LARGE-SCALE VIRTUAL CALIBRATION OF MEMS SENSORS

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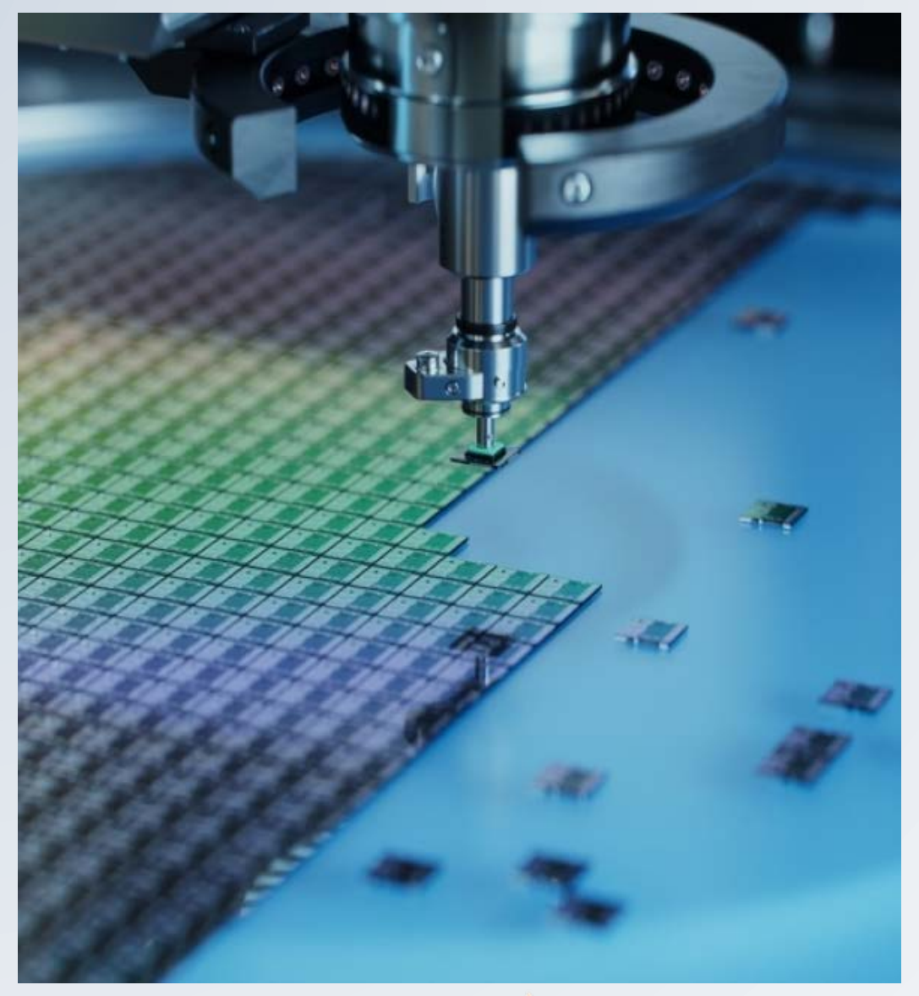
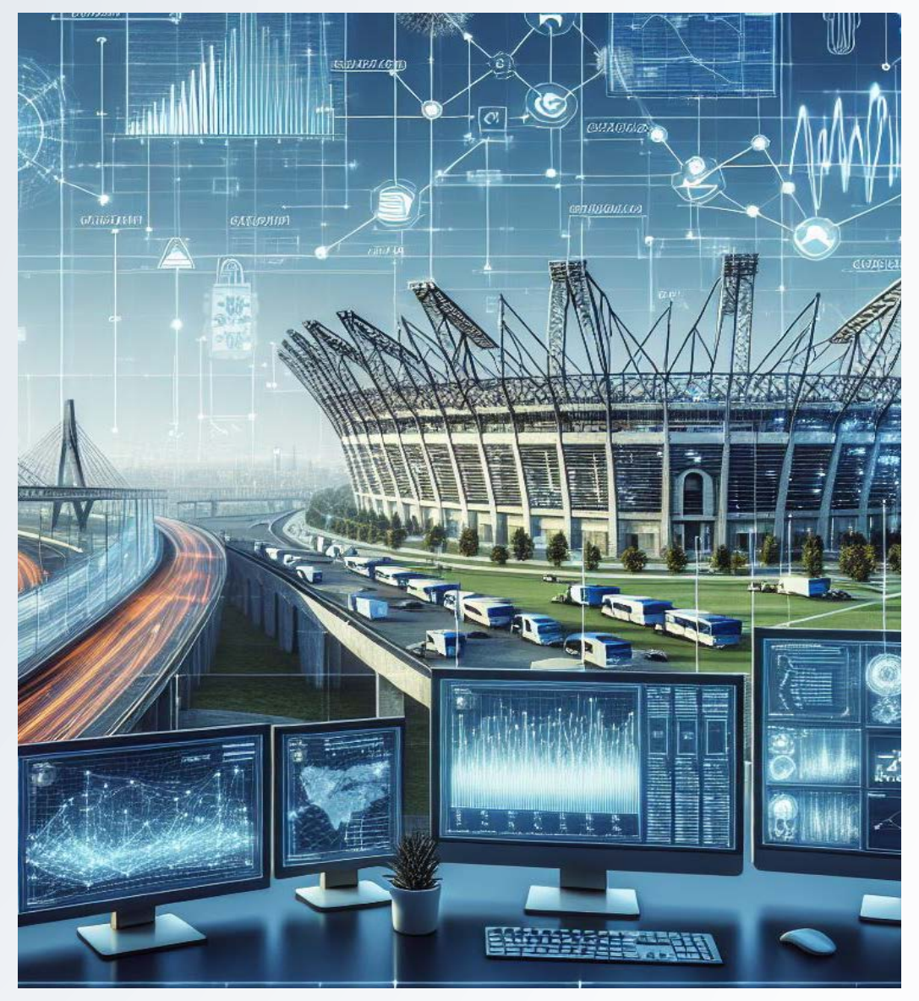
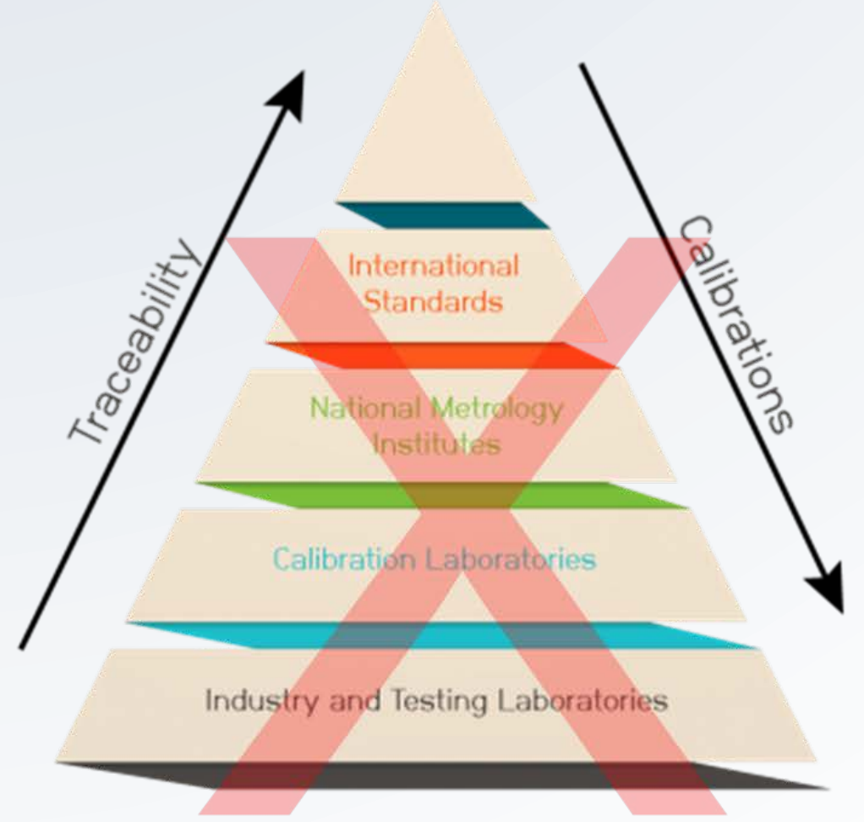
The research aims to develop virtual calibration methods using Bayesian statistics to provide traceability to large-scale MEMS sensors and related sensor networks by reducing calibration time and costs

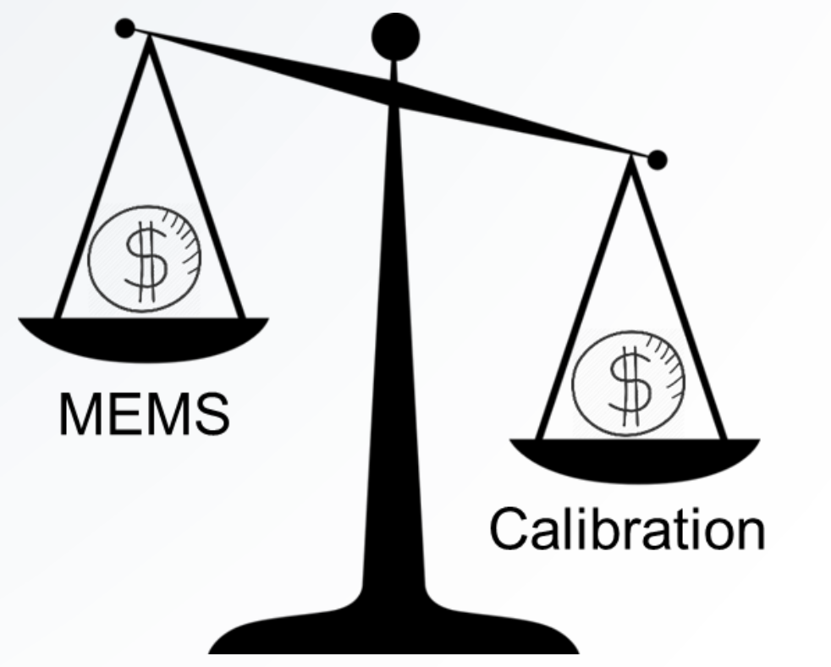
NEEDS

- Secure and reliable digital environment to support Europe's digital transformation
- Impossibility to apply one-to-one (in-the-lab) calibration procedures
- **Cost-effective calibration methods** for high-volume (million/week) MEMS sensor production
- Traceability for large-scale **MEMS sensor networks**
- Standardized calibration **procedures for broad** adoption by NMIs, calibration labs, industries and end-users



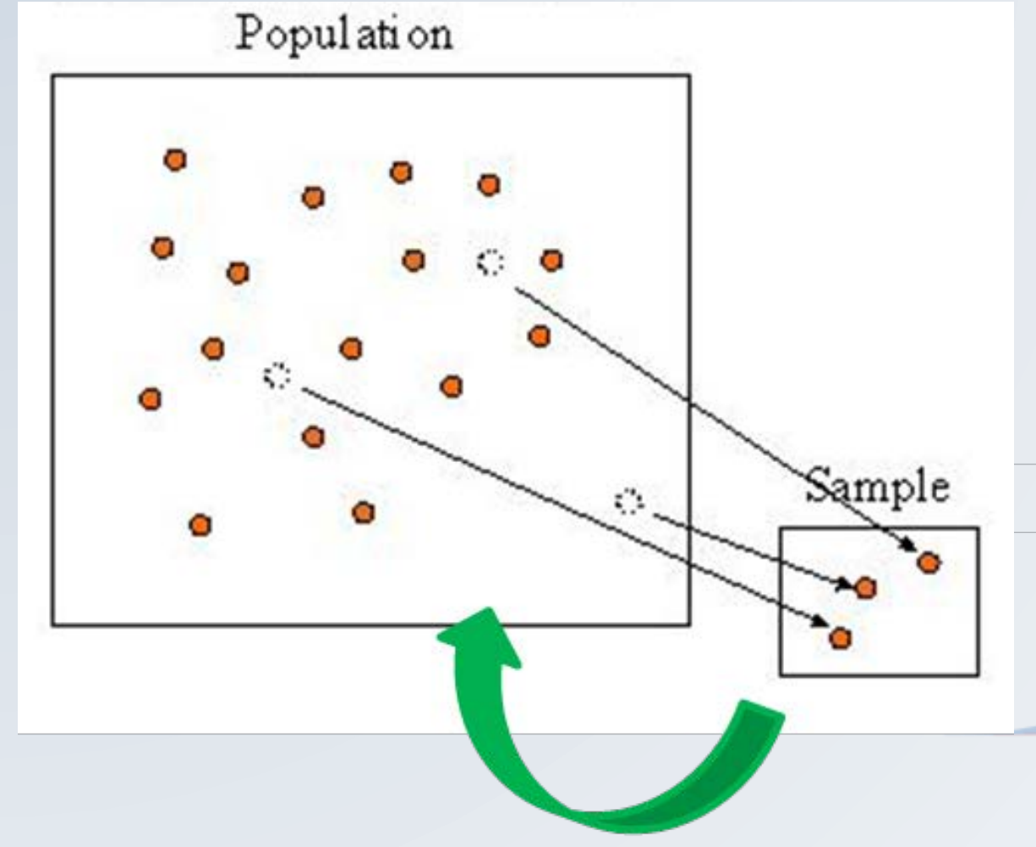


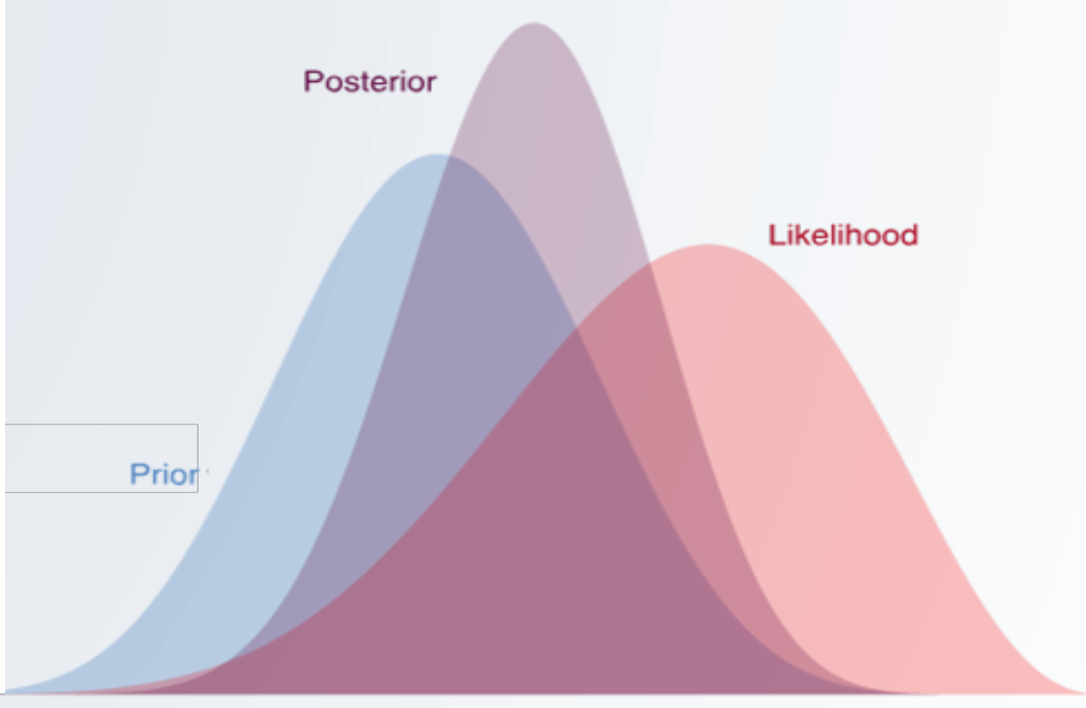




STATISTICAL SOLUTION

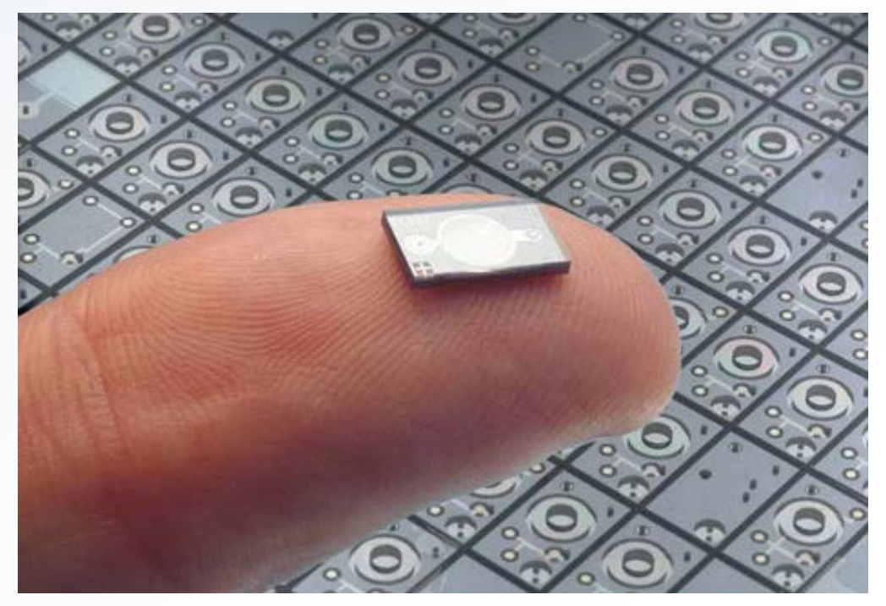
- Statistical models to **reduce the burden of experimental calibrations of huge batches**
- **Bayesian inference** adopted to exploit prior information on the MEMS quality and update it with fresh information from a sample of MEMS
- Prior knowledge comes from the experimental calibration of a whole (large) **'benchmark' batch** (*N*) – Binomial prior
- For any future batch to be calibrated, updated information comes from **the experimental calibration of a small (*n*) sample of those MEMS** – Hypergeometric likelihood
- **Virtual calibration** of the batch in terms of **value**, **uncertainty** and metrological **reliability metric**





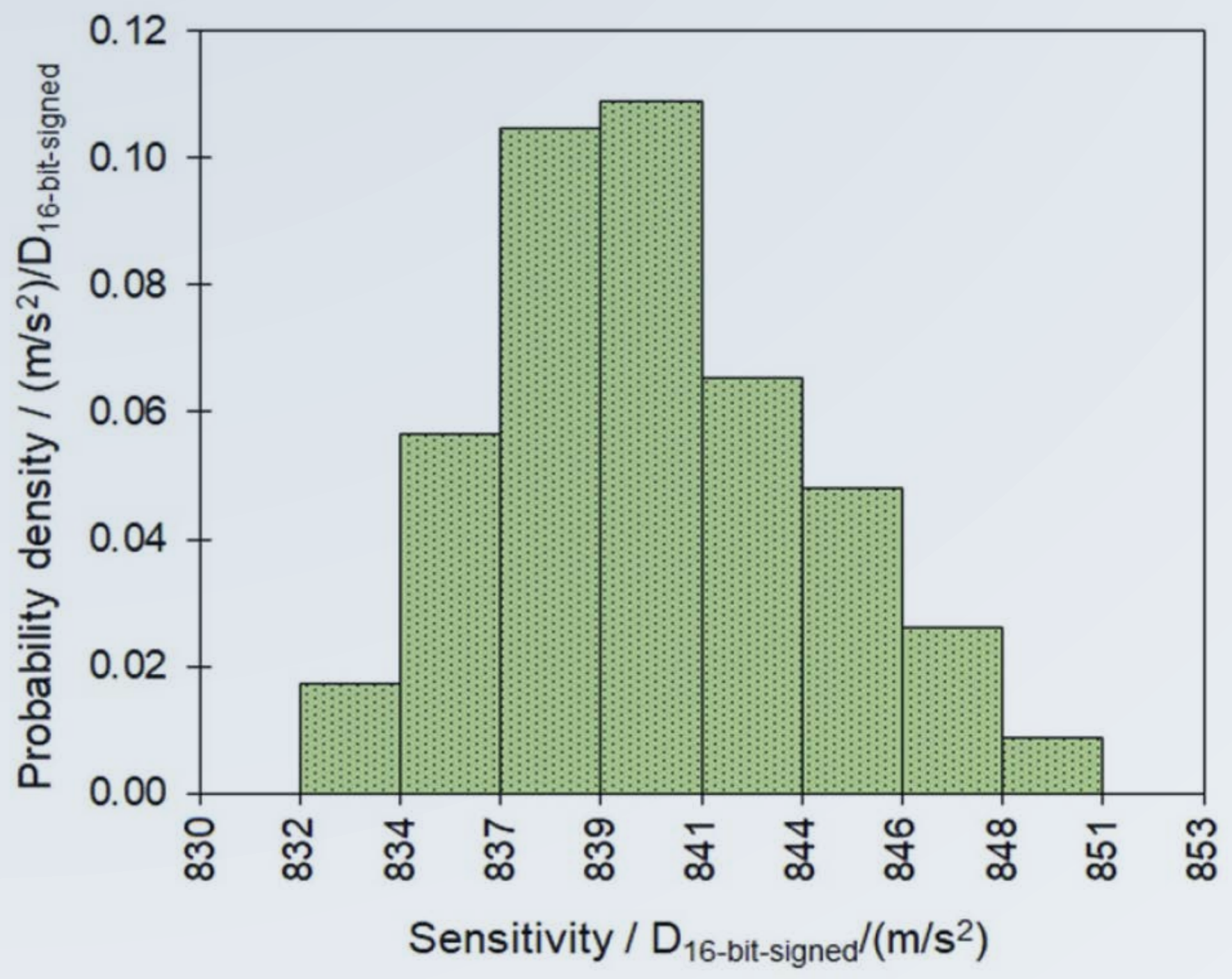
$$\overset{\text{Posterior}}{\Downarrow} \qquad \overset{\text{Likelihood}}{\Downarrow} \qquad \overset{\text{Prior}}{\Downarrow}$$

$$P(A|B) = \frac{P(B|A) * P(A)}{\underset{\text{Evidence}}{\underset{\Uparrow}{P(B)}}}$$

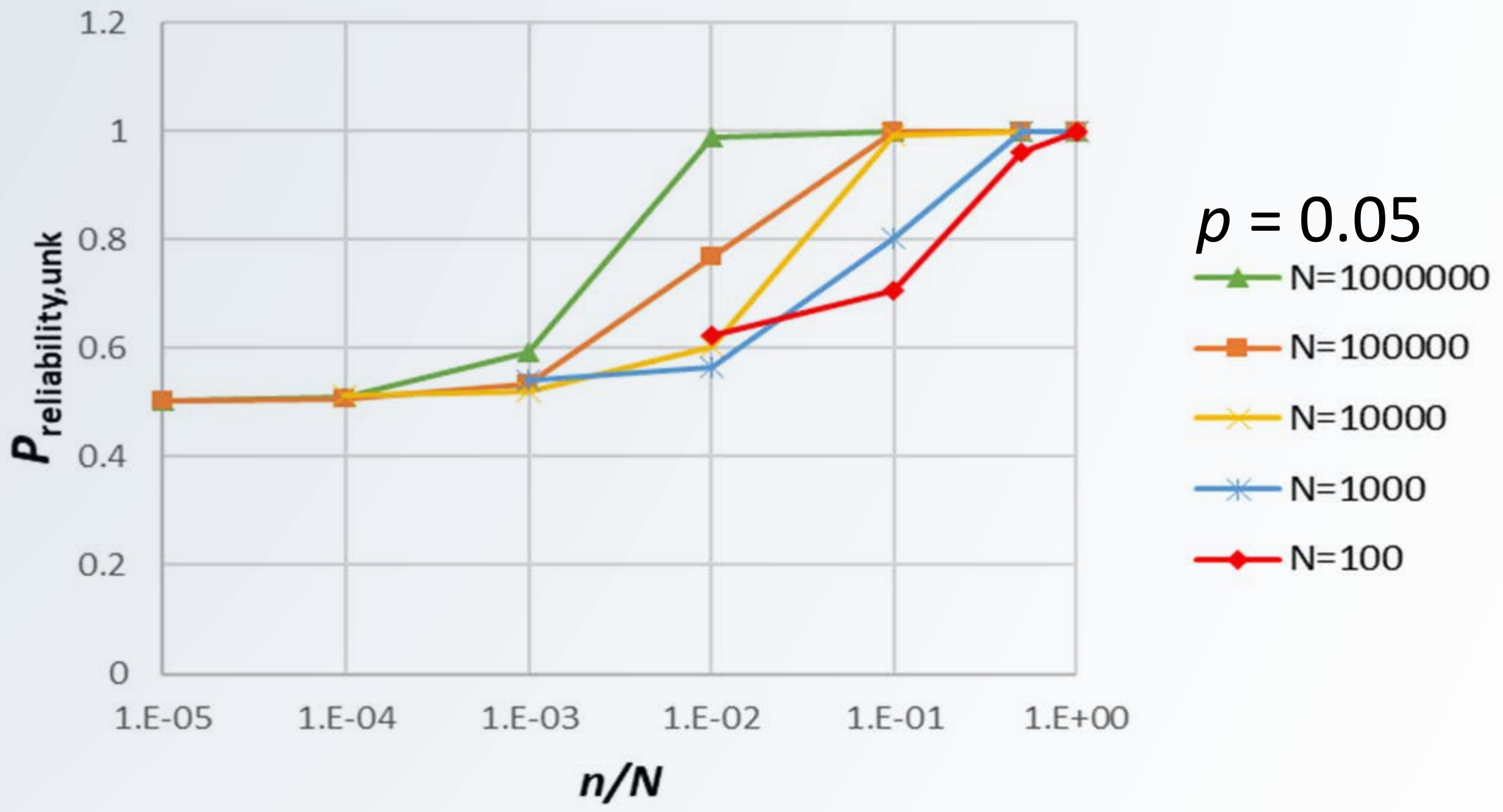


RESULTS & DEVELOPMENTS

- Procedure applied to 100 nominally identical digital MEMS accelerometers, calibrated at INRIM for validation purposes (with calibration standard uncertainties of about 4.2 $D_{\text{16-bit-signed}}/(\text{m s}^{-2})$ and probability *p* of out-of-tolerance sensors of 5 %)
- Bootstrap validation (*N* = 50, *p* and *n* varying) of the reliability metric w.r.t. theoretical values → differences within ± 7 %

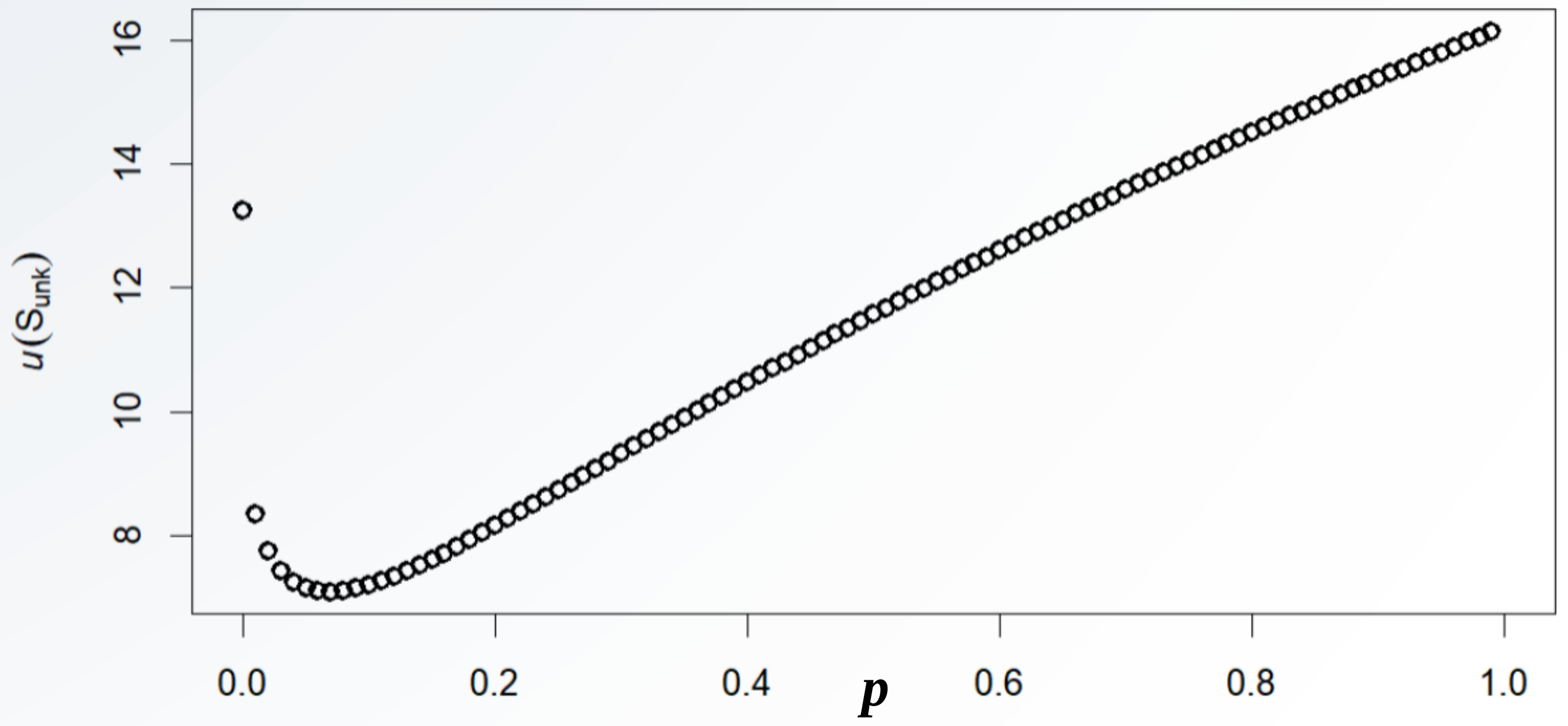


Distribution of the amplitude sensitivities along *z*-axis of the 100 MEMS at 10 Hz.



Reliability metric (for $p = 5$ %) w.r.t. the sample-size/batch-size ratio

- Price to be paid: the uncertainty of the virtually calibrated MEMS is always larger than the experimental one and increases for *p* increasing.
- Under development: hierarchical model introducing a beta hyperprior on *p*
- Under development: alternative metrics for the reliability of the virtually calibrated batches



Uncertainty of the virtually-calibrated sensors w.r.t. proportion *p* of out-of-tolerance sensors in the batch

CONCLUSIONS

- Methods for large-scale virtual calibration will allow accredited calibration laboratories to apply standard procedures and attribute sensitivity and uncertainty to millions of MEMS sensors, ensuring their reliability
- Large sensor networks containing both statistically calibrated MEMS sensors and traditional higher quality measurement instruments are safer and more trustworthy (and traceable) than any other network containing low-cost sensors of unknown or undefined sensitivity

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