Metrology for

New Industrial Measurement Technologies (NIMTech)

International Workshop on

Advances in Coordinate Measurement Techniques for Industrial Applications

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NIMTech

Importance of Software in Coordinate Metrology – Achievements and Perspectives

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THEORIA
MOTUS CORPORUM
COELESTIUM

IN

SECTIONIBUS CONICIS SOLEM AMBIENTIUM

AUCTORE

CAROLO FRIDERICO GAUSS

HAMBURGI SUMTIBUS FRID. PERTHES ET I. H. BESSER

1809.

Gauss' Estimation SW (Least-Squares) & the very general problem in natural philosophy

175.

Ad hunc finem a problemate nostro speciali ad disquisitionem generalissimam in omni calculi ad philosophiam naturalem applicatione foecundissimam ascendemus. Sint V, V', V'' etc. functiones incognitarum p, q, r, s etc., μ multitudo illarum functionum, ν multitudo incognitarum, supponamusque, per observationes immediatas valores functionum ita inventos esse $V = M$, $V' = M'$, $V'' = M''$ etc. Generaliter itaque loquendo evolutio valorum incognitarum constituet problema indeterminatum, determinatum, vel plus quam determinatum, prout fuerit $\mu < \nu$, $\mu = \nu$, vel $\mu > \nu$*). Hic de ultimo tantum casu sermo erit, in quo manifesto exacta cunctarum observationum repraesentatio tunc

ACKNOWLEDGEMENTS

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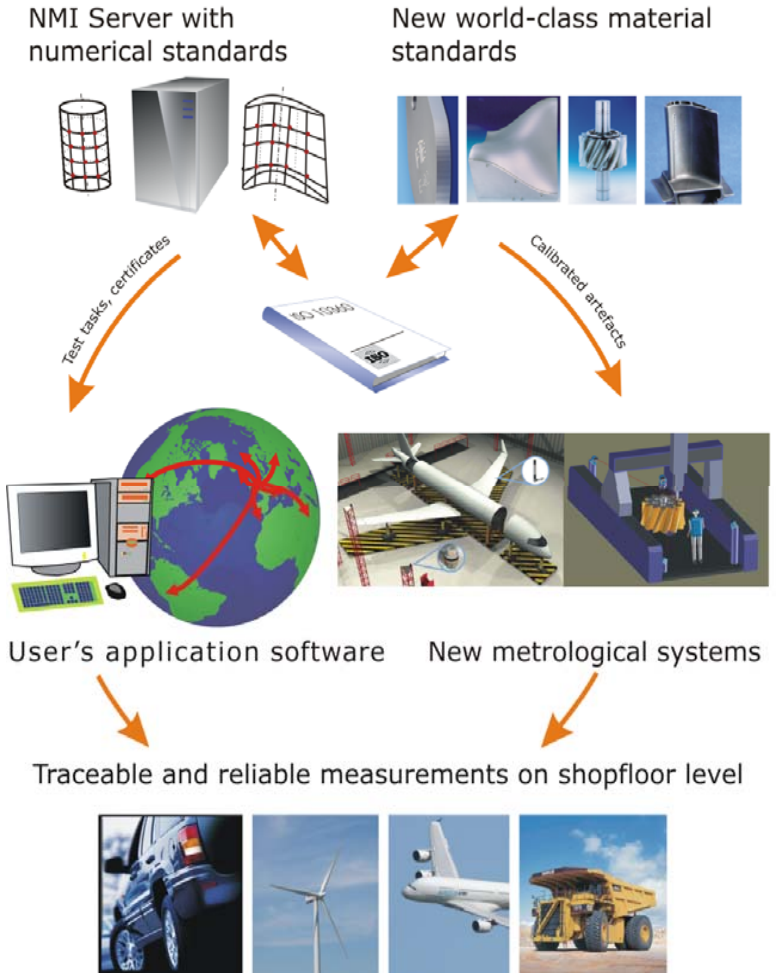
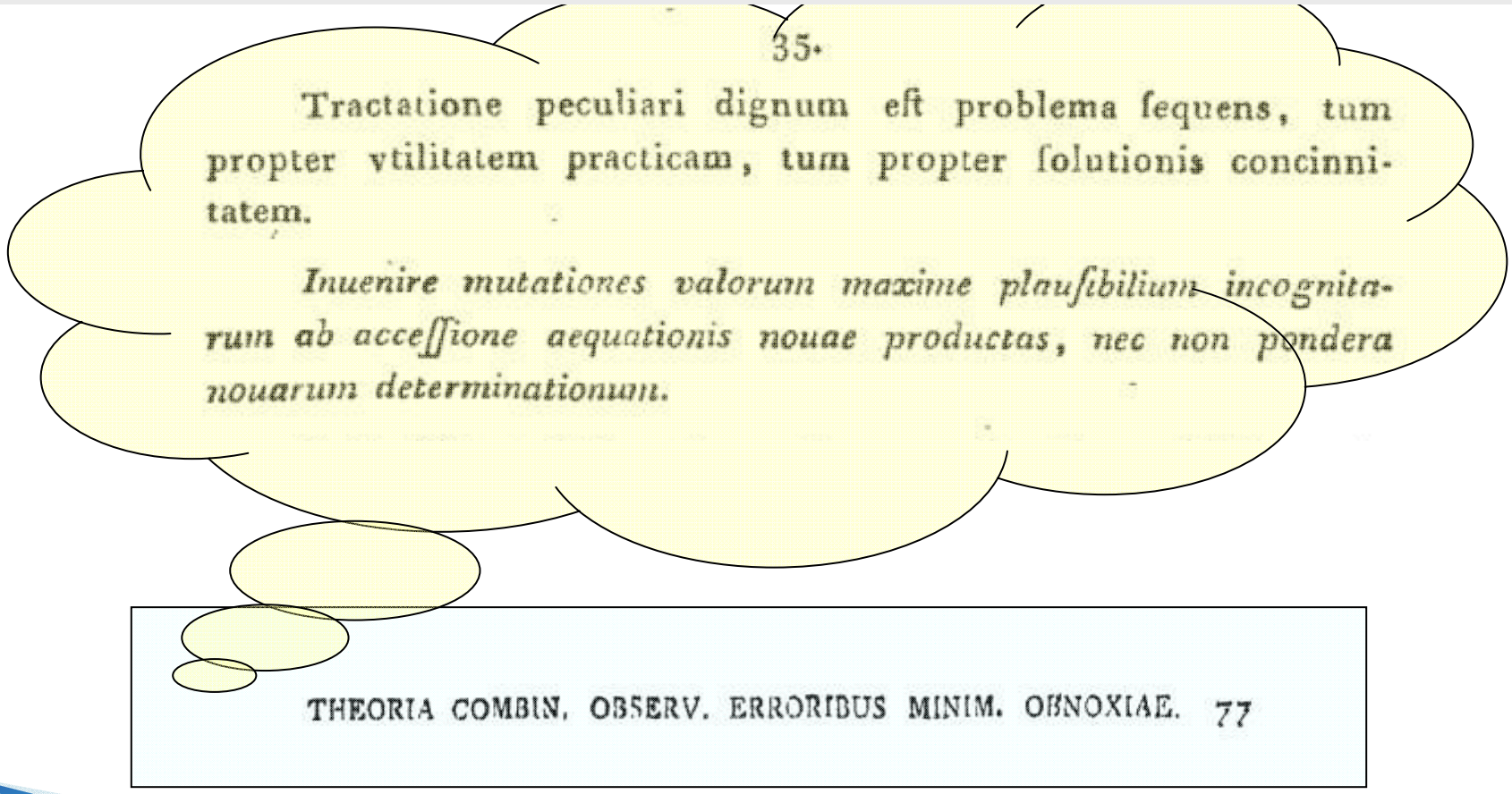


NIMTech basic ideas

Gauss' idea of recursive estimation: to update estimates with current data, re-processing all previous ones isn't needed



35.

Tractatione peculiari dignum eſt problema ſequens, tum propter vtilitatem practicam, tum propter ſolutionis concinnitatem.

Inuenire mutationes valorum maxime plauſibilium incognitarum ab acceſſione aequationis nouae productas, nec non pondera nouarum determinationum.

THEORIA COMBIN. OBSERV. ERRORIBUS MINIM. OBNOXIAE. 77

Software for On-Line Support to Industrial Metrology

Following these introductive notes, the presentation is organised in three parts:

1. Simultaneous estimation of measurand and related uncertainty. Metrological customization of a Kalman filter technique is shown to perform Bayesian integration of expert's pre-process knowledge and in-process measurement results.

2. Reference data to implement the ISO 10360-6 test on SW to evaluate geometrical features associated to point coordinates.

3. To conclude: final remarks and future perspectives.

Simultaneous estimation of measurand and related uncertainty

System rational:

- ***Strategy: Bayesian transformation of prior relative ignorance into posterior estimates of measurand and associated uncertainty;***
- ***Technique: Kalman filtering algorithm and GUM law of uncertainty (type A & type B) composition;***
- ***Scope: in-process dimensional metrology.***

Bayesian inference

$$p(z|x) = \frac{p(z)p(x|z)}{p(x)}$$

z, measurand value; x, measurement

$p(x|z)$ probability of x given z (the likelihood): for type-A uncertainty processing;

$p(z)$ prior probability of z and $p(x)$ prior probability of x (a normalizing factor): for type-B uncertainty processing

$p(z|x)$ posterior probability of z given x: to combine type-A⊕type-B.

Recursive estimation (kernel of Kalman filter)

All involved pdf's are supposed Gaussians $G(mean, variance)$.

The estimate of the measurand z is thus the mean=mode (=median) of the posterior. So, it is optimal according to criteria of Least Square and Maximum Likelihood.

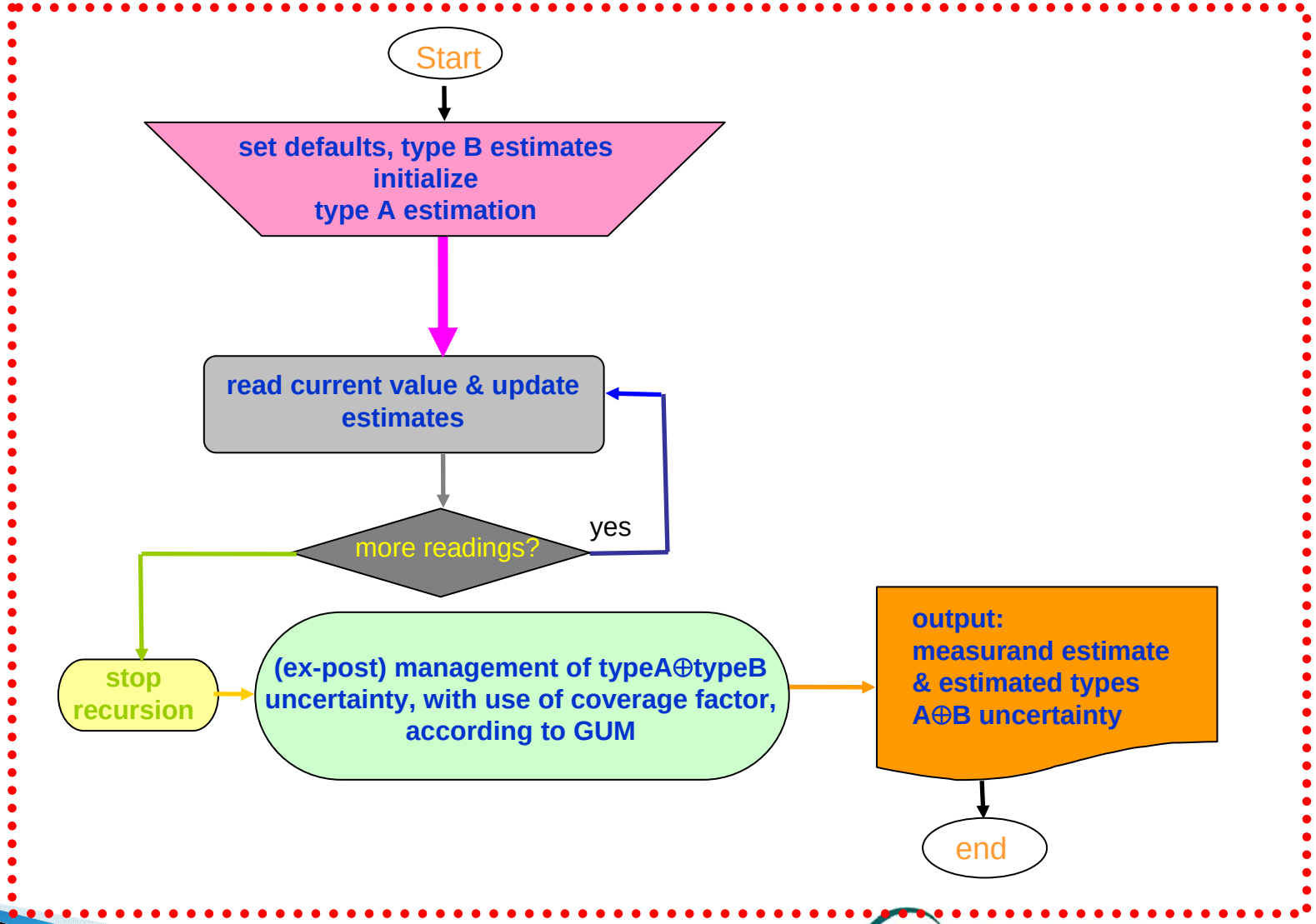
If: $p(z)=G(mean_0,var_0)$ and $p(x|z)=G(mean_1,var_1)$

then: $p(z|x)=G(mean_2,var_2)$ with

$$mean_2 = (x_0 var_1 + x_1 var_0)/(var_1 + var_0)$$

$$1/var_2 = (1/var_0)+(1/var_1)$$

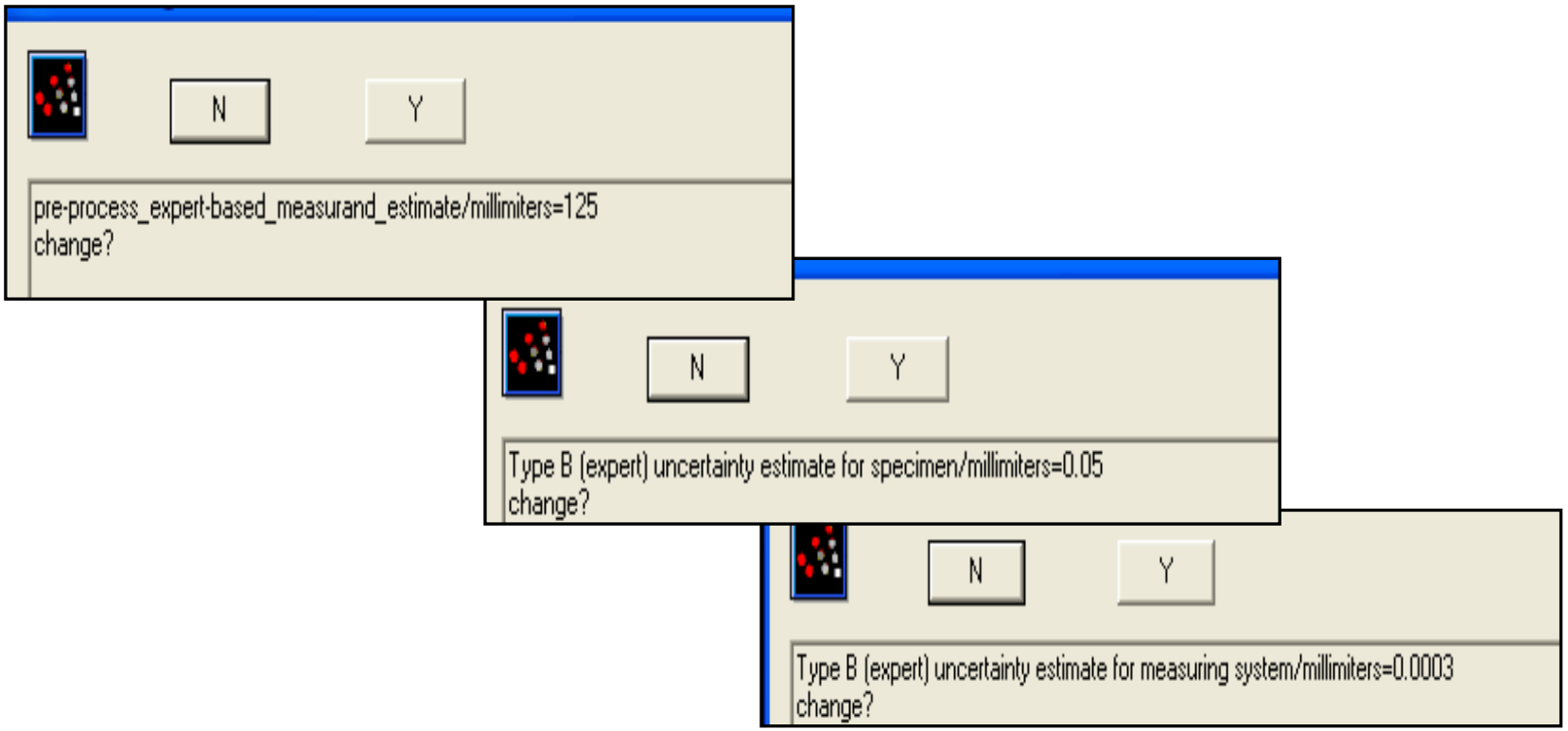
STRATEGY Flow chart



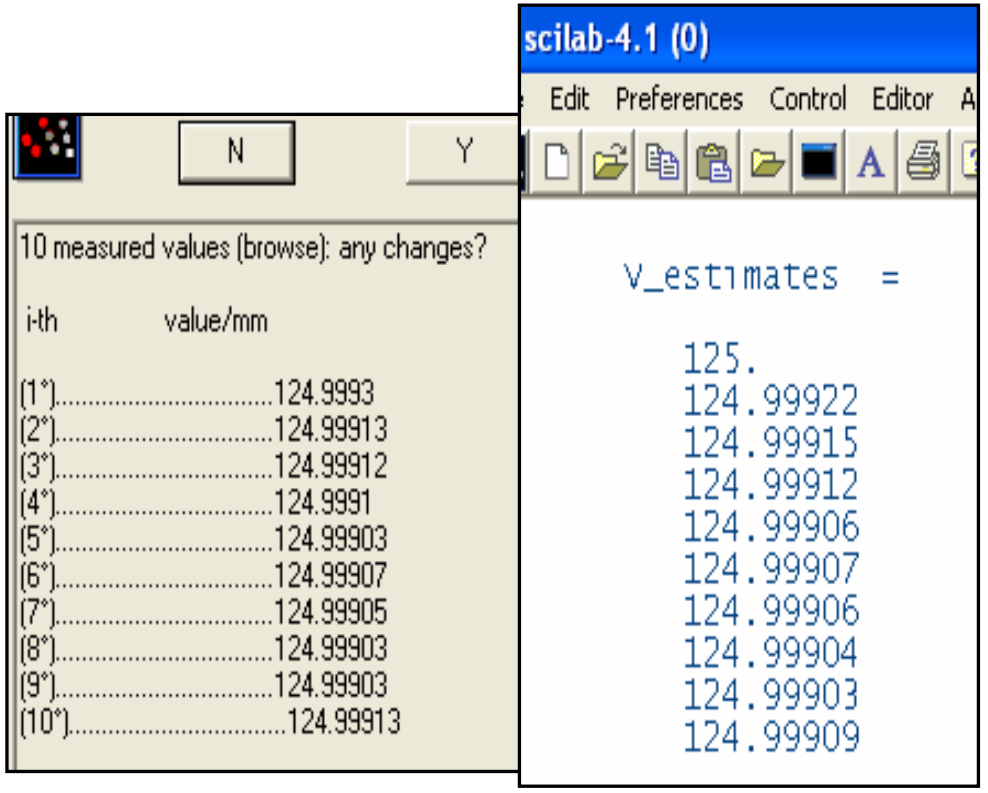
Simulation and lab implementation

- The procedure has been first coded in the Scilab© open source software environment.
- This phase was aimed at debugging the estimation strategy and testing its performance in off-line simulations.
- After optimization, the underlying kernel logic has been re-written in the proper language as a routine embedded in a part program for run-time execution on a Leitz PMM-12107 Precision Measuring Machine working under the Quindos-7™ operating system: an example follows

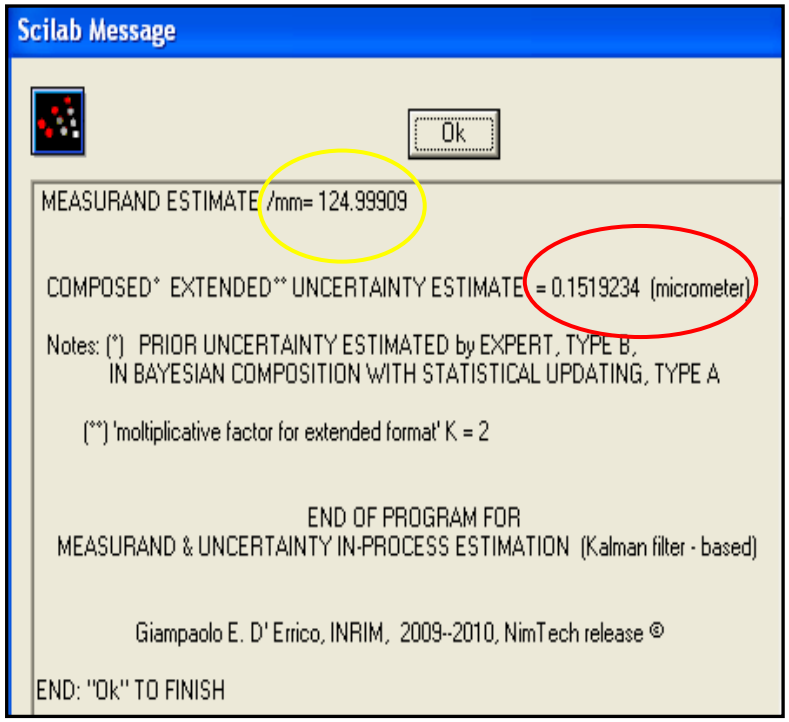
Start of Program: initialization



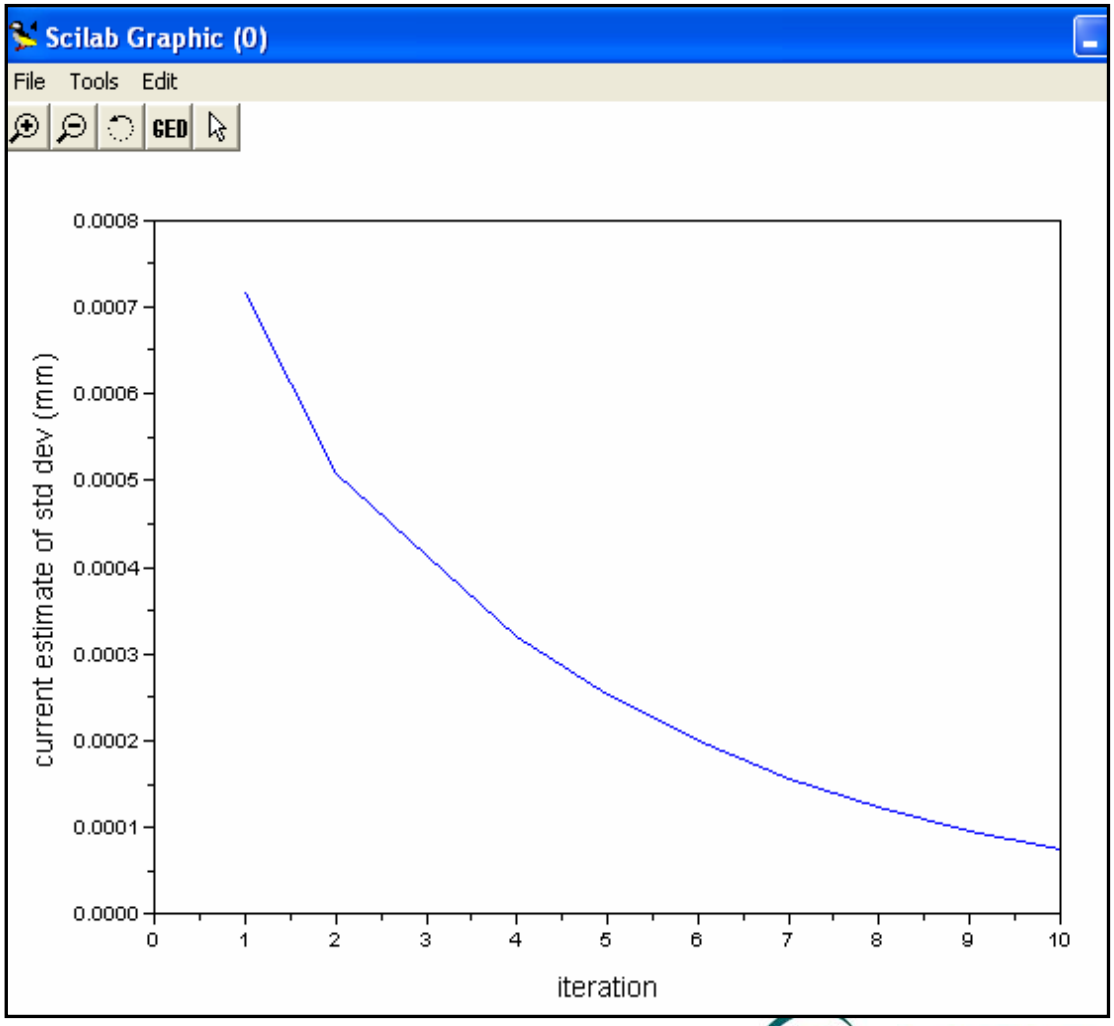
Recursion


N
Y
10 measured values (browse): any changes?
i-th value/mm
(1°).....124.9993
(2°).....124.99913
(3°).....124.99912
(4°).....124.9991
(5°).....124.99903
(6°).....124.99907
(7°).....124.99905
(8°).....124.99903
(9°).....124.99903
(10°).....124.99913
scilab-4.1 (0)
Edit Preferences Control Editor A
V_estimates =
125.
124.99922
124.99915
124.99912
124.99906
124.99907
124.99906
124.99904
124.99903
124.99909

End of Program: output



Convergence performance



Validation of SW according to ISO 10360-6

- The ISO 10360-6 aims at providing standardized tests of the performance of SW for evaluating features associated to point coordinates.
- This standard requires a testing body to provide reference pairs, consisting of reference data and reference parameter values.
- The testing body is a third-party organization; the reference data are sets of point coordinates; the reference parameter values (e.g. centre coordinates and radius of a sphere) are the numerical representation of geometrical features.

Validation of SW according to ISO 10360-6

- The test is black-box, based on comparing the results of the SW under test when input with reference data, with the corresponding reference parameter values.

- The test outcome is a set of standardized numerical figures of the detected discrepancy.

- A task in the NIMTech project was to implement the ISO 10360-6, and specifically to generate reference pairs for the main features (2D and 3D line, plane, 2D and 3D circle, sphere, cylinder, cone, torus).

How to implement data generators

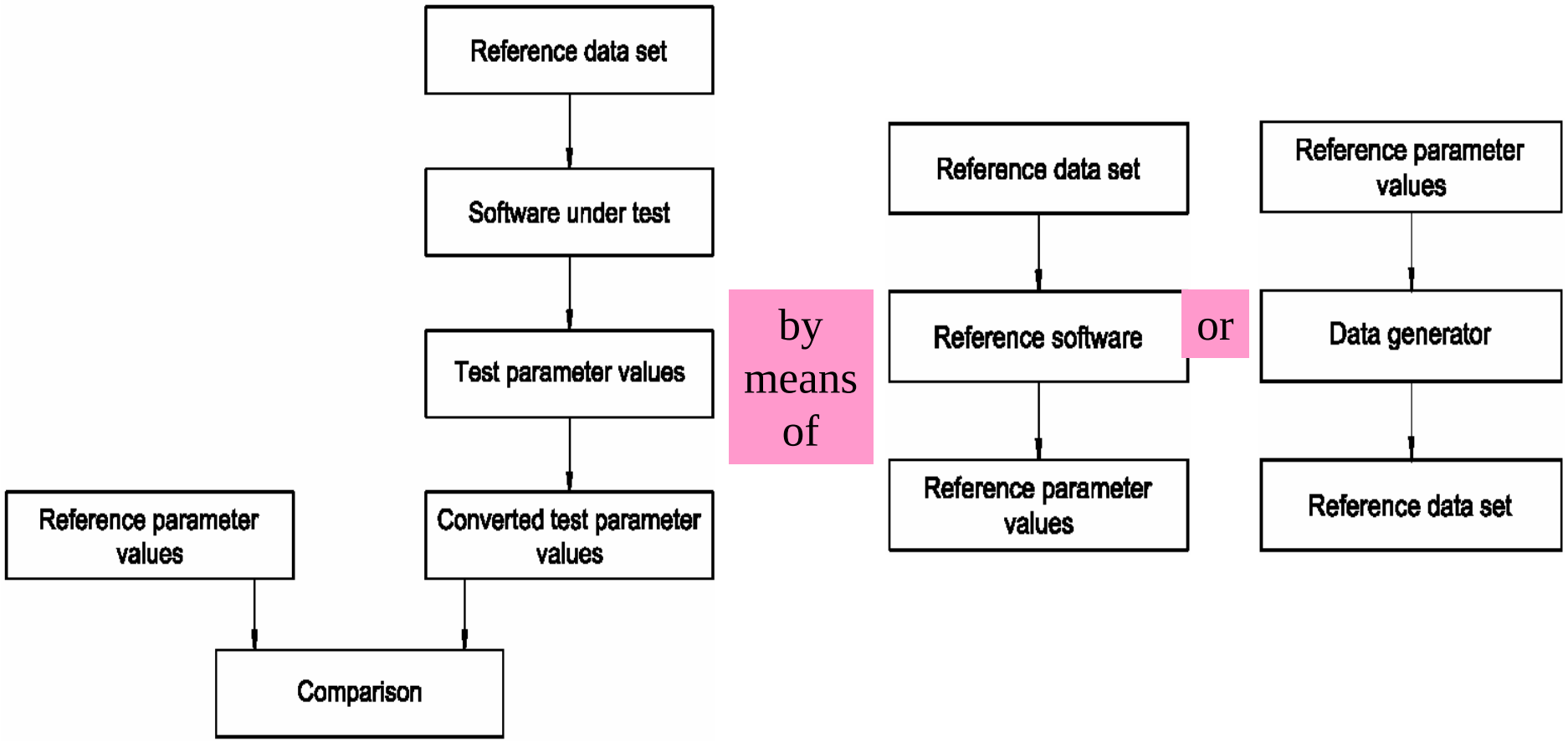
- The EN ISO 10360-6 describes a procedure to generate data which is unfit for data generators
- Data generators are based on the null space method (NPL)
- Therefore, the data are generated according to the 10360-6 rules, and then projected onto the null space, to find the “closest” reference data set as it would be made by a data generator

Null space method (introduced by project partner NPL)

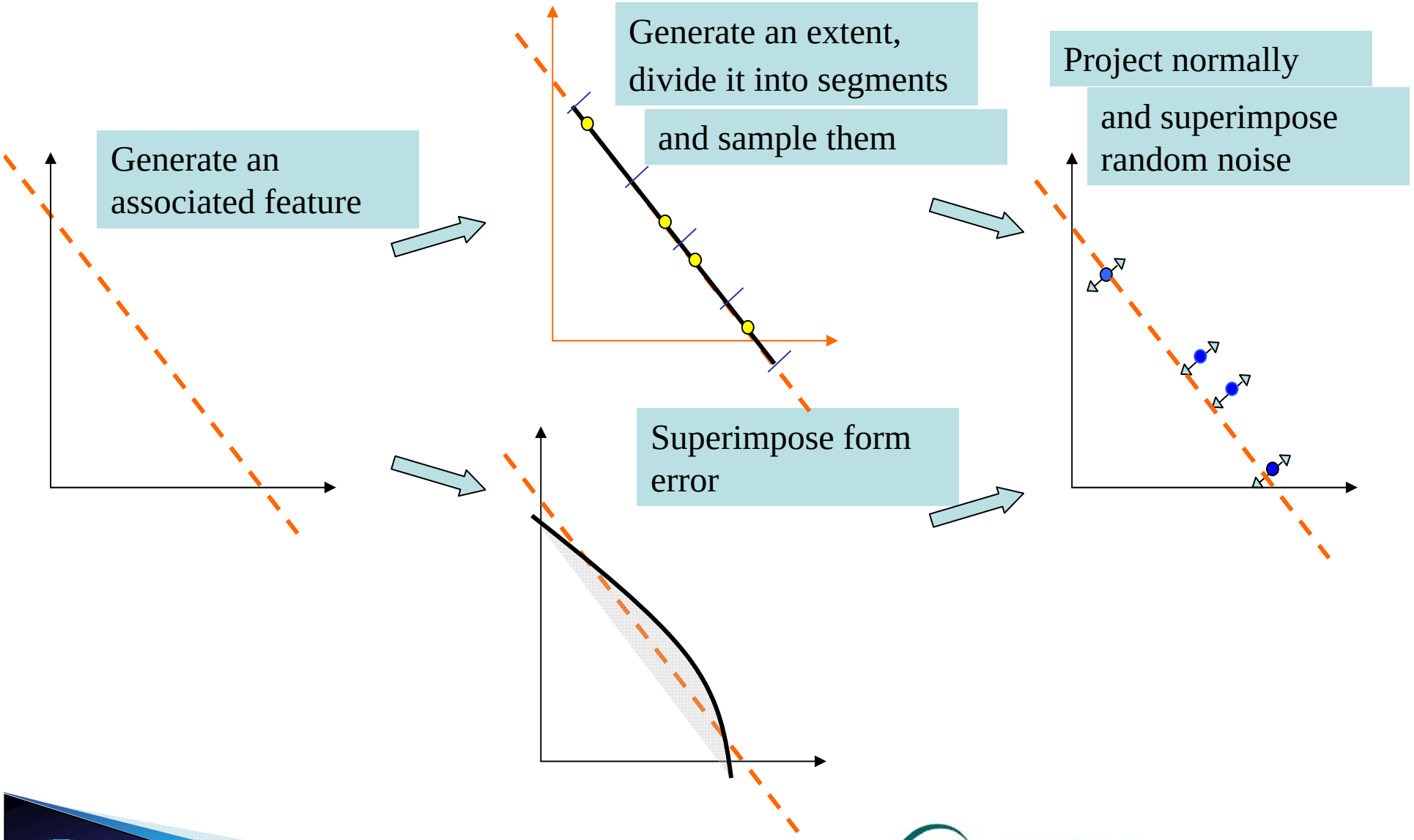
- The data generation has been based on the null space method, introduced by the project partner NPL in the 90's. It consists in reversing the data flow of the software under test.

- This latter takes point coordinates as input and yields parameter values of an associated feature; the data generator generates an associated feature – as expressed by parameter values – and derives point coordinates.

Principle


Reference data set
Software under test
Test parameter values
Converted test parameter values
Reference parameter values
Comparison
by means of
Reference data set
Reference software
Reference parameter values
or
Reference parameter values
Data generator
Reference data set

A simple example: the 2D line



CONCLUSIONS

A CMM case-study was considered in the framework of real-time estimation. Simulation and laboratory results have been obtained with promising applicability to dimensional metrology.

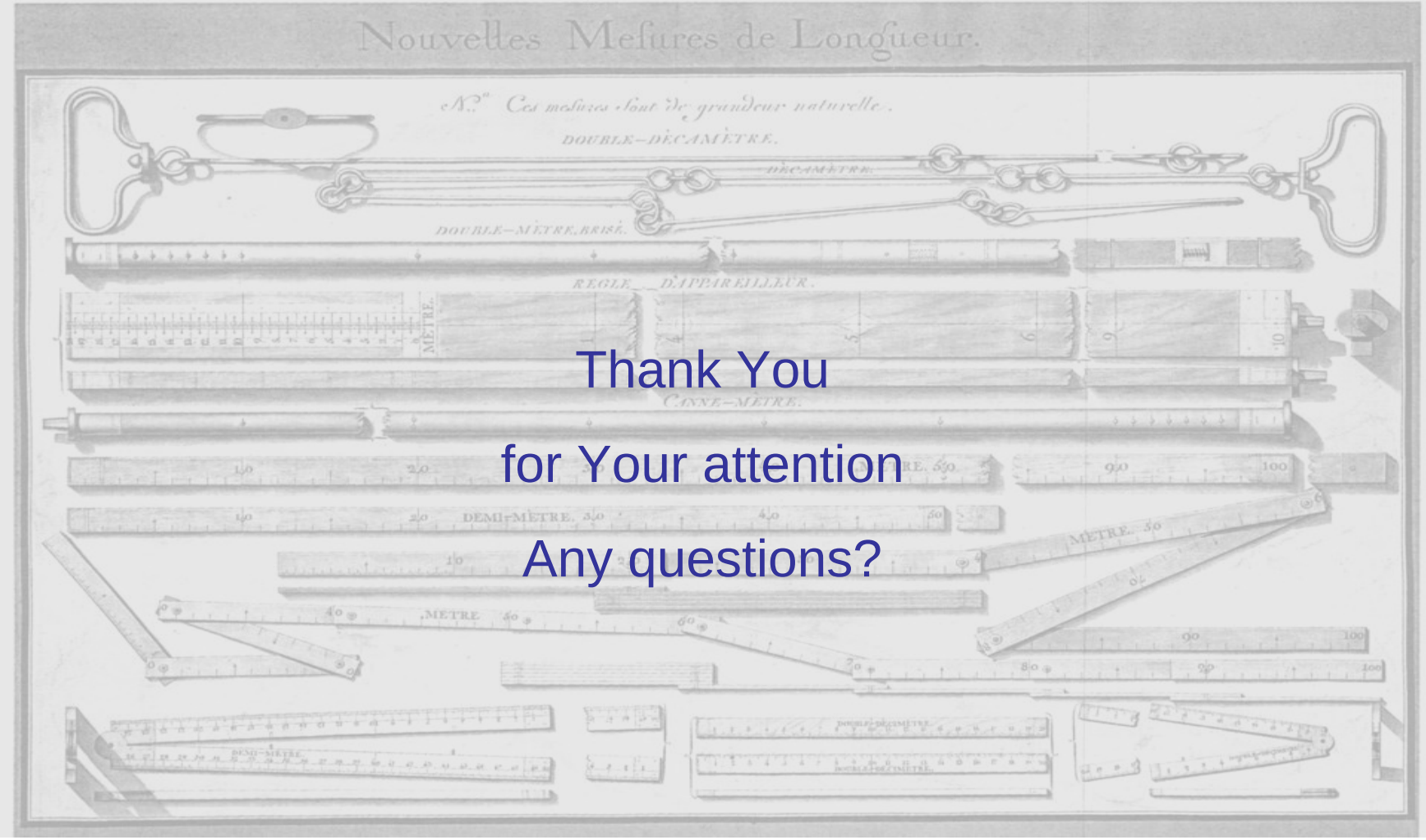
A cross-disciplinary approach to monitoring and control systems engineering (on one hand), and to measurement science and practice (on the other hand), helps integrating computational intelligence within industrial metrology.

Future perspectives may be envisaged in the direction of possible outliers treatment with improved computational intelligence for automatic decision making in the presence of uncertainty.

CONCLUSIONS (contd.)

SW programs evaluating geometrical features associated to point coordinates are more and more required to be third-party evaluated. An ISO standard exists which defines a *super partes* test procedure.

Given the underlying infrastructure for implementing a web-based platform is developed, a remote testing service can be envisaged.



Thank You

for Your attention

Any questions?

New Industrial Measurement Technologies

"Perhaps all the morality of mankind has its origin in the tremendous inner excitement which seized on primeval men when they discovered measure and measuring, scales and weighing (the word *Mensch*, indeed, means the measurer, he desired to name himself after his greatest discovery)."

[Friedrich Nietzsche (1878),
Human, All Too Human:
aphorism No. 21].