

# Emerging Calibration & Traceability Challenges

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**Emerging Calibration & Traceability Challenges**  
Caused by Smart Sensor Technologies & Digitally Networked Measurement Systems (as Part of IoT)

308. PTB-Seminar  
**Berechnung der Messunsicherheit – Empfehlungen für die Praxis**  
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Veranstalter:

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## In Retrospect: Sensor Technologies & the GUM (1)

Nach: P. Krause, FirstSensor GmbH, BMBF-Expertengespräch, 28.08.2014

**Sensor 1.0**  
*mechanical sensors/transducers*  
e.g. Vidie Round-box, 1844  
end of 18th century

**Sensor 2.0**  
*electrical sensors*  
e.g. strain gauges 1938, Simmons/Ruge  
begin of 20th century

**Sensor 3.0**  
*electronical sensors*  
e.g. compensated pressure sensor, dig. interfaces, AD converters, electron. memories, simple computational capabilities etc.  
late 60th to late 70th of 20th century


**Sensor 4.0**  
*smart sensors*  
e.g. in-situ oil-quality sensors with temperature and degradation compensation, communication capabilities, condition monitoring systems etc.  
today

↑ complexity

← ...this technological leap gave the initial impulse for the 1993/95 „GUM 3.0“

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## The Guide to the Expression of Uncertainty in Measurement

Result of the New Data-Evaluation Opportunities of the 60th/70th  
A Review

**State-of-the Art of measurement evaluation up to the mid-80th:**

- A Error Analysis with special **emphasis on random errors**
- B **Systematic errors were seen as principally recognisable**, but ...

**The technology leap 3.0 of the 60th/70th: New technological reality:**

- C **Digital measurement-data processing** as well as **digital data storage**
- D ... therefore, **automatically repeated acquisition & computer-aided processing of measured data**

- consequently, **random errors became** (more or less) **negligible**
- tighter **focus on** so-called **unknown systematic errors**  
e.g. ambient temperature, degradation, instrument error, ...

**The metrological answer was given (as late as) 1993  
by publishing the GUM !**

See [www.bipm.org/en/publications/guides/](http://www.bipm.org/en/publications/guides/)

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## The Guide to the Expression of Uncertainty in Measurement

The Data-Evaluation Problem of the 60th/70th – A Brief Review

**State-of-the Art of uncertainty evaluation up to the mid-80th:**

- A
- B
- C
- D

**GUIDE TO  
THE EXPRESSION  
OF UNCERTAINTY  
IN MEASUREMENT**

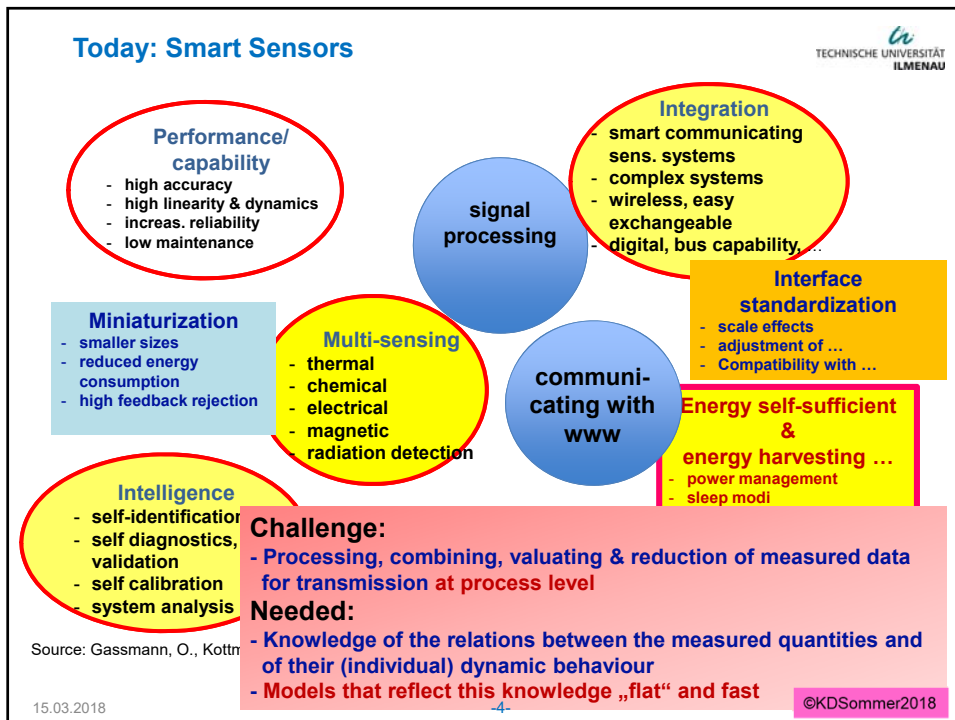
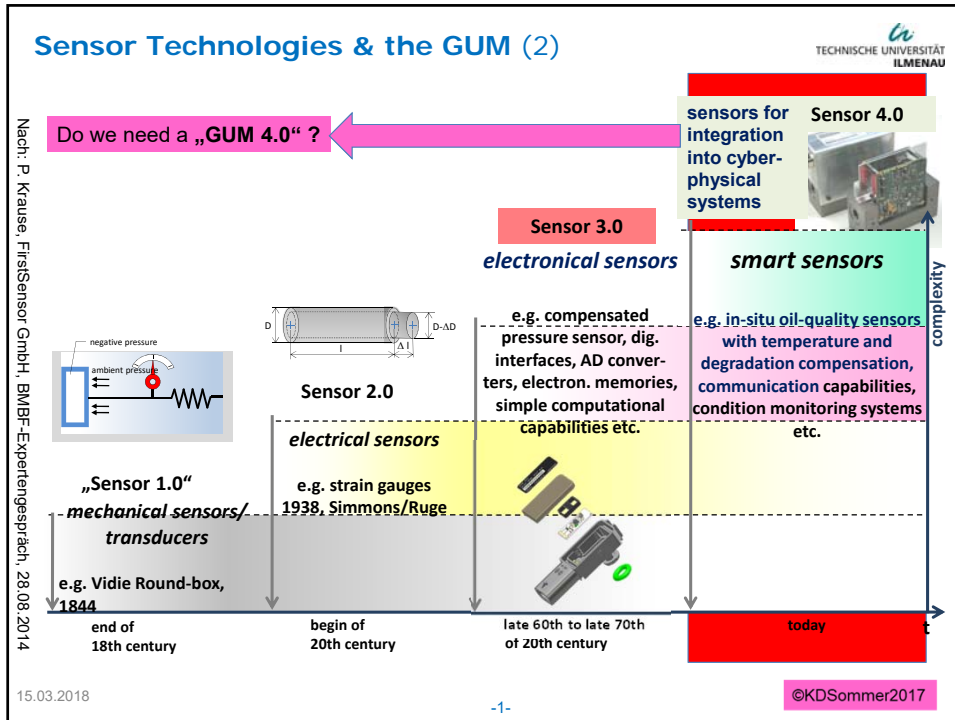
**Obviously, technology was the driving force for theory**

CORRECTED AND REPRINTED, 1995

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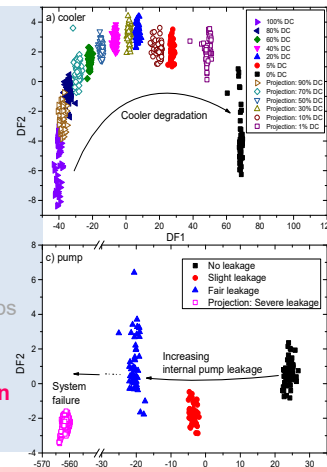
### Challenge: Condition Monitoring (1)

Example: Characteristic Damage Function (LDA - linear discriminant analysis)

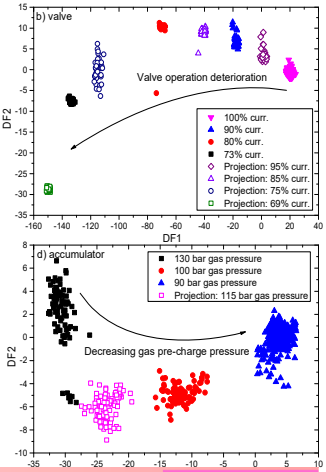
- Damage process is represented in 2-D LDA-space
- DF1 enables the quantification of the damage grade
- Evaluation of the statistical models by projecting of intermediate steps successful

→ **Calibration of the measurement/determination of the damage state !**

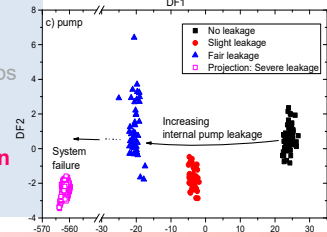




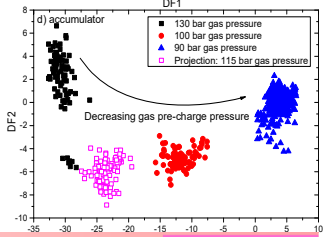
a) cooler



b) valve



c) pump



d) accumulator


**Challenge:**

- Nobody wants to know the detailed information avail. or can process it mentally. The essential, really relevant part is needed, only!
- Big amounts of data and information resp. can't be transferred at process level!

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### Challenge: Condition Monitoring (2)

Satisfying Customers Demand – Trend Beyond Classical Measurements?



**Example:**

Hydraulic system

- pressure  
• sampling-rate 100 Hz
- vol.-flow  
• sampling-rate 10 Hz
- temperature  
• sampling-rate 1 Hz
- oil quality  
• sampling-rate 1/Zyklus

Data reduction

→

analyzing sensor data

Modelling challenges:

synchronizing and calibrating the raw-data points of sensors

signal pre-processing (e.g. smoothing, normalization/standardization)

faeture extraction (form-describing or statistical)

feature selection

classification (e.g. LDA+k-nn, SVM, NN)

validation of the statistical models (e.g. k-Fold CV)

completely automatable

**Automatically defined application/provocation of mal-functions & relevant influences**

**Condition monitoring – Determination of relevant system states**  
instead of individual measurands, e.g.

- *Maintance needed*
- *System needs your attention – or don't touch the system*

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## Challenge: Dealing with Large Numbers of Sensors

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Production output of one German sensor manufacturer:  
**1.000.000 sensors per day !**

My pers. estimate:  
**Number of sensors will grow by 20 times next 5 years !**

**Challenges:**

- Sensors can't be removed from the systems → **no classical calibration possible**
- **Correlation** – may change uncertainty significantly, therefore, **must be taken into account**
- Sensors might have **different/critical dynamic behaviour**

**Needed:**

- **New calibration and traceability strategies?**
- **Calibration regarding dynamic properties?**

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## Challenge: Digitally (i.e. *flexible*) Networked Measurement & Sensor Systems

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>300.000 Sensoren  
 maybe 2000 calibrated reference points needed

The diagram shows a system architecture with 'System engineering' at the top, 'Human-machine interaction' below it, and 'Human-machine interface' connecting to a 'Human' box. Below the human is a yellow circle containing 'Information', 'Energy', and 'Substances'. At the bottom is an 'Environment' box. In the center, 'Non-cognitive control' and 'Sub-system' are connected to 'Sensor systems' (represented by pink boxes). 'Sub-systems' are also shown on the left. Arrows indicate data flow between these components.

**Challenge:**

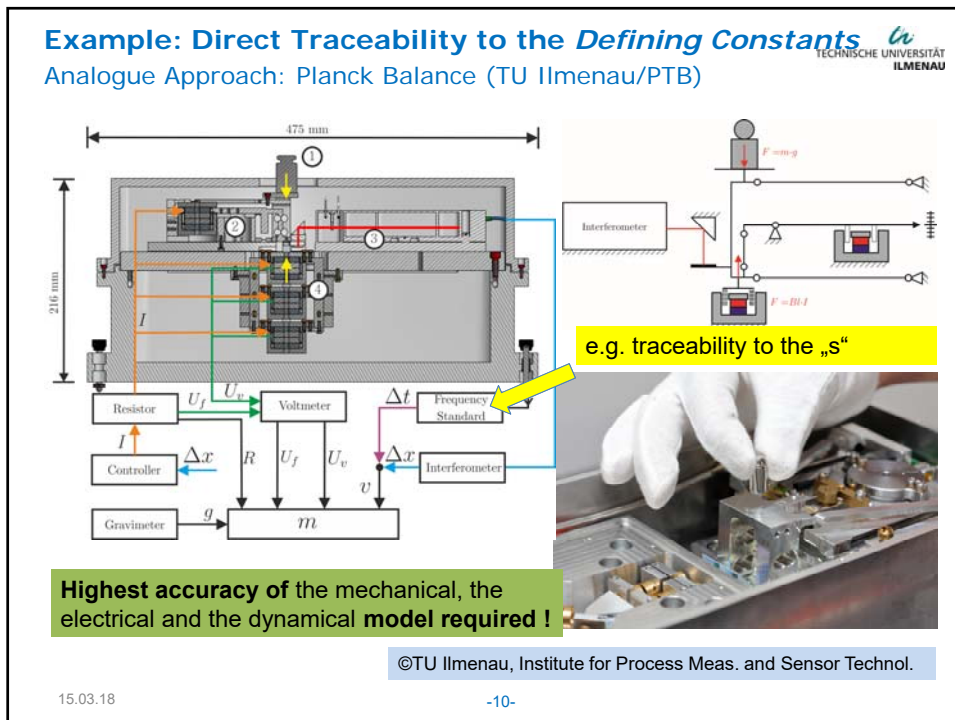
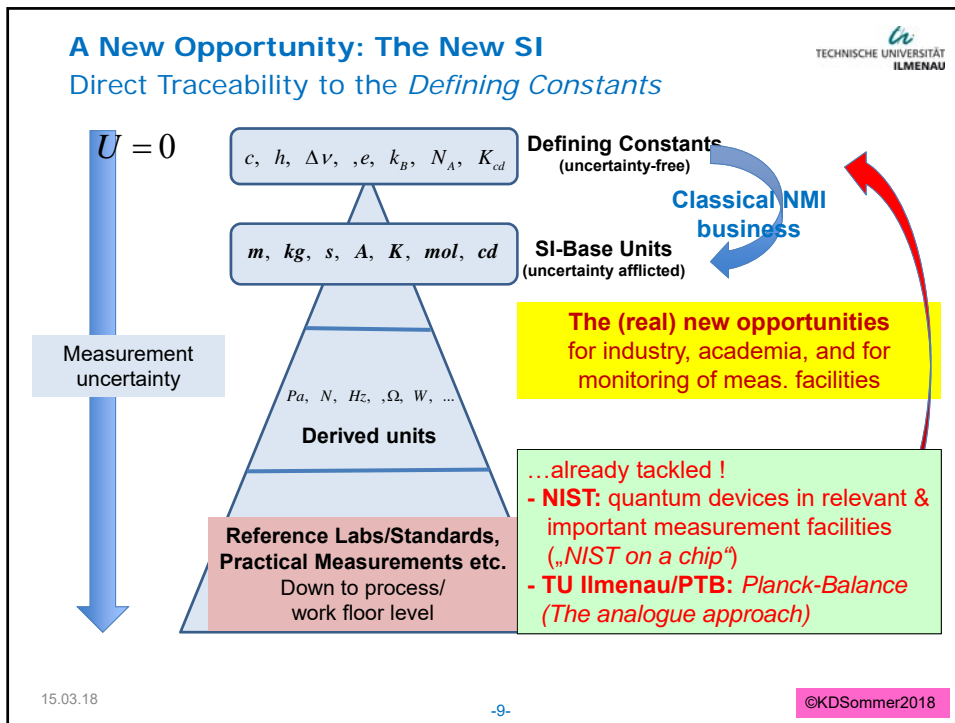
- How to find/define the correct quantity values of the relevant reference points?
- How to calibrate them traceable to the SI?

**Needed:**

- Novel calibration and data evaluation strategies?
- Reorganisation of our quality infrastructures?

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## Novel Approaches to Ensure Traceability

### Approaches at Lower Hierarchy-Levels

Selected approaches:

- 1 **Utilizing virtual standards - digital twins -** →  
 e.g. virtual coordinate measuring machines
- 2 **Self-X strategies**, incl. self-provocation/defined change of influence quantities, comparison with collaborating sensors of the system as well as ...
- 3 **Artificial-intelligence solutions, e.g. machine learning - fast checking** a large number of (mostly data-driven) model combinations (preferred by German sensor and instrumentation manufacturers)


All these solutions are to be combined with

- Classically calibrated references
- Built-in or system-inherent references

or to be traceable directly to the *Defining Constants*

Additionally:

- Application of *big-data* methodologies
- Reference to plausible environmental values, e.g. *smart-phone sensors*



Source: Siemens


**4** ...  
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## Utilizing Digital Twins

### Example: Holistic Dimensional Measurements



**Example:** Quality check of a whole vehicle body, regarding

- Form/Shape
- Dimensions
- Surface quality
- Colour
- Defects
- ...

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**Ensuring measurement correctness:**

- utilizing a **virtual standard / digital twin** of the complete car body
- Model includes the thermal behaviour, material properties, mechanical stress responses and uses empirical uncertainty values ...

Virtual standards are models !

## Emerging Calibration & Traceability Challenges

### Conclusion: There Seems to be a Clear Need to Extend the GUM



Based on its proven *Bayesian* way, the GUM should to be extended to enable it to recognize i4.0 technologies in measurement:

- Generally, the GUM should be extended to be capable to **deal with (flexible) networked measurement systems**
- **Modelling** (parametric, data-driven, „flat & fast“, including data/information reduction and classification) will become a **key competence of uncertainty evaluation**
- **Quantifying Traceability reliability** in case of **virtual standards** – digital twins?
- Uncertainty propagation through **machine learning** solutions?
- Due to the future dominating role of (flexible) data processing, reduction and transmission, use of **information measures & sensor data fusion** come in focus again!
- **Dynamic effects** will play an increasing role, and ... (much more)