Title

Bayesian statistical methods for metrological applications in the field of sensor calibration and conformity assessment.

Description and Objectives (max 200 char.)

Development of statistical (Bayesian) methods for virtual calibration of large batches of sensors, conformity assessment of samples of items and characterization of certified reference materials.

Detailed description of the proposed research "Bayesian statistical methods for metrological applications in the field of sensor calibration and conformity assessment".

"*Data analysis and uncertainty evaluation*" is the one of the three high-level topics of the EMN Mathmet Strategic Research Agenda (SRA) [1] (to which INRiM if strongly committed, chairing the network since 2022), recognising that an increased use of mathematics and statistics is required to face new measurement challenges. This is a very cross-cutting topic, potentially applicable to all metrology areas, and it requires strong competencies in mathematical modelling, probability and statistics. In this framework, the research proposed for this PhD grant focuses on updating and developing new statistical methods (Bayesian, in particular) to answer some metrological needs that still have to be effectively addressed, such as the virtual calibration of measurement instruments/sensors, conformity assessment of items, uncertainty evaluation for small sample sizes, data analysis for interlaboratory comparison, evaluation of homogeneity and stability in reference material production. These needs well align with the INRiM Vision Document (https://www.inrim.it/en/about-us/history/vision-document), that mentions measurement technologies for digital and chemical metrology among the most challenging topics.

The topic "*Accelerating digital transformation and supporting industrial transitions*" in the INRiM Vision specifically asks for the development of better metrology for large-scale sensor networks, including manufacturers' in-line control systems and large-scale calibration procedures. In this respect, and in line with the suggestions of the CCAUV strategic document [2], a promising line of research is now under development at INRiM concerning the large-scale virtual calibration of Micro-Electro-Mechanical systems (MEMS) sensors for sensor networks. MEMS sensors are widely used in large sensor networks for many applications. Their mass production of millions/week requires costly and time-consuming calibration processes that lack metrological traceability. The idea, based on a recent publication on digital accelerometers [3], is to develop virtual calibration methods, employing Bayesian statistics, able to substitute or complement traditional laboratory calibrations, hence significantly reducing calibration time and costs while ensuring acceptable uncertainty and reliability levels. The aim of the PhD research is to expand the model proposed in [3] to more sophisticated ones (e.g. conjugate and hierarchical), identifying suitable criteria for out-of-tolerance sensors, performing sensitivity analyses in dependence of the chosen prior distribution and the involved parameters, applying appropriate validation procedures, developing alternative metrics for the reliability of the virtual calibration, and elaborating strategies for balancing costs of in-the-lab calibrations and acceptable scores of reliability for batches that are virtually calibrated. It has to be underlined that although the statistical framework was originally conceived for accelerometers sensor, it could be potentially applied to any kind of sensors, hence resulting of huge impact for the large community of low-cost sensor manufacturers, sensor network providers and relevant end-users.

The topic above is strongly related to the framework of conformity assessment and sampling plans. Document JCGM 106:2012 [4] provides a fully Bayesian framework for conformity assessment, but it has limitations: it is conceived for the assessment of a single item at a time, having just a scalar characteristic to be assessed. In recent years, some research has been conducted to generalize this framework to a set/sample/lot of items [5] and to multivariate item properties [6, 7]. Nonetheless, further research on this topic is still needed and would be developed by the PhD research: a full generalization of the producer and

consumer risks defined in JCGM 106:2012 to a whole sample of items should be investigated, the new models should be validated, and their relationship with actually available (frequentist) acceptance sampling plans (in the ISO series 2859 and 3951) and some new ones that are under development by the ISO TC 69 / SC 5 should be assessed (subcommittee SC 5 is now elaborating a technical report on “Conformity assessment in acceptance sampling” with the aim of producing a Bayesian counterpart of the ISO series 2859 and 3951).

Furthermore, INRiM is involved in the EPM Project “Metrology for standardised moisture / water content measurements in plant-origin bulk materials in support of International and European food safety and trade” [8]. The PhD research will also support INRiM activities that will be conducted in this project, in particular through the development of statistical modelling to evaluate uncertainty for measurements of water / moisture in grain / flour, to analyse measurement results from interlaboratory comparisons and to characterize (in terms of uncertainty, homogeneity, stability) a candidate grain simulant certified reference material that will be developed in the project.

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