the proposed modeling, numerical simulations are carried out to demonstrate thepotential of TMM in nanoscale measurement.

Poster Session 1: Optical Metrology

Poster ID	Paper ID	Paper Title
P1-18	40	Design of Optical Detection System for Centrifugal Microfluidic Chip
P1-19	51	Numerical investigation on refractive index compensation performance of three-color method
P1-20	97	High Precision FMCW Laser Ranging System with an Imperfect ECDL
P1-21	115	Alignment Error in Bearing Ball Measurement System With Laser Interferometry
P1-22	116	A circular gird pattern detection method based on multi-exposure image fusion

Paper No. 40: Design of optical detection system for centrifugalmicrofluidic chip

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Keywords: microfluidic chip; optical detection; concentration detection; real-time display; intelligent instrument

Abstract: Microfluidic chip is the forefront of the current development of science and technology. Now people have made great progress in the field of microfluidic chip. In contrast to the development of microfluidic chip, optical detection system used on microfluidic chip is relatively backward. Owing to the small size of chip, the short optical depth, the accomplishment of the analysis in seconds, and so on, traditional detection system is far from the requirements of miniaturization, high sensitivity and high precision. In order to solve the problem of high precision detection of liquid concentration of micro detection pools in microfluidic chip and the miniaturization of the optical detection system, an optical detection method based on Lambert-Beer's law is adopted and an optical detection system for centrifugal microfluidic chip detection is designed in this paper. In this system, the sodium light with a wavelength of 598nm provides stable imported light; the light that condensed by the condenser passes through the chip detection pool; the photodiode receives the transmitted light; microprocessor processes signal and LCD displays test results. In addition, the paper designs a multi-sample centrifugal microfluidic chip for HBV based on ELISA, using the optical detection system designed in this paper to inspect the concentration of the reaction pools. By analyzing the inspection results, the accuracy of the optical detection system is proved to be about ±1%(concentration). Finally, the problem of high precision optical detection in microfluidic chip and the miniaturization of the optical detection system is well solved. Experiments results show that the system can realize the function of detection of the liquid concentration. The system is simple in design, reliable in operation, fast in detecting and has the high accuracy to meet the requirements of optical detection.

Paper No. 51: Numerical investigation on refractive index compensation performance of three-color method

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Keywords: Three-color method; Length measurement; Refractive index of air; Uncertainty; Optimization
Abstract: The three-color method is the few methods to eliminate the influence of the refractive index of air, because a length measured in air need to be converted to a length in vacuum. However, the error of the method is not well known. We investigate the limit of its compensation performance using numerical simulations.Numerical calculations reveal the change of the uncertainty with environmental parameters (for example, temperature, air pressure) and wavelengths. These characteristics can be used to further develop our understanding of the three-color method.

Paper No. 97: High precision FMCW laser ranging system with an imperfect ECDL

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Keywords: FMCW laser ranging, Absolute distance measurement, Interference measurement, Industrial large-scale measurement, Signal processing
Abstract: The measurement precision of frequency modulation continuous wave (FMCW) laser ranging system is depend on the mode-hop-free frequency scanning range and linearity of the tunable laser. However, the mode hopping of a commercial tunable laser is difficult to avoid, when the scanning range exceeds 1THz. And this seriously affects the measurement resolution. A signal cropping and stitching method is present in this paper, for single target distance measurement, the part of the mode-hopping in the interference signal can be removed to eliminate its influence. A distance measuring experiment is demonstrated that the influence caused by the mode-hop of ECDL was eliminated. The repeatability precision of the system was below ±15μm at the range of 5m.

Paper No. 115: Alignment error in bearing ball measurement system with laser interferometry

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Keywords: Laser interferometry; Alignment error; Bearing ball; Zernike polynomials; Sphere deviation
Abstract: Requirements on high-performance of bearing ballsare increasing as the continuous development of automotive, aerospace, and power generation industries. In recent years, laser interferometry has been a potential method for surface measurement of the balls as it provides rapidand accurate measurement with optic waves. In this paper, we propose a Tyman-Green interference method for bearing ball measurement which used a plane reference mirror instead of a spherical mirror for surface error measurement of bearings ball to reduce the reference error in measurement result. Generally, due to the difficulty of accurate positioning of the balls, there is a wavefront aberration in the interferometry systems. In order to analyses the wavefront aberration caused by alignment error in bearing ball measurement system with laser interferometry (BBMSLI), we apply Zernike polynomials fitting method to eliminate the error according to the corresponding relationship between the polynomials and the error. The result of experiment with different location of bearing ball shows that the method we proposed is effective in alignment error elimination. The final results may be useful to encourage the method application in other fields of optical measurement.

Paper No. 116: A circular gird pattern detection method based onmulti-exposure image fusion

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Keywords: strain measurement; multi-exposure; image fusion; circular gird pattern detection
Abstract: Inthis paper we present a circular grid image acquisition and detection method based on the multi-exposure image fusion technology. Circular grid pattern is electrochemically etched onto the surface of flat sheet metal before forming, and multi-exposure images are recorded from each photo station using a single camera. Subsequently, the multi-exposure sequence are fused into a high quality image by using Laplacian pyramid-based multi-exposure image fusion technology. Then image adaptive thresholding is applied to the fused image to separate the grid nodes from the background. Next we extract the outline of the target ellipse in the binarized gird images. Finally, the 2D coordinates of the circular gird nodes in the fused high quality image can be detected accurately using direct least squares fitting of ellipses. Experimental results illustrate that the novel method completely improves the grid detection rate and detection accuracy.

Poster Session 1: Sensors and Actuators

Poster ID	Paper ID	Paper Title
P1-23	130	Fabrication and Testing of Wireless Passive and Thin Film Temperature Sensor
P1-24	135	Bio-electronic System for Megapolis Water Supply Monitoring
P1-25	226	Study on Novel Temperature Sensor based on Amorphous Carbon Film
P1-26	236	Development of a Cutting Force Sensor Based on MEMS strain gauge
P1-27	239	Research of a novel ultra-high pressure sensor with high-temperature resistance

Paper No. 130: Fabrication and testing of wireless passive and thin film temperature sensor

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Keywords: HTCC, LC, passive wireless sensor,temperature, near-field coupling
Abstract: In this paper,on the basis of HTCC, namely high temperature co-fired ceramic technology,which can obtain the overall size of 50 mm × 50 mm × 0.36 mm white dense alumina ceramic substrate adopting the high temperature sintering process,we proposed a method that reasonably makes a design for resonant special circuit structure based on LC by means of making an analysis of the sensor modeling, and form LC resonant circuit by combining with screen printing technology as well as using thick film technology to print silver paste on the substrate. The special circuit structure forms the LC resonant circuit via using inductance and its parasitic capacitance. Its simple structure makes the sensor easier to fabricate, which has more practicality. Finally,a high temperature test platform that consists of high-temperature furnace,network analyzers and near-field coupling antenna is built to test the sensor at high temperature by employing return loss. And the wireless coupling test of the sensor is realized in the temperature range of 25 ℃ ~ 900 ℃. The results show that the thin film type temperature sensor exhibits good linear characteristics.The sensitivity of the resonant frequency of the average temperatureis about 7.71 kHz / ℃.

Paper No. 135: Bio-electronic system for megapolis water supply monitoring

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Keywords: bio-electronicsystem, crayfish cardiac activity, cardiac activity parameters, biosensor selection criteria, metrological self-check
Abstract: A tendency has been noted in development of bio-electronic systems applying animals as sensors. They are designed to detect various objects and phenomena. Using the example of bio-electronic system intended for warning in the case of sudden water pollution, the advantages of such systems, special requirements for them as measuring

systems, a "biosensor" selection criteria, the need for organization of their metrological self-check, and its features are considered.

Paper No. 226: Study on novel temperature sensor based on amorphous carbon film

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Keywords: Amorphous carbon film, Thermistor, Temperature sensor, Temperature resistance characterization, Temperature coefficient of resistance

Abstract: In this study, a new type of thermistor temperature sensor was developed. The sensing materials was amorphous carbon (a-C) film prepared using electron cyclotron resonance (ECR) plasma processing system under low energy electron irradiation sputtering. The nanostructure of a-C film was observed by transmission electron microscope (TEM), the atomic bonding and carbon hybridization condition was analyzed by Raman spectra and X-ray photoelectron spectroscopy (XPS) respectively. The linearity of temperature-resistance curve of this kind of a-C film was very good in certain temperature range, with high temperature coefficient of resistance (TCR). The a-C film by 50 eV electron irradiation can measure larger temperature range from -75 ℃to 155 ℃, with good repeatability. The working temperature range of a-C film by 100 eV electron irradiation wasmuch smaller, but TCR absolute value of this film was higher. It can be concluded that the lower sp2 / sp3, the better linearity of temperature-resistance curve, the lower TCR absolute value in certain working temperature range. The research shows that this kind of a-C film temperature sensor has good linearity and repeatability, also it can be integrated with other MEMS sensor simply.

Paper No. 236: Development of a cutting force sensor based on MEMS strain gauge

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Keywords: MEMS, Strain gauge, Cutting force sensor, Sensitivity, Accuracy

Abstract: Cutting force measurement plays a key role in machining status monitoring and controlling for intelligent manufacture.This paper developed a traixial cutting forcesensorbasedonsemi-conductive strain gauge thatfabricatedby Micro-Electro-MechanicalSystem (MEMS)technology, a two mutual-perpendicular octagonal ring structure is proposed as elastic sensitive element that can achieve good rigidity and decoupling ability. The developed sensor owns fine accuracy, and its sensitivity is about 30 times of traditional strain gauge type cutting force sensor. The developed sensor can precisely measure dynamic cutting force and reflect cutting status variation during machining process, which possesses great potential in practical application.

Paper No. 239: Research of a novel ultra-high pressure sensor with high-temperature resistance

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Keywords: Ultra-high pressure sensor; SOI piezoresistive chip; Small size; High temperature resistance; MEMS technology

Abstract: A novel structure for ultra-high pressure sensor is proposed to measure the pressure up to 2GPa. This structure combines truncated-cone and SOI piezoresistive chip. The truncated-cone is designed to attenuate the pressure exerted on upper end-face to a value that can be detected by the SOI piezoresistive chip. Four piezoresistors of the SOI chip fabricated by MEMS technology are placed in specific crystal orientation and configured as a Wheatstone bridge to obtain voltage signal. The sensor has an advantage of high-temperature resistance, in that the structure of the chip can avoid the leakage current at high temperature and the truncated-cone separates the chip from the heat environment. Furthermore, the diameter of bearing surface is designed to be 1 mm for the application of small scale. The result of static pressure test shows that the sensor exhibits a good performance in the hysteresis and repeatability. This study would provide better insight to the research of ultra-high pressure sensors with higher GPa and smaller size.

Poster Session 1: SurfaceMetrology

Poster ID	Paper ID	Paper Title
P1-28	122	Study on the measurement and evaluation method for large-diameteraspheric surface based oncylindrical coordinate system
P1-29	306	Eddy Current Testing for Blade Edge Micro Cracks of Aircraft Engine

Paper No. 122: Study on the measurement and evaluation method for large-diameter aspheric surface based oncylindrical coordinate system

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Keywords: Cylindrical coordinate; Large-diameter aspheric; Profile error; Three-dimension profile; Nonlinear least square

Abstract: Large-diameter aspheric optical components are increasingly used in the fields of modern science and technology, such as, laser technology, space telescopes and satellite remote sensing, and they are manufactured by the processing, measuring, compensation processing in order to satisfy the profile accuracy requirements. To improve the machining accuracy and efficiency as well as solve the problem of profile measurement and evaluating in the grinding stage, high precision profile measurement solution for large-diameter aspheric was proposed based on the cylindrical coordinate measurement mode. Firstly, the path planning is carried out for the coordinate measurement on the sampling method, the eccentricity and tilt deviation was calculated based on the analysis of the error of the measurement coordinate and workpiece coordinate, and the corresponding deviation was obtained, the influence of deviation was eliminated to improve the measurement accuracy according to the coordinate transformation theory. In order to evaluate the whole surface profile error, mathematical model of the three-dimensional profile error was established. Based on the nonlinear least squares method, aspheric surface parameters of the ideal aspheric equation coefficient were fitted by Newton's algorithm after several iterations, the 3D profile error is evaluated by the fitting parameter. The measurement experiments on 300-mm-diameter K9 glass workpiece was conducted, the profile accuracy could be improve from 35μm to 10μm after the eccentricity and tilt error elimination. Experiment results show that after repeated compensation grinding for the 300mm aspheric mirror according to the three-dimension profile error, the profile error was reduced to be 4μm from 9μm. The proposed measuring method and mathematical model are effective to improve profile measurement accuracy in the grinding stage.

Paper No. 306: Eddy current testing for blade edge micro cracks of aircraft engine

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Keywords: aeroengine blade; the differential excitation; eddy current sensor; micro crack.

Abstract: Based on the problems of low detection efficiency in the micro cracks detection of aircraft engine blades, a differential excitation eddy current testing system was designed and developed. The function and the working principle of the system were described, the problems which contained the manufacture method of simulated cracks,

signal generating, signal processing and the signal display method were described. The detection test was carried out by taking a certain model aircraft engine blade with simulated cracks as a tested specimen. The test data was processed bydigital low-pass filter in the computer and the crack signals of time domain display and Lissajous figure display were acquired. By comparing the test results, it isverified that Lissajous figure display shows better performance compared to time domain display when the crack angle is small. The test results show that the eddy current testing system designed in this paper is feasible to detect the micro cracks on the aeroengine blade and can effectively improve the detection efficiency of micro cracks in the practical detection work.

Poster Session2: Calibration and machine tool performance & in-process and online metrology

Poster ID	Paper ID	Paper Title
P2-01	279	The Design of Automatic Detection System of High - speed Locomotive Anti - skid Valve
P2-02	289	Measurement and Compensation Method of Gantry CNC Machine Tool Based on Single Laser Synchronization Method
P2-03	308	A Study of Data Acqusition System of FPGA-based Multichannel DMA Data-Caching Technolog
P2-04	205	Research on the Practical Application of the Optimal Measurement Area of Articulated Arm Coordinate Measuring Machine
P2-05	295	Research on Environmental Test On-line Detection Device Based on Flow Metrological Instrument

Paper No. 279: The design of automatic detection system of high - speed locomotive anti - skid valve

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Keywords: Anti-skid valve; detecting system; action response time; the intake andexhaust performance; LABVIEW

Abstract: Based on the high-speed data acquisition technology, PWM control technology and sealing detection method, the Anti-skid valve detecting system is designed to realize the action response time, the intake and exhaust performance test of the Anti-skid valve. Under the condition of simulating the actual braking condition, the system controls the solenoid valve on-off by outputting the PWM with fast response performance. It realizes the high accuracy detection of performance of Anti-skid valve. The repetitive experiments are performed on detecting system. The test data show the detection of the Anti-skid valve can be completed stably with the detecting system automatically.

Paper No. 289: Measurement and compensation method of gantry cnc machine tool based on single laser synchronization method

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Keywords: Gantry CNC Machine Tool, Measurement, Compensation, Laser

Abstract: The gantry CNC machine tool has unique structure and characteristic. The gantry machine tool does not always form a symmetrical structure and symmetrical force during the machining process, as well as various uncertainties in the course of operation. The inconsistency will cause a non-synchronized error in the biaxial synchronous system. The no-synchronized error will affect the machining accuracy, cause the beam to be pulled and the gantry frame or drive element to be damaged. Therefore the biaxial synchronization error of the CNC machine tool

is one of its most important specifications, and it should be solved firstly when compensating. This paper presents a new method called single laser synchronization method, which bases on the structure and operation characteristics of the gantry CNC machine tool, and puts forward the measurement method and compensation method of positioning error. This new method includes a special optical path layout, a characteristic way of measurement and compensation. This method has some advantages such as high precision, low-cost, efficiency etc.

Paper No. 308: A study of data acqusition system of fpga-based multichannel DMAdata-caching technology

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Keywords: Data acquisition; DMA cache; Gear hobbing; FPGA;CNC
Abstract: Error compensation and on-line monitoring is an important means to reduce the gear machining error and improve the machining accuracy. High speed and high accurate data acquisition system is the key to improve the performance of the control system. For the problem of low data transmission utilization ratio during data acquisition process, a FPGA-based DMA data-caching method was proposed so as to realize DMA data autosave and improve data-caching efficiency. The accuracy and real-timeliness of sampling data of the acquisition system are proved by Verilog simulation and data acquisition experiment.

Paper No. 205: Research on the practical application of the optimal measurement area of articulated arm coordinate measuring machine

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Keywords: articulated armcoordinate measuring machine; initial installation angle; particle swarm optimizationalgorithm
Abstract: In the measurement space of articulated arm coordinate measuring machine (AACMM), there is the optimal measurement area with smaller measurement error. If a tiny part is measured in optimal measurement area, better measurement accuracy can be achieved. In order to make the optimal measuring area located in easy-to-use area such as work platform, a practical method of optimal measurement area was proposed in this paper. The influence of the angle between the circle encoder zero position and the joint zero position (initial installation angle) on the measurement error and the spatial error distribution was analyzed, the initial installation angle was determined by particle swarm optimization algorithm (PSO) and the error of the given area was reduced. This method can be used to guide practical measurement and assembly of measuring machines.

Paper No. 295: Research on environmental test on-line detection device based on flow metrological instrument

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Key words: flow metrology meter; impact of ambient change; online dynamic measurement
Abstract: The metrological performance of flow meter should be tested under the condition of ambient temperature and humidity changes according to appendix A type evaluation outline of JJG 1033-2007 "Electromagnetic Flowmeter"

verification procedures. In order to meet the requirements of the type of evaluation outline, an "environmental test on-line detection device based on flow metrological instrument" is developed. The pipe and the meter can be directly connected to this device. The metrological performance of the meter can be assessed and the environment’s temperature and humidity can be controlled at the same time. Experts have identified that the device can fully meet the requirement that metrological performance of flow meter can be tested under the condition of ambient temperature and humidity changes.

Poster Session2: Intelligent Instruments for Automation& Machine Vision and Image Processing

Poster ID	Paper ID	Paper Title
P2-06	241	Design and Research of Transmission in Automatic Optical Inspection of Glass Substrate
P2-07	266	A method for fast alignment of the beam verticality in high precision absolute gravity measurement
P2-08	273	Design of pipeline leak data acquisition and processing system on LabVIEW
P2-09	67	A Method Based on Transfer Learning for automatic Metallographic rating
P2-10	154	AUniform and Flexible Model for Three-dimensional Measurement of Line-structured Light Sensor
P2-11	164	Global Data Registration Technology Based on Dynamic Coded Points

Paper No. 241: Design and research of transmission in automatic optical inspection of glass substrate

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Keywords: Vacuum adsorption, Vacuum source, Vacuum degree, Vacuum sucker, Floating platform.

Abstract: With the industry of the flat-panel display continues to flourish, the industry of glass substrate which is one of the most important components in flat production continues to grow and develop, but also moving toward a lighter and thinner direction. It is particularly important that the defects of the glass substrate are detected in the non-contact transmission environment, which is to ensure the rate of fine variety of glass substrates. And it is necessary to design a new transmission method that is different from the traditional mechanical contact for transmission, in order to achieve low pulsation, high speed, high stability and high cleanliness of the glass substrate in optical transmission. The use of gas circuit as a transmission medium, has a wide range of applications in the production and testing transmission. On the basis of fully analyzing the relevant research results at home and abroad, the glass substrate is adsorbed and transported by negative pressure which is produced by vacuum sucker with vacuum generator or vacuum pump. Through the analysis and discussion of the force of the transmission load, and the axial load and deformation of vacuum chuck, as well as system holistic considerations, it is analyzed that the influence of the vacuum generator and the vacuum pump as the generating device of the vacuum source on the system and the cost of the generating device. Finally, the vacuum pump is selected as a vacuum source of the device. Based on above, the gas circuit is designed that can absorb the glass substrate by vacuum generated by vacuum pump. The suction and release of the suction cup is controlled by the detection of the signals of the two pressure switches on the cylinder carrying the suction cup. The experimental results show that the design has low disturbance, high efficiency and high cleanliness in the process of liquid crystal substrate transmission and practical application value.

Paper No. 266: A method for fast alignment of the beam verticality in high precision absolute gravity measurement

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Keywords: gravity measurement, laser interferometer, wedge-shaped element, beam verticality
Abstract: The beam verticality is one of the error sources for the free-fall absolute gravimeter. A non-vertical laser beam in the laser interferometer results in a negative system error of g. A misalignment angle of 9 arc second (arcsec) corresponds to a deviation of 1 μGal (1 μGal=1×10-8m/s2) in the gravity measurement. The general method for the alignment of the beam verticality is to adjust the input angle of the laser beam with a standard reference of liquid surface, which needs complex operations and multiple cycles. Here, we propose a novel method which can be used to achieve a fast auto-alignment. The method is based on the beam deflection property of the wedge-shaped element. The beam deviation from the plumb line is nearly compensated by the deflection of the wedge-shaped liquid only if the refractive index-matching condition is satisfied. According to this property, an auto-alignment device is developed and tilt tests are implemented. The results indicate that a deviation angle of less than 9 arcsec can be achieved only by using two orthogonal spirit levels the precision of which is better than 4 arc minute (arcmin). This solution is simple and fast in comparison to the complicated alignment procedure.

Paper No. 273: Designof pipeline leak data acquisition and processing system on LabVIEW

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Keywords: Pipeline Leak Detection;Virtual Instrument;LabVIEW;Data Acquisition;SignalProcessing
Abstract: This article aims at the pipeline leakage data acquisition and the location problem. A pipeline leakage signal acquisition and processing system based on virtual instrument have been designed. In this system, the STM32F103RBT6 is used as the lower computer and processing chip. Leakage signal, which have been modulated by circuit, is collected by On-chip ADC module. And then, the signal data was transferred to host computer by ZigBee wireless transmission module. In the host computer, a set of signal acquisition and processing system is designed based on the LabVIEW development platform. The software system can be used in conjunction with MATLAB software. Based on modularization design concept, the software integrates the functions of data acquisition, time frequency analysis, correlation analysis and so on. And all functions, such as sub VI, data acquisition and processing, can be simply achieved by the clicking corresponding buttons.

Paper No. 67: A method based on transfer learning for automatic metallographic rating

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Keywords: Metallographic rating; transfer learning; image classification; SFTA; Naive Bayes classifier
Abstract: Metal strength, toughness, plasticity and other mechanical properties are closely related to its grain size. Metallographic rating must to detect the grain size to determine the level of metallographic images. The traditional rating method must extract the grain boundary to quantitatively calculate the grain size. But in metallographic images, grains are often blurred and broken, it is hard to detect the grain completely. So, here we propose a metallographic

rating method based on machine learning and similar to image classification. This method does not require the extraction of grain, and then calculate the grain area and other operations. Here, we directly extract texture feature from the original metallographic image. Use these feature vector extracted from labeled images to train a classifier, and then use this classifier to judge and detect the new images. But there is a difficult place here, the number of manually labeled pictures is too small. The training classifier may be overfitting. So here we rely on the idea of transfer learning, with the help of other databases to enrich the training set. After the experimental analysis, this method can overcome the difficulty of the number of target sets, improve the accuracy of classification.

Paper No. 154: A uniform and flexible model for three-dimensionalmeasurement of line-structured light sensor

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Keywords: Line-structured light sensor, Three-dimensional measurement, Mathematical model, Structural parameters, Constraint condition.

Abstract: Line-structured light sensor is a three-dimensional measurement method which combines the advantage of high precision and speed, applicable in many fields. The mathematical model of line-structured light sensor is an essential foundation which determines measurement precision. Through the comparison of the three representative models which are deduced from different starting points and analysis of the model constraint conditions, we build a uniform and flexible model which shows the common characteristics and connections of the previous models and combines the flexibility and clear geometric meanings of the structural parameters with a correctable constraint condition. It is suitable to most conditions and structural parameters design of line-structured light sensor.

Paper No. 164: Global data registration technology based on dynamic coded points

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Keywords: machine vision; time parameter; the dynamic coded point; 3D date registration; coordinate transformation.

Abstract: For the problems that the global control points are difficult to realize automatic matching and inefficient in the process of 3D vision measurement, and considering introducing the parameter of time as a feature into the global control point, a global data registration method based on the dynamic coded points is proposed. The system used in this method contains a local and a global control binocular measurement systems. The local binocular measurement system measures the data of each subdomain as the local measurement data. The dynamic coded points, which are encoded based on time parameter as their encoded values, are projected to the measured object's surface using a projector. Two sets of binocular measurement systems acquire the dynamic coded points to calculate their encoded values and match them automatically, then the transformation relations between the local coordinate system and the global control coordinate system can be calculated, so the local measurement data coordinates are integrated into the global control coordinate system through the transformation relations, achieving the global data registration. Experimental results show that the dynamic coded points can automatically match accurately, registration accuracy reaches 0.26mm, which can satisfy the measurement requirements of large-scale aviation components.

Poster Session2: Management of Measurement Processes & Material Characterization & Micro and Nano Metrology

Poster ID	Paper ID	Paper Title
P2-12	89	Evaluation of uncertainty in product inspection andcalculation of misjudgment probability
P2-13	52	Optical Transparent and Millimeter-wave Resonance Mesh Coating with Annular Aperture Array
P2-14	142	Focus variation microscopy based on efficiency-optimized Gray Level Variance
P2-15	171	Two-dimensional displacement measurement based on two parallel gratings
P2-16	232	A novel calibration method for NIR MOEMS spectrometer with one single detector
P2-17	247	The Design of Two Dimensional High Precision Displacement Stage for Nanometer Line-width Measurement

Paper No. 89: Evaluation of uncertainty in product inspection andcalculation of misjudgment probability

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Key words: Product inspection; Measurement uncertainty; Conformance testing; Misjudgment probability

Abstract: The product inspection process with measurement uncertainty as a quality indicator is researched. Based on the product quality control information and the design and processing precision, the relationship between the misjudgment probability and measurement uncertainty of conformance testing is established. In view of the limitation of uncertainty evaluation based on the single piece in product inspection, the method for evaluating uncertainty fusing multiple product measurement information in a fully integrated batch is proposed. The uncertainty components caused by the measurement repeatability and reproducibility of the whole test work are evaluated based on the conjugate Bayesian estimation method. The test results show that there is a certain false positive rate in the whole test of the product under the condition of uncertainty. Research results show that the misjudgment probability caused by the measurement uncertainty cannot be ignored. In the product test, batch detection information should be fully integrated to improve the representation of uncertainty evaluation results.

Paper No. 52: Optical transparent and millimeter-wave resonance mesh coating with annular aperture array

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Keywords:mesh coating, resonance, optical diffraction, Fourier optics

Abstract: This paper proposes a high optical transparent and millimeter-wave resonance mesh coating for dual-mode communication instruments. The optical/millimeter-wave dual-mode resonance mesh coating is designed with a high porosity metallic mesh substrate combining with annular aperture array. Metallic mesh coating consists sub-millimeter scale period and micrometer scale linewidth and has the advantage of high conductivity and high optical transparency while the annular aperture array consists periodic millimeter scale circular loop apertures and has the advantage of millimeter-wave resonance bandpass filtering. In order to analyze the high optical transmission characteristics of the designed optical/millimeter-wave resonance mesh coating, firstly, the optical window function is developed, then the point spread function is obtained by optical Fourier transferring the above optical window function. Then the optical diffractive characteristics are analyzed in detail through simulation of the point spread function. So it can be concluded that the designed resonance mesh coating can be optimized to achieve good optical transparency.

Paper No. 142: Focus variation microscopy based on efficiency-optimized gray level variance

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Keywords: Focus variation, focus measure, micro- and nanotechnology, surface topography, optical microscopy, automatic measurement

Abstract: Focus variation microscopy (FVM) is a very powerful tool for the measurement of surface topography. Owing to strong robustness in relation to different materials and being able to measure steep flanks, FVM has attracted attention in both academy and industrial. The focus measure (FM) is crucial for the entire FVM process and fundamentally determines the accuracy of final measurement result. In previous studies, the Gray Level Variance (GLV), one of the classic FM operator, is renowned for the noising robustness, but the computation complexity cannot be ignored. Aiming at reducing the time of full measurement cycle for FVM, we proposed an approach to optimize the computational efficiency of GLV operator. Experiments on real and synthetic images show that the efficiency-optimized GLV operator we proposed can greatly reduce calculation time with little or no accuracy loss.

Paper No. 171: Two-dimensional displacement measurement based on two parallel gratings

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Keywords: Two-dimensional, displacement measurement, planar encoder, interference stripes, diffraction grating.

Abstract: A two-dimensional (2-D) planar encoder based on two parallel gratings, which includes a scanning grating and a scale grating, has been presented. The scanning grating is a combined transmission rectangular grating including a 2-D grating located in the center and two one-dimensional (1-D) gratings located at the sides, and the grating lines of the two 1-D gratings are perpendicular to each other and parallel with the 2-D grating lines respectively. The scale grating is a 2-D reflective-type rectangular grating placed parallel with the scanning grating, and there is an angle difference of 45° between the grating lines of the two 2-D gratings. With the special structural design of the scanning

grating, the encoder can measure the 2-D displacement in the grating plane simultaneously, and the measured interference signals in the two directions are uncoupled. Moreover, utilizing the scanning grating to modulate the phase of interference signals instead of the prisms, the encoder has a compact structure. Experiments have been implemented for demonstrating the validity of the 2-D planar grating encoder.

Paper No. 232: A novel calibration method for NIR MOEMS spectrometer with one single detector

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Keywords: Calibration method, Single-detector, Micro spectrometer, MOEMSignal processing.
Abstract: The NIR (near-infrared) MOEMS spectrometer based on one single detector has prominent advantages, such as smaller size, lighter weight, lower cost, higher integration level, and more stable performance, over conventional spectrographs with detector arrays. A NIR MOEMS spectrometer based on one single detector has been designed in this paper. Furthermore, in order to improve the accuracy of the instrument calibration for our design, a novel dual-source calibration method is developed. In this method, a high pressure mercury lamp is utilized as the standard light source and a halogen lamp as the secondary light source. This new calibration method is based on high-order fitting algorithm by using characteristic lines of standard light source and feature points which found by combining the spectrum of halogen lamp with narrowband filters. It improves the accuracy and stability of calibration and is well suited for spectroscopy with wide spectral ranges.

Paper No. 247: The design of two dimensional high precision displacement stage for nanometer line-width measurement

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Keywords: Precision displacement stage; Flexure hinge; Stiffness; Stress; coupling displacement; Angular adjustment; Finite element analysis
Abstract: With the development of semiconductor industry, critical dimensional size such as line width in wafer has increasing influence in the performance of electrical components. In order to meet the demands of line width measurements, the metrological ultraviolent microscope was designed to measure nanometer geometric size. In the paper, a two dimensional precision displacement stage with large size, adjustable long stroke for ultraviolent microscope was designed to achieve 100μm range with 5nm resolution. In the design, three piezoelectric ceramics actuators were adopted as driving device and controlled separately to finely adjust the azimuth angle of the stage in real time and ensure the flexibility of the measurement. In order to evaluate the performance of the stage, the theoretical formulas of stage stiffness, angular adjustment, coupling coefficient as well as hinge stress are deduced by modeling the stage. The finite element analysis method is also used to verify the theoretical formula, which shows a good consistency and gives a preference for flexible hinge parameter design. For cross validation purpose, the structure of precision displacement stage was built to measure the line width. The result verifies the reliability of stage design.

Poster Session 2: Optical Metrology

Poster ID	Paper ID	Paper Title
P2-18	151	Non-focused Common-path Laser Rotar y Encoder
P2-19	158	Optical frequency comb distance measurement and laser tracking system
P2-20	166	A synthetic dual-frequency self-mixing interferometer
P2-21	177	A Stable Heterodyne Interferometer with Tens Picometers Periodic Error
P2-22	186	Dual-comb metrology with a free-running fiber laser
P2-23	203	Research on Effect of Rough Surface on FMCW Laser Radar rang Accuracy

Paper No. 151: Non-focused common-path laser rotary encoder

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Keywords: Common-path, Rotary, Laser Encoder, Long-term, Environmental disturbances, Resolution, Accuracy.

Abstract: Rotary encoders are very important sensors in industry. All of high resolution rotary encoders are interference type. This paper proposes a simple and innovative laser rotary encoder called NFCPRE. NFCPRE can overcome the tight tolerance problem of the grating scale in our previous works on laser linear encoders. As NFCPRE adopts a common-path configuration, it can physically slash the effect from environmental disturbances including temperature, pressure, and humidity variations as well as mechanical vibrations. The experimental results were compared with a commercial Renishaw Tonic encoder. For a small range angular displacement of 0.0005 degree, the average discrepancy between the NFCPLRE and the Renishaw Tonic encoder was 0.0001 deg. For a large range angular displacement of 360 degree, the average discrepancy between the NFCPLRE and the Renishaw Tonic encoder was 0.00149 degree. The system drift of NFCPLRE was measured for a period of three hour and was found to be 0.00067 ± 0.0002 deg. The estimated resolution was 0.00014 ± 0.00007 deg.

Paper No. 158: Optical frequency comb distance measurement and laser tracking system

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Keywords: femtosecond optical frequency comb, distance measurement, laser tracking system, mode-locked fiber laser, dual-comb ranging method

Abstract: Optical frequency comb consisting of a set of spacing fixed, stable frequency lines with narrow linewidth can be used to precise metrology. In this paper, two distance measurementmethods based on optical frequency comb are demonstrated with spectrally-resolved interferometry anddual-comb technique. Moreover, to eliminate the noise of air refractive index and optical comb source with dual-comb, all-path air refractive index compensation and phase distortion correction methods are proposed respectively so that ranging accuracy can be effectively improved. Based on the high-speed dual-comb distance measurement, a portable femtosecond laser tracker is designed and built to be a compact instrument for high-precision 3D geometric measurement and trace monitoring with high speed, high precisionand large range. Thesystem has wide potential applications in scientific research and large-scale

manufacturing industries.

Paper No. 166: A synthetic dual-frequency self-mixing interferometer

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Keywords: Dual-frequency laser; Self-mixing interference; Synthetic-wavelength; Zero-crossing phase detecting; Displacement measurement

Abstract: A synthetic dual-frequency self-mixing interferometer for micro/nanometer displacement measurement is proposed in this work. When the frequency difference of the birefringent dual frequency He-Ne laser is limited in a reasonable range, mode competition can be neglected, and synthetic wavelength configuration can be applied in the laser self-mixing interferometer. An experimental configuration is designed and a novel signal processing system is proposed to generate a real synthetic signal with an ultra-low frequency. A tiny micro/nanometer displacement of the object can be measured through the phase change of the synthetic signal. The disadvantage from both laser self-mixing interference and synthetic wavelength for measuring tiny displacement can be deeply reduced, which can provide a potential approach to realize contactless measurement in engineering application.

Paper No. 177: A stable heterodyne interferometer with tens picometers periodic error

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Keywords: Nano metrology, Optical metrology, Instrumentation, Periodic error, Nonlinearity, Interferometry

Abstract: In this paper, a novel symmetrical optical configuration of heterodyne interferometer with separated-beams is designed and achieved. To minimize the periodic nonlinearity error, the optical configuration adopts spatially separated beams to prevented frequency mixing that is the primary source of that error. Moreover, the thermal error, which affect more significantly than the periodic error, has been effectively suppressed by a balanced optical path between reference beam and probe beam. In addition, the use of the retro-reflectors is benefit to simplify the alignment and suppress the ghost reflection. Experimental results show in the interferometer the residual periodic caused by ghost reflection is 42pm and the thermal error is 1.6 nm with temperature changes of 1.2℃.

Paper No. 186: Dual-comb metrology with a free-running fiber laser

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Keywords: Asynchronous cross-sampling;Optical Metrology; Spectroscopy; Optical frequency comb; Ultrafast lasers

Abstract: Dual-comb technique is a highly attractive tool for fast, high-resolution measurement such as absolute distance measurement, frequency measurement and spectroscopy. A conventional dual-comb source is realized with two mode-locked ultrafast lasers with their lasing mode spacing and carrier-envelop offset frequencies both stabilized. This kind of dual-comb system with complicated control electronics has limitations of large volume and weight, low environmental stability, hindering its wide use. In this paper, significantly simplified dual-comb metrology schemes are demonstrated by replacing two lasers with an all-optical dual-comb lasing scheme. Asynchronous ultrashort pulses are oscillated in a single free-running fiber laser with different center wavelengths or polarization states by using

multiplexing mechanisms in mode-locking. The difference of repetition rates of the two pulse trains is induced by cavity dispersion or birefringence and shown to have good stability as they share the same light path. Such lasers could be an alternative to the traditional dual-laser, dual-comb source in metrologies. It had been demonstrated with good stability and inherent coherence for dual-comb application including pump-probe, coherent ranging and optical spectroscopy. Our proposed single-fiber-laser-based dual-comb scheme could result in significant simplification in the implementation complexity and provide an alternative approach to change the paradigm of low-complexity dual-comb-based instrumentations.

Paper No. 203: Research on effect of rough surface on fmcw laser radar rang accuracy

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Keywords: rough surface; FMCW; laser radar

Abstract: The non-cooperative targets large scale measurement system based on frequency-modulated continuous-wave laser detection and ranging technology has broad application prospects. It is easy to automate measurement without cooperative targets. However, the complexity and diversity of the surface characteristics of the measured surface directly affects the measurement accuracy. First, the theoretically analysis of range precision for FMCW laser radar was studied, the relationship between surface reflectivity and accuracy was obtained. Then, to verify the effect of surface reflectance for ranging accuracy, standard tool ball and three standard roughness samples were measured within 7m to 24m. The uncertainty of each target was obtained. The results show that the measurement accuracy is found to increase as the surface reflectivity gets larger. Good agreements are obtained between theoretical analysis and measurements from rough surfaces. Otherwise, when the laser spot diameter is smaller than the surface correlation length, multi-point averaged measurement can reduce the measurement uncertainty. The experimental results show that this method is feasible.

Poster Session 2: Sensors and Actuators

Poster ID	Paper ID	Paper Title
P2-24	261	Fabrication of Capacitive Micromachined Ultrasonic TransducersBased on Low Temperature Wafer-BondingTechnology
P2-25	262	A Simulation Analysis of a Novel Ultra-high g Piezoresistive Shock Accelerometer
P2-26	264	Finite Element Analysis of Resonant Fluid Density Sensor Based on CMUT
P2-27	271	SU-8 MEMS Force Sensor Using Laterally Movable Gate Array field Effect Transistor

Paper No. 261: Fabrication of capacitive micromachined ultrasonic transducers based on low temperature wafer-bonding technology

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Keywords:CMUTs;Lowtemperaturewafer-bonding technology; parasitic capacitance; deflection; impedance-frequency curve

Abstract: This paper presents the first demonstration of Capacitive Micromachined Ultrasonic Transducers (CMUTs) fabrication via direct wafer-bounding under a temperature of less than 400℃, in which the device layer of an 8 inch silicon-on-insulator (SOI) wafer was directly bonded on a SiO_2 layer grown on a silicon substrate to vacuum seal the cavities. Based on this approach, a 15×15 CMUTs array has been successfully fabricated with a single membrane diameter of 120μm and membrane thickness of 2μm as well as the cavity height of 0.45μm. The resonant frequencies of CMUTs under different bias voltages were obtained. For this new fabrication technology, three distinctive advantages have been achieved: (1) the temperature is reduced from 1050 ℃ of previous wafer-bonding technologies down to 400 ℃, which enables the direct integration of CMUTs with integrated circuits (ICs); (2) the reduced fabrication temperature decreases the thermal stresses caused by thermal expansion coefficient mismatch among different layers of CMUTs to improve the device performance.

Paper No. 262: A simulation analysis of a novel ultra-high g piezoresistive shock accelerometer

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Keywords: Self-supporting micro beam, Piezoresistive accelerometer, Ultra-high g value, MEMS

Abstract: For the improvement of sensitivity, a novel structure of MEMS (Micro Electro Mechanical Systems) high-g shock accelerometer with self-supporting piezoresistive micro beams is proposed for 100,000×g measuring range.The finite element method (FEM) simulations are carried out toverify the structure for high-shock measurement. The simulationresults indicate that the nearly pure-axial deformations occur on self-supporting piezoresistive micro beams, and the stress is 81.5 MPa, the resonant frequency is about 505 kHz.Therefore, the feasibility of proposed structure is capable of measuring ultra-high g loading shock with high resonant frequency and high sensitivity.

Paper No. 264: Finite element analysis of resonant fluid density sensor based on CMUT

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Keywords: CMUT, resonant density sensor, fluid-structure interaction, frequency shift, finite element method.

Abstract: Sensing fluid properties like mass density and viscosity is important in the fields of petrochemical, energy power and medicine industries. Owing to the advantages of high accuracy,high sensitivity and fast response, resonant sensors have become the research hotspot on the measurement of fluid density. In this paper, anovel resonant density sensor based on CMUT(capacitive micromachined ultrasonic transducer) was proposed. The CMUT is promising as a density sensor due to its high resonant frequency, small volume and wide temperature range. When the CMUT works in the fluid,fluid-structure interaction(FSI) will occur between the vibrating membrane of CMUT and fluid to cause the resonant frequency shift. The finite element method (FEM) was employed to do further study on the performance of the CMUT-based density sensor. The numerical results showed that the resonant frequency linearly decreased when the density increased from 550 kg/m3to 1050 kg/m3. The density sensing sensitivity of CMUT under first order vibration mode can reach 1250.06 Hz/kg/m3,and the non-linearity between the resonant frequency and the fluid density was better than 1%. Moreover, the higher order vibration modes of the CMUT and the bias voltage can be used to improve sensing sensitivity.

Paper No. 271: SU-8 MEMS force sensor using laterally movable gate array field effect transistor

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Keywords: MEMS Force sensor, SU-8 , Movable gate, FET, high sensitivity.

Abstract: In this research, we carry out the design and analysis of a novel SU-8 Micro Electromechanical Systems (MEMS) forcesensor based on Laterally Movable Gate Array Field Effect Transistor (LMGAFET). Photoresist SU-8, owing to its unique physical and chemical characteristics, is a chosen material to fabricate laterally movable structure of the device. Gate electrodes are designed as an array form and adhere to the lower surface of SU-8 structure. A novel structure of LMGAFET based MEMS force sensor with reasonable parameters is verified with a modified MOS3 model by finite element method (FEM) softwares such as ANSYS and MAXWELL. The analysis results show that the proposed sensor has an ultra high sensitivity of 0.091m A/n N, low cross-axis sensitivity and low non-linearity less than 0.3%FS

Poster Session 2: Surface Metrology

Poster ID	Paper ID	Paper Title
P2-28	315	Key operations of areal surface topography measurement
P2-29	333	Four-probe Error Separation Method for On-line Measuring Cylindricity
P2-30	353	A generalized approach of form error evaluation for sculptured surfacewithin the framework of the new generation GPS standards system

Paper No. 315: Key operations of areal surface topography measurement

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Keywords: Surface topography measurement, Filtering, Form removal, Areal parameters
Abstract: Areal surface morphology has played an important role in the control of surface quality. With the rapid development of modern manufacturing, effective measurement and characterization of surface topography has been of great importance, especially in precision manufacturing and measurement field. However, many factors controlled by users about the set-up and operations will have significant effects on the measurement results. Otherwise, improper operations will introduce inevitable measurement errors, which reflect directly on the obtained areal parameters. Here, an in-depth study about the influence of fringe set up (levelling), form removal, filtering, data filling, and the light intensity was carried out. Surface topography measurement and areal parameters analysis were conducted using a Talysurf Coherence Correlation Interferometer (CCI) provided by Taylor Hobson and its processing software compliant to ISO 25178. The influence of the mentioned key operations on the obtained areal parameters were analysed in case studies and the interpretation of the variation was made. The results suggested that areal parameters show different sensitivities and vary significantly with different options. This general principle proposed for the key operations of areal surface topography measurement can guide users in effective measurement and unify the measurement process, thus ensuring the reliability and repeatability of the data.

Paper No. 333: Four-probe error separation method for on-line measuring cylindricity

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Keywords: On-linemeasurement;Reconstruction; Form error; Error separation technology;Multi-probe method.
Abstract: Four-probeerror separation method implementssynchronously two kinds of errorseparation calculations so as to realize the on-line measuring the large cylindrical profile.The three-probe roundness error separation is employed to extract the out-of-roundness and radial deviation of the cross-section profile, but not determine exactly the geometric center vector due to the harmonic suppression. The another probe at the next cross-section profile senses the radial mixed errors. We derived a formula to calculate the differential vector of the geometric center at adjacent two cross-sections by the outputs of four probes during one-circle measuring. The geometric center vector of each cross section profile is determined by the accumulation operation alike the two-probe straightness error separation method. And then, the cylindrical profile is reconstructed based on a curving median line fitted bythe geometric center vector of cross-section profile, supplemented bythe out-of-roundness and radial deviation extracted by the

three-probe error separation method. On this basis, the cylindricity can be evaluated easily. Theoretical analysis and numerical validation have proved that the method is immune to both the spindle radial run-outs and the linear slide error motions. Just so, the method makes it possible to lower requirements for the spindle motion precision and the linear slide motion precision, and save the manufacturing cost of on-line measurement equipment.

Paper No. 353: A generalized approach of form error evaluation for sculptured surface within the framework of the new generation GPS standards system

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Keywords: New generation GPS standards system;CMM; Form error; Evaluation; Least square method; MATLAB

Abstract: The form error is an important index used to evaluate the form precision of parts; the accuracy of its evaluation method has a significant influence on the quality and use performance of a mechanical product. With the development of modern measuring techniques, especially thecoordinate measuring machines (CMM) and other precision measuring instruments have already been applied to practical production extensively, it has important practical meaning to study sculptured surface form error evaluation method based on the coordinate measuring data. In view of this current situation, based on the related principle of the form error evaluation within the framework of the new generation GPS standards system, a generalized mathematical model of form errors evaluation based on the least square method is proposed in this paper, and then the way of solving the evaluation model byusing multiple nonlinear optimization function in MATLAB optimization toolbox is also studied. Finally, a numerical example based on the actual measurement data obtained by CMM is given to verify the evaluation model.

Poster Session 3: Calibration and Machine Tool Performance& In-Process and Online Metrology & Intelligent Instruments forAutomation

Poster ID	Paper ID	Paper Title
P3-01	326	Geometric error measurement of a 4-axis machinetoolusing a touch trigger probe
P3-02	358	Integrated Optomechanical Design and Analysis of a Korsch-typeThree Mirror Anastigmat Telescope
P3-03	337	Tolerance Analysis of Slider-crank Mechanism for Assembly Functionality Check
P3-04	280	The Development of the Relay Valve Comprehensive Performance Testing system
P3-05	376	Filter Algorithm for Multi-Spectrum Dynamic Temperature Measurements on Turbine Blades

Paper No. 326: Geometric error measurement of a 4-axis machine tool using a touch trigger probe

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Keywords: Geometric error, Machine tool, Touch trigger probe

Abstract: The geometric errors of a 4-axis machine tool are modeled and identified using a touch trigger probe and sphere artifacts. There are 7 position-independent geometric errors in a 4-axis machine tool which is composed of three linear axes and a rotary axis. Three squareness errors are defined among the linear axes, and two squareness errors and two offset errors can be also defined between a linear axis and rotary axis. These errors are constant regardless of the position of each axis component since those errors are usually fixed by the assembly process. To identify the error terms, the positions of the sphere center at each rotary position and the probe tip in reference coordinate system are calculated using the homogeneous transform matrix(HTM), respectively. The error vector is generated using the 7 geometric errors between the probe and the center point of sphere artifact. The 7 geometric errors can be calculated from the error vectors measured at the several different positions of the sphere artifact.

Paper No. 358: Integrated optomechanical design and analysis of a korsch-type three mirror anastigmat telescope

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Keywords: Optomechanical design, Three mirror anastigmat, Korsch TMA

Abstract: This article reports an integrated optomechanical design and analysis technique to predict the performance of a Korsch-type three mirror anastigmat (TMA) telescope. A straightforward approach is proposed for the optomechanical analysis by using finite element method (FEM) combined with Zernike polynomials. A large aperture optomechanical structure of Korsch-type TMA optical system was configured and demonstrated. The results show that the approach is successfully to optimum design of a Korsch-type TMA telescope.

Paper No. 337: Tolerance analysis of slider-crank mechanism for assembly functionality check

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Keywords: Tolerance analysis, Assembly tolerance, Tolerance stack-up model, Assembly clearance, Slider-crank Mechanism

Abstract: Tolerance analysis is an effective way to improve the quality and decrease the cost of product. It is necessary to establish the analysis model for it is the key of tolerance analysis. After introducing the existing methods of tolerance analysis by ADCATS, the nominal geometric transfer model and the stack-up model were established based on the Small Displacement Torsor and Homogeneous Transformation Matrix (HTM), and then, HTM expression of the tolerance loop was constructed. Took slider-crank mechanism as an example, the contrastive study of tolerance analysis for functionality check was done after establishing stack-up model of assembly tolerance analysis. The results show that it is prone to lead to misjudgment when analyzing only dimension tolerance, the analysis results of considering dimension tolerance, geometric tolerance and assembly clearance are more restrictively, however, it is more compliance with actual engineering.

Paper No. 280: The design of the relay valve comprehensive performance testing system

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Keywords: Detection system; Relay valve; Static characteristics; Dynamic characteristics; Simulation

Abstract: In view of the domestic relay valve as one of the core parts of air brake system, using high speed data acquisition system, the application of computer control technology, relay valve comprehensive performance testing system is designed, the system can realize automatic clamping, fast automatic detection. The static characteristics, dynamic characteristics and air tightness of the relay valve are tested. In order to verify the validity of the test system results, the simulation model of the relay valve was established using AMESim software. Simulation results compared with the experimental results show that the performance parameters of the curve is consistent, accurate and reliable detection system design, the system can well comprehensive performance evaluation of relay valve.

Paper No. 376: Filter algorithm for multi-spectrum dynamic temperature measurements on turbine blades

Xuecong Zhang, Yongjun Yang, Jing Cai, Lei Dong
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Key words: Multi-spectrum; Turbine blade; Dynamic; Digital filtering

Abstract: This thesis focuses on the research of noise interference of multi-spectrum thermometry in a turbine blade temperature field. Imitate the high-speed rotating turbine blade with a dynamic simulation experimental device to generate the raw signal. Analyze the characteristic of raw signal and design a FIR digital filter in a linear phase to filtering signals based on the raw signal and the frequency distribution of noise. The results indicate that the standard deviation of temperature fluctuation is able to reduce from 13.5℃ to 3℃ which will be of great significance to ensure an accurate measuring result.

Poster Session 3: Machine Vision and Image Processing& Management of Measurement Processes & Material Characterization

Poster ID	Paper ID	Paper Title
P3-06	364	The Extraction of Red Maple Tree in Complex Background
P3-07	375	Image Distortion and Non-Uniformity Correction
P3-08	96	Optimization Design of a 12m High Supporting Structure for a Vibration Isolation Platform
P3-09	117	Trajectory Planning Strategy of 3 - PUU Parallel Coordinate Measuring Machine
P3-10	119	Alumina and zirconia ceramics properties in high temperature

Paper No. 364: The extraction of red maple tree in complex background

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Keywords: Red maple;HSV space; Otsu binarization; Morphology
Abstract: In order to analyze the characteristics of the red maple in the image, it is necessary to extract the red maple from the figure. This paper presents a method of extracting red maple tree in complex background. The extraction of red maple tree is divided into four parts. The first step is to convert RGB-formatted image into HSV format, and the red area image is obtained in HSV space. The leaf image will be gained after the red region image be binarized and morphologically processed. Simultaneously, the four boundary datum of the red maple tree and the four boundary datum of the original leaf part in the original image are acquired. Next, the otsu binarization and morphological processing were performed on the original branch part of the image to get the maximum connected domain. And the branch image was got through the maximum connected domain. Then, according to the obtained two sets of boundary data, the trunk part of the original image is intercepted so that otsu binarization and morphological processing are carried out on the truncated trunk part to catch the trunk image. At last, the leaf, branch and trunk images are spliced into the same pair of image, so as to acquire red maple images.

Paper No. 375: Image distortion and non-uniformity correction for transient imaging multi-spectrum thermometry

Jing Cai, Xuecong Zhang, Yongjun Yang,Su Meng
(Changcheng Institute of Metrology & Measurement, Beijing 100095, China)

Key words: Transient Imaging; Multi-spectrum; Temperature Field; Image Distortion; CCD
Abstract: This thesis focuses on the research of multi-spectrum thermometry image distortion and non-uniformity correction based on the characteristic of single CCD transient imaging multi-spectrum thermometry. A distortion correction based on Zhang calibration is used to rectify the lens distortion. A non-uniformity correction combined two-point calibration with neural network is carried out to rectify the non-uniform images. Compare the images before and after correction, the distortion calibration method used in this thesis can decrease the error between the field image and the target location. The comparison of the images before and after non-uniformity correction illustrates that the non-uniformity correction used in this thesis can reduce the temperature measurement error caused by CCD pixel conformance differences observably.

Paper No. 96: Optimization design of a 12m high supporting structure for a vibration isolation platform

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Keywords: supporting structure, vibration isolation, stiffness-mass ratio, natural frequency, finite element analysis
Abstract: In order to design a high performance 12 m tall supporting structure for a 10m×7.5m vibration isolation platform, a main target is to achieve a natural frequency of above 10 Hz and make the stiffness-mass ratio as high as possible. Optimization design based on tower structure and finite element analysis (FEA) is carried out. On the basis of a preliminarily designed structure consisting of four vertical poles and eight horizontal reinforcement tubes, X-shaped cross bar structures and tilting supporting tubes are introduced as further reinforcement, besides dimensional and position parameters of the reinforcement structures are optimized based on FEA results. FEA simulation results show that the first order natural frequency of the supporting structure is optimized from 4.88 Hz up to 10.02 Hz, and the incremental weight of the reinforcement structure is as low as 6.4 t.

Paper No. 117: Trajectory planning strategy of 3 - puu parallel coordinate measuring machine

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Keywords: Parallel mechanism Trajectory planning Linear interpolation ADMAS simulationCMM
Abstract: Trajectory planning is an important module in parallel coordinate measuring machinecontrol and is also the basis for completing operations, which will determine the dynamicperformance and working efficiency of the parallel coordinates measuring machine. The trajectoryplanning strategy of the 3-PUU parallel coordinates measuring machine as Fig.1 is studied.Combined with the actual measurement needs, the path of the probe movement is set to establish acontinuous measurement trajectory. Firstly, the kinematics positive solution model of the measuringmachine is established by using the matrix method, and then the inverse solution model is obtainedaccording to the derived positive solution model. Based on the solution model, the appropriateinterpolation distance is selected according to the precision requirement in the three directions of X,Y and Z axis by using the method of linear interpolation in the operation space of the probe. Andthen establish the mapping relationship between the movement space of the operation space and themoving space of the slider. In the control process, whenever the interpolation of a track point of thecoordinates of the value, through the kinematic inverse solution equation, the slider into thecoordinates of the track, and then through the two adjacent interpolation points, Find the sliderdisplacement, thus completing the probe track movement. Finally, using MATLAB to optimize theresults, the simulation platform is built in ADMAS environment, and the results of the trajectoryplanning are simulated and analyzed by physical prototype experiment as Fig.2 shown. Theresults show that the trajectory planning method based on the linear interpolation motion law in theprobe space has high feasibility, which provides a theoretical basis and technical basis for the laterresearch of the parallel coordinates measuring machine control system. It is instructive for theprecision calibration and positioning control of the subsequent 3-PUU coordinate measuringmachine.

Paper No. 119: Alumina and zirconia ceramics properties in high temperature

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Keywords: high temperature pressure sensor, flexural strength, flexural modulus of elasticity, thermal conductivity, high temperature-resistant ceramic

Abstract: In order to find the most appropriate substrate materials to develop high temperature pressure sensors that can work above the 1000 ℃, alumina ceramics and zirconia ceramics were chosen as the object of research to test their properties in high temperature. Three points bending test method was chosen to test the flexural strength and flexural modulus of elasticity of these high temperature-resistant ceramics, and Transient laser emission method were chosen to test the thermal conductivity. 99Al2O3, 97Al2O3, and ZrO2 samples were prepared by hot-pressing sintering, with size of 3.5*5*50mm3 for the bending test and size of φ12.5*1.5mm3 for the thermal conductivity test. Curves of flexural strength, modulus of elasticity, and thermal conductivity changed with temperature were obtained after the measurement. The test result showed that the thermal conductivity of alumina remained stable above 1000 ℃ and its flexural modulus is much greater than ZrO2. Finally, it can be concluded that 99Al2O3 is most appropriate material to be used for the preparation of the high temperature pressure sensor operating up to 1000 ℃.

Poster Session 3: Micro and Nano Metrology

Poster ID	Paper ID	Paper Title
P3-11	256	Effect of the different substrates and the film thickness on the surfaceroughness of step structure
P3-12	335	Arc discharging parameters for fabricating the micro ball tips
P3-13	351	Theoretical analysis of capacitive sensor based micro-angle measurement unit and micro-angle interferometer using spatial geometric modeling and Monte Carlo simulation for achieving nano-radian accuracy
P3-14	356	Error Analysis and Correction of Probe System of Coordinate Measuring Machine

Paper No. 256: Effect of the different substrates and the film thickness on the surfaceroughness of step structure

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Keywords: Surface roughness; Step structure; Wet etching; Bonding energy; Surface energy
Abstract: The step structure was obtained on the Al_2O_3 thin film. The Al_2O_3 film was technique. The surface roughness of all kinds of surface were measured by atomic force microscopy(AFM). Analysis of the surface roughness revealed that the roughness of the Al_2O_3 step were related to the film thickness and the type of substrate. It can be found that negative correlations between the surface roughness and the thickness of the film, it can be found that positive correlations between the lower surface and the thickness of the film, both of the Si substrate and the Si_3N_4 substrate have the same rules. No matter the surface roughness of films or the surface roughness of step structures, the Si substrate were superior to that on the Si_3N_4 substrate. Due to the bonding energy of Si-N bond is larger than that of Si-Si bond, the surface energy of Si_3N_4 is larger than that of Si. The surface roughness can be reduced after optimizing the process parameters.

Paper No. 335: Arc discharging parameters for fabricating the micro ball tips

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Keywords: Micro ball tip, Monolithic tungsten probe, Arc discharge, Discharge parameters, Micro/Nano CMMs
Abstract: Micro geometric dimensions with high aspect ratio, such as deep holes and grooves, cannot be measured by conventional optical and contact measuring instruments. Micro/nano coordinate measuring machine (CMM) with a high-precision ball-ended stylus tip can be used to overcome this technical problem. The performance of the CMM is determined by the diameter and roundness of the ball tip to a great degree. The method of fabricating micro monolithic

tungsten ball tip, which was based on the arc discharge principle and the surface tension phenomenon, has been proposed by our group several years ago. However, the success rate of fabricating a good ball tip is still low because the ball tip's quality is subject to many process parameters, such as impulse voltage, pulse frequency, electric discharge duration, and diameter of the raw tungsten. This paper presents the experimental method to explore the rules between the fabricating parameters and the ball tip's quality. A micro tungsten ball tip with 43 μm diameter and 1 μm roundness error was obtained using an 100 μm diameter tungsten wire and selected parameters. It can be used in micro/nano CMMs to achievedeep microhole and microgroove measurements of size less than 50μm.

Paper No. 351: Theoretical analysis of capacitive sensor based micro-angle measurement unit and micro-angle interferometer using spatial geometric modeling and Monte Carlo simulation for achieving nano-radian accuracy

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Keywords: Angle measurement; Nano-radian; Capacitive sensor; Angle interferometer; Spatial geometric modeling; Monte-Carlo simulation

Abstract: Theoretical analysis of capacitive sensor based micro-angle measurement unit (CMAM) and micro-angle interferometer (MAI) using spatial geometric modeling and Monte Carlo simulation is presented to guide the design and optimization of them for achieving nano-radian angle measurement accuracy. The generation mechanism and the magnitude of principle errors of CMAM and MAI are analyzed and compensated to the angle measurement results using the established models. Monte Carlo simulations are done after introducing machining and assembling errors and measurement errors of capacitive sensor and interferometer to the models for synthetic error assessments. Simulation results indicate that the standard deviations of measurement errors of the symmetric tangent-arm CMAM and the MAI are 0.120 arcsec and 0.025 arcsec in the range of ±900 arcsec and 0.039 arcsec and 0.008 arcsec in the range of ±300 arcsec respectively with resolution of 0.0015 arcsec (7.5 nrad). It can be seen that the absolute angle measurement accuracy of both CMAM and MAI are much lower than the resolution, which means calibrations are needed for higher angle measurement accuracy. The established models and analysis procedures can be used for further optimization and improvement of both CMAM and MAI.

Paper No. 356: Error analysis and correction of probe system of coordinate measuring machine

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Keywords: coordinate measuring machine; probe system; pre-travel error; diameter of probe

Abstract: As probe is the key component of coordinate measuring machine (CMM), its dynamic performance has direct influence on the final measurements. In order to enhance the accuracy of CMM composition of the probe dynamic error system was studied with focus on introducing the touch trigger probe. Probe pre-travel error sources and influencing factors were analyzed. The method combining dynamic calibration of probe radius and micro plane compensation was put forward to make compensation for the probe radius. After measuring the outline of a concave wheel and comparing probe radius before and after the compensation in reverse engineering software, the results showed that the method made better compensation for the probe radius and was worth more applications.

Poster Session 3: Optical Metrology

Poster ID	Paper ID	Paper Title
P3-15	234	Research on Air Supply Mode of Flotation Platformof LCD Glass Optical Detection Instrument
P3-16	248	Study on Engineering Module Design for Liquid Macromolecular Ingredient Content Detection
P3-17	272	A synthetic dual-frequency self-mixing interferometer
P3-18	284	Analysis and Research on the Noise of Points Cloud of the 3D Laser Scanning Measurement of Rail Tankers
P3-19	322	3D Feature Point for Point Cloud Registration

Paper No. 234: Research on air supply mode of flotation platform of lcd glass optical detection instrument

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Keywords: flatstatic pressurebearing, air supply mode, static characteristic,Fluent simulation, LCD glass

Abstract: LCD glass plate on-line testing process requirements of the membrane flow field pressure distribution and velocity distribution is gentle, high stability requirements. In order to compare the influence on the air film stability that caused by the different air supply mode, and study the static performance of flat static pressure gas bearing, using the gas lubrication theory, theoretical analysis of flotation platform model and the pressure calculation formula were obtained.Through-holes in the air floating plate are generally arranged in the array. We use Gambit to establish 3D model of flotation platform model and division of grid, and use Fluent software to do numerical simulations in two ways:positive pressure supply and positive and negative pressure at the same time supply. At last, gas bearing film pressure distribution and velocity distribution are obtained. Compared with airfoil support, the performance of positive and negative pressure at the same time supply is obvious. Under the condition that other geometrical parameters are invariable, in terms of economy, positive and negative pressure at the same time the gas flow of gas less.

Paper No. 248: Study on engineering module design for liquid macromolecular ingredient content detection

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Keywords:ingredient content detection; engineering; scattered through ratio

Abstract: The liquid milk with the main ingredients of protein and fat was used as the research background in this paper. And the rapid real-time detection method using the ratio of transmitted light and scattered light intensity was studied deeply. Based on this, the photoelectric detection module was designed. Multiple photoelectric detection module circuit boards had been tested, the average error of the scattered light direction photoelectric detection circuit was 0.0072, and the average error of the photoelectric detection circuit in the direction of transmission light was 0.0094. In addition, the relative errors of multi-block A/D conversion module were analyzed, and results were between 0.1% and 0.2%. The above test results show that the design meet the engineering application indicators basically. The

detection module designed in this paper had the convenience, fast and efficient real-time performance, the reproducibility and stability was satisfactory.

Paper No. 272: A synthetic dual-frequency self-mixing interferometer

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Keywords: Dual-frequency laser; Self-mixing interference; Synthetic-wavelength; Zero-crossing phase detecting; Displacement measurement

Abstract: A synthetic dual-frequency self-mixing interferometer for micro/nanometer displacement measurement is proposed in this work. When the frequency difference of the birefringent dual frequency He-Ne laser is limited in a reasonable range, mode competition can be neglected, and synthetic wavelength configuration can be applied in the laser self-mixing interferometer. An experimental configuration is designed and a novel signal processing system is proposed to generate a real synthetic signal with an ultra-low frequency. A tiny micro/nanometer displacement of the object can be measured through the phase change of the synthetic signal. The disadvantage from both laser self-mixing interference and synthetic wavelength for measuring tiny displacement can be deeply reduced, which can provide a potential approach to realize contactless measurement in engineering application.

Paper No. 284: Analysis and research on the noise of points cloud of the 3D laser scanning measurement of rail tankers

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Key words: 3D laser scanning; Point cloud; Noise; Rail tankers

Abstract: Through researching the applied technology of 3D laser scanning the rail tankers volume, carried out lots of scanning experiments, the noise problems which were found in the process of scanning were analyzed. The different factors and the noise sources that influence scanning point cloud effect were contrastively analyzed and summarized. The T-Fo denoising method was designed, which was based on the actual scanning point cloud of the railway tankers. This method can effectively deal with noise from outside to inside of railway tankers by the three-steps in a relatively short time. According to the result of the scanning, it can greatly improve the efficiency and accuracy of the 3D laser scanning measurement, effectively promote the development of technology on 3D laser scanning measurement of rail tanker volume

Paper No. 322: 3D feature point for point cloud registration

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Keywords: Point cloud match, point feature histogram, 3D feature points, double neighborhood

Abstract: 3D point cloud registration is an important but difficult step for optical 3D measurement. There are many methods for this problem characteristic with efficiency, stability, accuracy and convergence, and so on. It is still a big challenge for the matching problem with complex point cloud, random space position, high noise and weak surface

texture. In this paper, 3D feature points are used as corresponding point to register different view point clouds. These 3D feature points are described with the intrinsic shape signature algorithm and the point feature histogram. The proposed double neighborhood constraint optimization algorithm is used to minimize the sum of Euclidean distance of the point's and feature point's local neighbors. The proposed method is not only immune to noise, view-independent representation of the 3D shape, but also reduce the search range for matching points, and improve the correct feature point matching rate of weak surface texture. At last, the matching accuracy and stability of proposed method are verified with experiments.

Poster Session 3: Sensors and Actuators

Poster ID	Paper ID	Paper Title
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P3-24	363	Calibration Device for Hemodialysis Instrument

Paper No. 277: Design and simulation of MEMS piezoelectric vibration energy harvesters with center mass block

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Keywords: Energy harvesting, Piezoelectric, MEMS

Abstract: MEMS-based piezoelectric vibration energy harvesters (MEMS-PVEHs) with center mass block are designed with the overall size 10×10×2mm3, two prototype including piezoelectric unimorph & bimorph beams are used respectively. The MEMS-PVEHs have a lower resonant frequency (unimorph 109.20Hz/ bimorph 84.80Hz), and high mechanical and piezoelectric power density (unimorph 22.30mW/ (g2cm3) / bimorph 29.02mW/ (g2cm3)). This paper studies the characteristics of MEMS-PVEHs by modeling and simulation in COMSOL. The eigenfrequency is analyzed firstly, the optimal piezoelectric output is explored by changing excitation frequency and load impedance secondly, piezoelectric unimorph & bimorph beams are compared finally. The simulation results show that the optimal excitation frequency is slightly higher than the eigenfrequency, and the maximum piezoelectric power of the PVEH can be obtained only when the appropriate excitation frequency and load impedance are selected, and the power generation efficiency is 0.5. By comparing the unimorph & bimorph, it is suggested that the unimorph & bimorph MEMS-PVEHs should be designed to improve the piezoelectric output through aiming at decreasing resonant frequency and increasing input mechanical power.

Paper No. 299: Research on non-contact electromagnetic field measurement system for AC/DC transmission lines

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Keywords: Electromagnetic field measurement, transmission lines, two-dimensional electric field sensor, magnetic field sensor
Abstract: Electromagnetic field is an important parameter for state diagnosis and electromagnetic environment evaluation of transmission lines. In this paper, a non-contact electromagnetic field measurement system aimed at AC/DC transmission lines is designed. Firstly, for the purpose of electric field measurement with high accuracy, AC electric field measurement method with metal spherical sensor is deduced and a two-dimensional spherical AC electric field measurement sensor is developed. The sensor is rotated by a servo motor at the frequency of 2 Hz when measuring DC electric field. Then, the calibration of the sensor is finished. The results reveal that the relationship between the measurement results and the applied electric field is good linear from 1kV/m to 100kV/m. In addition, the HMR2300 magnetic field sensor, whose measurement range is ±2Gs and resolution is67 μGs, is used in this system to measure the magnetic field. By means of the DHT11 humiture sensor, this system can monitor the environment and calibrate data. Besides, the acquisition unit adopts STM32F103 microcontroller for A/D conversion and data processing. The sampling data is transmit to the host computer by wireless method. Finally, the monitor system in host computer is designed with LabVIEW, which has online filtering and FFT power spectrum analysis functions.

Paper No. 352: Submicron centroid position measurement method of screw connected structure under temperature load

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Keywords: submicronmeasurement method,screw connected structures,temperature load, screw pre-tightening force
Abstract: Screw connect structures are widely used in precision sensors such as electromechanical gyroscopes and optical sensors. For high-precision electromechanical gyroscopes under temperature load, the centroid of screw connected structure may change at the micron level ,which lead to severe drift of the gyroscopes. Hence, a centroid measurement method of screw connected structures in submicron precision is proposed in this paper. Specifically, a symmetrical fixture was designed to fix the screw connected structure, and two laser displacement sensors were placed at the both ends of screw connected structure for real-time measurements. The entire measuring device was put in a temperature controllable environment so as to apply the temperature load. The centroid position change of screw connected structure can be calculated on the basis of measurement data. Uncertainty of the measurement method was analyzed which was about 0.1μm. And a measurement experiment was carried out on a screw connected specimen with the length of 38.4 mm. Under the pre-tightening force of 400N and the temperature cycle of 40℃, the maximum centroid position change was about 7.5μm. Finally, mechanical simulation of the specimen was carried out. The simulation result shows the same trend with the experiment result, which proves the validity and accuracy of the method.

Paper No. 355: The calibration and analysis of inertia sensors for unmanned aerial vehicle

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Keywords: Inertia Sensor, Unmanned aerial vehicle, Error compensation
Abstract: This paper reports on a method for calibration and analysis of inertia sensors which is widely used for the area of unmanned aerial vehicles. This study analyzes the static and dynamic characteristics of the adopted device. A

system error model is built including accelerator and gyro. This static experiment of inertia sensor was carried on the six directions platform for getting the parameters which is used for calibrating the bias, scale factor and sensitivity. The relative error model is established for explaining the rate performance of the inertia sensor. Compared the performances with different inertia sensors such as the shock, bias and chaos, the optimal system of inertia sensor for unmanned aerial vehicle was confirmed with low system errors.

Paper No. 363: Calibration device for hemodialysis instrument

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Keywords: Hemodialysis; Calibration; Embedded system; STM32; Anti-interference
Abstract: In order to solve the issue of the increasing number of people with renal function disease in China in recent years, a small size calibration device for hemodialysis instrument with high accuracy and multi-channel blood purification parameter detection Simultaneously is developed. The design of the device solve disadvantages of traditional calibration device, such as single function, low measuring accuracy, heavy, slow reaction and so on, improve the level of independent medical service of blood purification in China and break the situation of technology monopoly by Europe and America. Main research works includes design of overall scheme and the study of detection parameters of the calibration device, hardware and software design of embedded system, mechanical design of calibration device and experimental analysis of calibration device.

Poster Session 3: Surface Metrology&Education and Training in Metrology

Poster ID	Paper ID	Paper Title
P3-25	367	Geometrical Deviation Induced Measurement Error of Freeform Surfaces for Coordinate Measuring Machines
P3-26	368	Correction of the optical setup error in simultaneousphase-shifting interferometry
P3-27	370	An improved white-light phase-shifting interferometry
P3-28	93	A Practical Method of VCMM Modeling and Measurement Uncertainty Evaluating

Paper No. 367: Geometrical deviation induced measurement error of freeform surfaces for coordinate measuring machines

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Keywords: freeform surface, coordinate measuring machines, measurement error, machining error, precision metrology, geometrical deviation
Abstract: The measurement error of the coordinate measuring machine (CMM) is affected by many factors such as the accuracy of the hardware of the machine, and measurement strategy, etc. The properties of the workpiece can also influence the measurement result such as the form error and surface roughness, especially in the situation of measurement of complex surfaces such as freeform and structured surfaces. Generally, a computer aided design (CAD) model of the designed surface is much desirable for the measurement of a freeform surface with a CMM by using the most commonly used touch trigger probe. The normal vectors of the designed surface are usually calculated by the software of the CMM from the CAD model as the probing directions. However, in the presence of the machining form error during the measurement process, the actual surface is deviated from the CAD model and this introduces associated measurement error. The measurement error influenced by the form of the workpiece which are geometrical errors induced by the workpiece itself which is independent to the CMM machine and the measurement environment. In other words, even if the CMM machine and the measurement condition are perfect without having any errors, the measurement result has certain amount of deviation from the true surface since there exists the geometrical error. There is little research to quantitatively determine such kind of error. In this paper, the influence of the geometrical error is studied theoretically. Moreover, a software tool has been developed to determine the measurement error affected by the geometrical error of the workpiece. With the developed software tool, the measurement error influenced by different factors such as different levels of errors and different probe radii can be derived and visualized in detail. A series of simulated experiments were conducted to demonstrate the effectiveness of the proposed error model.

Paper No. 368: Correction of the optical setup error in simultaneous phase-shifting interferometry

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Keywords: Phase measurement, simultaneous phase-shifting interferometry, error control
Abstract: This paper presents a method to remove the error of optical setup in simultaneous phase-shifting interferometry (spsi). It is achieved by measuring the distribution ratio of the measurement and reference light in different imaging channels and calculating the exact relative phase shift between interferograms. According to these obtained parameters, the ideal four-step phase-shifting formula is modified for applying to actual interferograms and the required phase with no optical setup error is obtained. The preliminary experiment result shows that the ripple error caused by the error of optical setup obtained by this method is much less than that obtained by the ideal four step phase-shifting formula, which proves the effectiveness of the proposed method.

Paper No. 370: An improved white-light phase-shifting interferometry

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Keywords: white-light phase-shifting interferometry; white-light interferometry; profilometry
Abstract: This paper proposes an improved white-light phase-shifting interferometry (WLPSI), which can achieve fast, accurate and stable measurement of surface with low-reflection areas, such as rough surface. In the proposed algorithm,

the shape from focus is used for detecting the low-reflection areas and estimating the approximate location of the zero-order fringes of these areas, utilizing the information of diffuse reflection reflected from the measured surface. Then the modified WLPSI algorithm is implemented in the vicinity of the approximate location, to achieve unambiguous and high-precision measurement of objects. The effectiveness of the algorithm is validated by comparison with traditional WLPSI. The proposed algorithm extends the application range of white-light interferometry, without change in instrument.

Paper No. 93: Apractical method of VCMM modeling and measurement uncertainty evaluating

Hongli Li[1, 2, a], Xiaohuai Chen[1,b], Houde Liu[2, c,#], Yinbao Cheng[1, d], Hanbin Wang[3,e] , Zhenying Cheng[1,f] andHongtao Wang[1,g]

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Keywords: VirtualCoordinateMeasuringMachine (VCMM); Uncertainty Evaluation; Monte Carlo Simulation Method (MCM); Constraint Simulation

Abstract: Measurement uncertainty is an important indicator of the quality of the measurement results. As a kind of widely used high precision instruments, Coordinate Measuring Machine(CMM) usually can only give the estimated value of the measured parameters in daily use, and the uncertainty evaluation of CMM task oriented measurement is difficult, which seriously restricts the full use of CMM. The uncertainty evaluation of CMM task oriented measurement using the Virtual Coordinate Measuring Machine (VCMM) will be a kind of effective method.

In this paper, a novel and practical method of implementing a VCMM model and uncertainty evaluation is presented based on constraint simulation, which would meet the basic measurement requirements for the general CMM users.The specific evaluation principle and process are presented. Finally, taking the typical measurement task of CMM as example, the measured data are used for the uncertainty evaluation. The proposed evaluation method using VCMM is applied. Compared with the uncertainty evaluation results of the traditional sensitivity analysis method and Monte Carlo simulation method, the uncertainty evaluation results of the proposed method are reasonable and acceptable, and the feasibility and practicability of the new method are shown.

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