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Quantitative analysis and processing of surfaces and profiles from profilometry images

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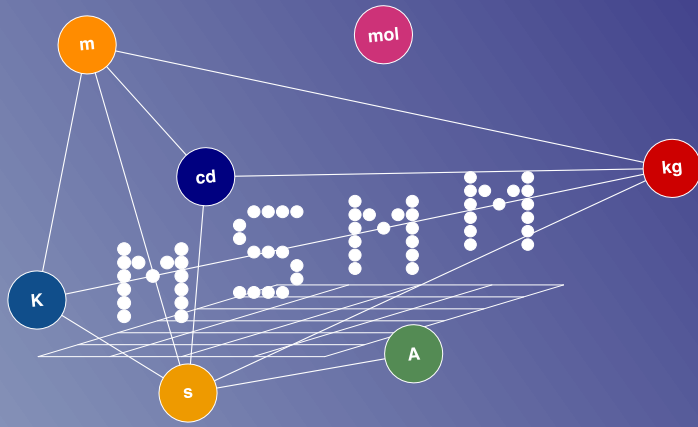
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*ENBIS and EMN Mathmet  
Joint Workshop*

# Mathematical and Statistical Methods for Metrology

*30-31 May 2023*



<http://www.msmm2023.polito.it/>

INRiM  
Istituto Nazionale di Ricerca Metrologica  
Strada delle Cacce, 91 – Torino, Italy



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# **The Programme**

(with [hyperlink to the abstracts](#))



Politecnico di Torino



Dipartimento di Scienze Matematiche G. L. Lagrange



ISTITUTO NAZIONALE DI RICERCA METROLOGICA



ENBIS - Mathmet

# MSMM 2023

Mathematical and Statistical Methods for Metrology



PROGRAMME  
30-31 MAY 2023

30 MAY - FIRST DAY

TIME (CEST)\*

08.00 - 09.00	<b>Registration at the INRiM</b> 📍 Strada delle Cacce 91, 10135 TORINO
09.00 - 09.15	<b>INRiM and Politecnico di Torino welcome</b> 📍 Room: Conference Hall  <b>Francesca Pennechi</b> (MSMM 2023 co-chair, Istituto Nazionale di Ricerca Metrologica, IT), <b>Pietro Asinari</b> (Scientific Director of the Istituto Nazionale di Ricerca Metrologica, IT) and <b>Enrico Bibbona</b> (DISMA, Politecnico di Torino, IT)
09.15 - 09.30	<b>ENBIS and Mathmet welcome</b> 📍 Room: Conference Hall  <b>Antonio Pievatolo</b> (MSMM 2023 co-chair, ENBIS Past President, IMATI-CNR) and <b>Alistair Forbes</b> (ENBIS SIG on Measurement Uncertainty co-chair, National Physical Laboratory, UK), <b>Francesca Pennechi</b> (MSMM 2023 co-chair, EMN Mathmet Chair) and <b>Nicolas Fischer</b> (EMN Mathmet Vice-Chair, Laboratoire national de metrologie et d'essais, FR)
09.30 - 10.20	<b>Invited speaker - Lorenzo Tamellini</b> , Institute of Applied Mathematics and Information Technologies "Enrico Magenes" (CNR-IMATI Pavia, IT)  <i>A multi-fidelity method for uncertainty quantification in engineering problems - Chair: Antonio Pievatolo</i> 📍 Room: Conference Hall
10.20 - 10.40	<b>COFFEE BREAK</b>
10.40 - 11.05	<b>MATHMET Project - Chair: Nicolas Fischer</b> 📍 Room: Conference Hall  <b>ID 122 The strategic research agenda of the European Metrology Network Mathmet</b> <b>Sebastian Heidenreich</b> - Physikalisch-Technische Bundesanstalt, DE
11.05 - 11.30	<b>ID 126 Mathmet Quality Assurance Tools for data, software, and guidelines</b> <b>Keith Lines</b> - National Physical Laboratory, UK
11.30 - 11.50	<b>Applications of Machine Learning Methods for Solving Inverse Problems</b> <b>Chair: Philipp Benner</b> 📍 Room: Conference Hall  <b>ID 53 Invertible neural networks for estimating electron densities from X-ray scattering measurements</b> <b>Philipp Benner</b> - Bundesanstalt für Materialforschung und -prüfung, DE
11.50 - 12.10	<b>ID 123 Reconstructions of nano-geometries from grazing incidence X-Ray fluorescence measurements using neural networks</b> <b>Sebastian Heidenreich</b> - Physikalisch-Technische Bundesanstalt, DE
12.10 - 12.30	<b>ID 70 Determining radius and refractive index of nanoparticles using machine learning</b> <b>Federica Gugole</b> - Nationaal Metrologisch Instituut, NL
12.30 - 12.50	<b>ID 76 Predicting Equivalent Electrical Circuits from Electrochemical Impedance Spectroscopy (EIS) Data with Convolutional Neural Networks and Global Optimization</b> <b>Alexander Kister</b> - Bundesanstalt für Materialforschung und -prüfung, DE
12.50 - 14.00	<b>LUNCH BREAK - EXPO ROOM</b>

\* ORAL PRESENTATION - all time listed are CEST (UTC+2)

PARALLEL SESSIONS

ROOM: CONFERENCE HALL

Design and optimisation methods

Chair: **Enrico Bibbona**

ID 58 *Bridging the Gap between Design and Metrology using Statistical Tolerance Analysis*

14.00 - 14.20

**Mattia Maltauro** - Department of Management and Engineering, University of Padova, IT

ID 18 *Simulated Annealing for Covariate-Adaptive Designs*

14.20 - 14.40

**Marco Novelli** - Department of Statistical Sciences, University of Bologna, IT

ID 81 *A procedure for optimal designs and modeling in technological processes: a case-study on freight trains*

14.40 - 15.00

**Nedka D. Nikiforova** - Department of Statistics Computer Science Applications "G. Parenti", University of Florence, IT

ID 55 *Improving cancer diagnosis times by optimising resource allocation*

15.00 - 15.20

**Elizabeth A. Cooke** - National Physical Laboratory, UK

Industrial applications

Chair: **Gianfranco Genta**

ID 96 *Subjective vs objective assembly complexity assessment: a comparative study in a Human Robot Collaboration framework*

15.20 - 15.40

**Elisa Verna** - DIGEP, Politecnico di Torino, IT

ID 155 *The thermal dynamics of a brake pad, and the estimation of its thermal parameters*

15.40 - 16.00

**Francesca Collini** - DISMA, Politecnico di Torino, IT

ROOM: SEMINAR ROOM

Conformity assessment

Chair: **Francesca Pennecchi**

ID 26 *Advanced methods for assessment of chemical compositions of multicomponent substances or materials and their categorical property values*

14.00 - 14.20

**Ilya Kuselman** - Independent Consultant on Metrology, IL

ID 97 *How do asymmetric measurement distributions affect risks in conformity assessment?*

14.20 - 14.40

**Stephen L R Ellison** - LGC limited, UK

Longitudinal data and time series

Chair: **Marco Coisson**

ID 38 *Modeling Lifetime Drift of Discrete Electrical Parameters for Automotive Semiconductors*

14.40 - 15.00

**Lukas Sommeregger** - Infineon Technologies Austria AG, AT

ID 125 *Forecasting oxygen content in seawater*

15.00 - 15.20

**Gianfranco Durin** - Istituto Nazionale di Ricerca Metrologica, IT

Reference data

Chair: **Alistar Forbes**

ID 128 *Towards Reference Point Cloud Generation for Data Fusion in Dimensional Metrology*

15.20 - 15.40

**Louis-Ferdinand Lafon** - Laboratoire Commun de métrologie et d'essais, FR

ID 132 *Reference data for Electrical Resistance Tomography*

15.40 - 16.00

**Alessandro Cultrera** - Istituto Nazionale di Ricerca Metrologica, IT

16.00 - 16.30

COFFEE BREAK & POSTER SESSION

ROOM: EXPO ROOM

ROOM: CONFERENCE HALL

Uncertainty and regression problems

Chair: **Walter Bich**

ID 88 *On the dB-to-linear conversion*

16.30 - 16.50

**Luca Callegaro** - Istituto Nazionale di Ricerca Metrologica, IT

ID 121 *Data smoothing and its application to the evaluation of the measurement uncertainty in a humidity standard*

16.50 - 17.10

**Rezvaneh Nobakht** - Istituto Nazionale di Ricerca Metrologica, IT

ID 103 *Callendar Van Dusen interpolation by means of Piecewise Constrained Least Squares with nullspace method - an update*

17.10 - 17.30

**Graziano Coppa** - Istituto Nazionale di Ricerca Metrologica, IT

ROOM: SEMINAR ROOM

Methods for dosimetry

Chair: **Stephen Ellison**

ID 50 *Meta-analysis of dosimetry audits*

16.30 - 16.50

**Ellie L. Smyth** - National Physical Laboratory, UK

ID 56 *Sensitivity Analysis for Gamma Index Calculations in Dosimetry Audits for Advanced Radiotherapy*

16.50 - 17.10

**Nadia Smith** - National Physical Laboratory, UK

Methods for Electric Properties Tomography

Chair: **Oriano Bottauscio**

ID 68 *Repeatability and Reproducibility Uncertainty Assessment in Magnetic Resonance-based Electric Properties Tomography of a Homogeneous Phantom*

17.10 - 17.50

**Alessandro Arduino** - Istituto Nazionale di Ricerca Metrologica, IT

ID 84 *Electric Properties Tomography via Green's Integral Identity*

17.10 - 17.30

**Luca Zilberti** - Istituto Nazionale di Ricerca Metrologica, IT

17.30 - 17.50



Social dinner

Venue: Kipling Restaurant & Wines

Via Giuseppe Mazzini, 10 - 10123 Torino

19.30 - 22.00

## 31 MAY - SECOND DAY

TIME (CEST) \*

<b>08.30 - 09.00</b>	<b>Registration at the INRiM</b> Strada delle Cacce 91, 10135 TORINO
<b>09.00 - 09.10</b>	<b>Welcome to day 2</b> Room: Conference Hall
<b>09.10 - 10.00</b>	<b>Francesca Pennecchi</b> (MSMM 2023 co-chair, Istituto Nazionale di Ricerca Metrologica, IT) <b>Invited speaker - Botond Tibor Szabó</b> , Bocconi University, Department of Decision Sciences (Milano, IT) <i>On the theoretical understanding of Bayesian methods in complex models</i> <b>Chair: Francesca Pennecchi</b> Room: Conference Hall
<b>10.00 - 10.20</b>	<b>Methods for Deep Learning</b> <b>Chair: Sebastian Heidenreich</b> Room: Conference Hall <b>ID 112 GUM-compliant uncertainty propagation for deep neural networks</b> <b>Björn Ludwig</b> - Physikalisch-Technische Bundesanstalt, DE
<b>10.20 - 10.40</b>	<b>ID 93 Efficient learning of the copula distribution using WGANs</b> <b>Jorg Martin</b> - Physikalisch-Technische Bundesanstalt, DE

**10.40 - 11.20**

### COFFEE BREAK & POSTER SESSION ROOM: EXPO ROOM

#### PARALLEL SESSIONS

#### ROOM: CONFERENCE HALL

<b>11.20 - 11.40</b>	<b>iMet-MRI Project</b> <b>Chair: Nadia Smith</b> <b>ID 65 T2 or not T2? A new tool for consistent processing of qMRI parameters</b> <b>Jack D. Clarke</b> - National Physical Laboratory, UK
<b>11.40 - 12.00</b>	<b>ID 111 An efficient way to generate synthetic spin echo signals by the extended phase graph</b> <b>Asante Ntata</b> - National Physical Laboratory, UK
<b>12.00 - 12.20</b>	<b>ID 129 Simulation of acquisition process in Magnetic Resonance Imaging to support standardization</b> <b>Riccardo Ferrero</b> - Istituto Nazionale di Ricerca Metrologica, IT
<b>12.20 - 12.40</b>	<b>Bayesian methods</b> <b>Chair: Gianfranco Durin</b> <b>ID 108 Separation of effects associated with measurement data</b> <b>Alistair Forbes</b> - National Physical Laboratory, UK
<b>12.40 - 13.00</b>	<b>ID 80 Investigation of a Bayesian approach for the calibration of large batches of sensors</b> <b>Andrea Prato</b> - Istituto Nazionale di Ricerca Metrologica, IT

#### ROOM: SEMINAR ROOM

<b>11.20 - 11.40</b>	<b>ViDit Project</b> <b>Chair: Sonja Schmelter</b> <b>ID 71 Challenges related with Virtual Experiments in Metrology</b> <b>Gertjan Kok</b> - VSL, NL
<b>11.40 - 12.00</b>	<b>ID 113 Trustworthy virtual experiments and digital twins (ViDiT) - Uncertainty evaluation for Digital Twins</b> <b>Giacomo Maculotti</b> - DIGEP, Politecnico di Torino, IT
<b>12.00 - 12.20</b>	<b>ID 130 Monte Carlo simulations for uncertainty estimation of error separation techniques</b> <b>Saint-Clair T. Toguem</b> - Laboratoire national de metrologie et d'essais, FR
<b>12.20 - 12.40</b>	<b>Modelling for engineering applications</b> <b>Chair: Maurizio Galetto</b> <b>ID 42 Multilayer Delamination Model</b> <b>Kirill Ivanov</b> - Infineon Technologies Austria AG, AT

**13.00 - 14.00**

### LUNCH BREAK - EXPO ROOM

\* ORAL PRESENTATION - all time listed are CEST (UTC+2)

**ROOM: CONFERENCE HALL**

**QUIERO Project**

**Chair: Luca Zilberti**

**ID 106** *Physiological variability in brain electric conductivity: correcting the effect of the age for the detection of pathological alterations*

14.00 - 14.20

**Sebastien Marmin** - Laboratoire national de métrologie et d'essais, FR

**ID 114** *Combining experimental design with digital twin and phantom experiments to optimise data acquisition for magnetic resonance fingerprinting (MRF)*

14.20 - 14.40

**Stephen L.R. Ellison** - LGC Limited, UK

**ID 127** *Myocardial Fibrosis Segmentation from MRF Images*

14.40 - 15.00

**Aleksander Sadikov** - Faculty of Computer and Information Science, University of Ljubljana, SI

**ROOM: SEMINAR ROOM**

**RaCHy Project**

**Chair: Alessandra Manzin**

**ID 107** *A machine learning approach for the estimation of magnetic nanoparticles specific loss power*

14.00 - 14.20

**Riccardo Ferrero** - Istituto Nazionale di Ricerca Metrologica, IT

**ID 120** *In silico experiments to investigate the heating efficiency of magnetic nanoparticles in hyperthermia preclinical tests*

14.20 - 14.40

**Marta Vicentini** - Istituto Nazionale di Ricerca Metrologica, IT

**ID 124** *Thermo-acoustic simulation in ultrasound hyperthermia applications*

14.40 - 15.00

**Silvia Pozzi** - National Center for Radiation Protection and Computational Physics, Italian National Institute of Health, IT

**PLENARY SESSION**

**ROOM: CONFERENCE HALL**

**Explainable Deep Learning**

**Chair: Gertjan Kok**

**ID 87** *Explainable deep learning inference to decode decision-making processes from multidimensional patterns of neural activities*

15.00 - 15.20

**Andrea Ciardiello** - "Sapienza" University of Rome, IT

**ID 94** *From "Wich" to "Why": Interpretation map for Explainable Deep Learning based on Influence methods*

15.20 - 15.40

**Andrea Ciardiello** - "Sapienza" University of Rome, IT

15.40 - 16.00

**CONCLUSIONS**

**Conference Hall**

**ONE LAST COFFEE**

ROOM: EXPO ROOM

30/05  
16.00 - 16.30

**POSTER SESSION**

**Room: Expo Room**

31/05  
10.40 - 11.20

**POSTER SESSION**

**Room: Expo Room**

ID 28

*Black-Box Uncertainty Estimation of Machine Learning Models*

**Georgi Tancev** - Federal Institute of Metrology METAS, CH

ID 45

*Quantitative analysis and processing of surfaces and profiles from profilometry images*

**Andrea Giura** - Istituto Nazionale di Ricerca Metrologica, IT

ID 51

*Ensuring the validity of measurement results through the use of triangulation rules*

**Iulian Mihai** - Istituto Nazionale di Ricerca Metrologica, IT

ID 101

*PyES - an open source software for the computation of in solution and precipitation equilibria*

**Lorenzo Castellino** - University of Turin, IT

ID 105

*Obsidian sourcing by combining SEM images and machine learning*

**Marco Coisson** - Istituto Nazionale di Ricerca Metrologica, IT

ID 115

*ViDiT project "Trustworthy virtual experiments and digital twins"*

**Sonja Schmelter** - Physikalisch-Technische Bundesanstalt, DE

ID 156

*Employing machine learning models to enhance the prediction of cocrystals formation*

**Eugenio Alladio** - University of Turin, IT



# Quantitative analysis and processing of surfaces and profiles from profilometry images

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**Key words:** Profilometry, texture, roughness, parameters, Python, topography, levelling, resampling, filtering

## 1. Introduction

Surface metrology is concerned with inspecting morphological parameters of a surfaces or profiles, by using contact or non-contact profilometers.

The following abstract describes the development of a software in Python environment that implements various processing methods on images from optical and stylus profilometers. In particular, the program focusses on image pre-processing and determination of dimensional parameters for 2D areas and 1D profiles.

It is worth mentioning that many open and closed source programs are already distributed, but they do not provide a sufficient automatization in the image processing, often requiring the user to repeat the same steps for each image to obtain the expected results.

The program has been initially developed within the framework of the EMPIR 20IND07 TracOptic project [1] for the processing of a batch of topographies on RS-M and RS-N linear step samples, in order to compensate for the lack of automation for the calculation of height parameters. The developed program [2] is designed to be modular and scalable for expanding the processing capabilities.

### 1.1 Surface processing

Surface measurements are usually obtained with optical profilometers or microscopes, and the resulting topographies must be processed to extract the parameters of interest.

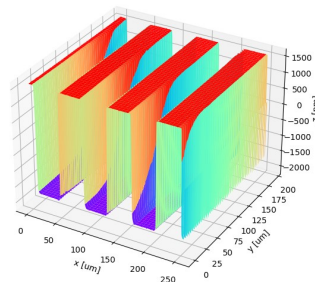
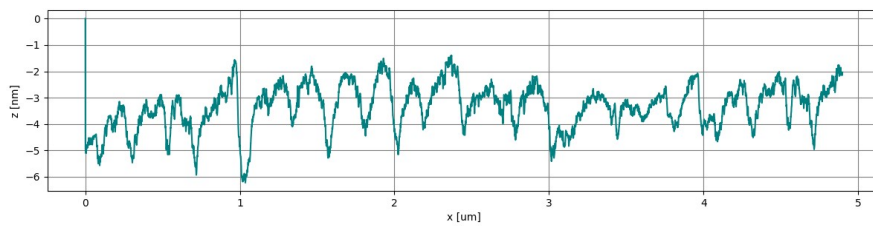


Figure 1: Topography

For the pre-processing of the images, three different levelling methods have been implemented which allow to correct any tilt of the topography: least square plane levelling, three points plane levelling and bounded least square plane levelling. The program also includes a method for resampling the image and for extracting cross-sectional profiles of the topography.

## 1.2 Profile processing

Profile measurements are usually obtained with stylus profilometers, confocal point sensors or by extracting a cross-sectional profile from a surface.



**Figure 2: Profile**

In order to pre-process the profile, least square line levelling and bounded least square line levelling were implemented as for the topography. An additional histogram levelling method has been developed to allow the tilt correction of profiles with a large feature on a flat baseline.

The program provides Gaussian filters according to the ISO 16610-21:2011 written standard [3] for the extraction of the morphological roughness parameters, and the erosion morphological filter according to the new ISO 21920-2:2021 written standard [4].

## 2. Conclusions

The methods previously described were validated using MountainsMap 7.4 [5] commercial software.

Regarding profile roughness parameters, an agreement within 0,05% for Ra, 0,2% for Rq, 0,5% for Rsk and Rku, below 1 ‰ for Rt, is achieved on different types of profile from stylus profilometers measurements.

Future developments will focus on uncertainty estimation of morphological parameters both using GUM and Monte Carlo methods. Moreover, the capabilities of the software will be expanded to allow the extraction of more complex surface features.

## Acknowledgements

The 20IND07 TracOptic project has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

## References

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<sup>1</sup> <https://www.ptb.de/empir2021/tracoptic/home/>

<sup>2</sup> <https://github.com/andeledea/pluopen>

<sup>3</sup> EN ISO 16610-21:2012 Geometrical product specifications (GPS) - Filtration - Part 21: Linear profile filters: Gaussian filters (ISO 16610-21:2011)

<sup>4</sup> EN ISO 21920-2:2022 Geometrical product specifications (GPS) - Surface texture: Profile - Part 2: Terms, definitions and surface texture parameters (ISO 21920-2:2021, Corrected version 2022-06)

<sup>5</sup> <https://www.digitalsurf.com/software-solutions/profilometry/>