Digital twin of robotic 3D scanning system: providing metrological traceability

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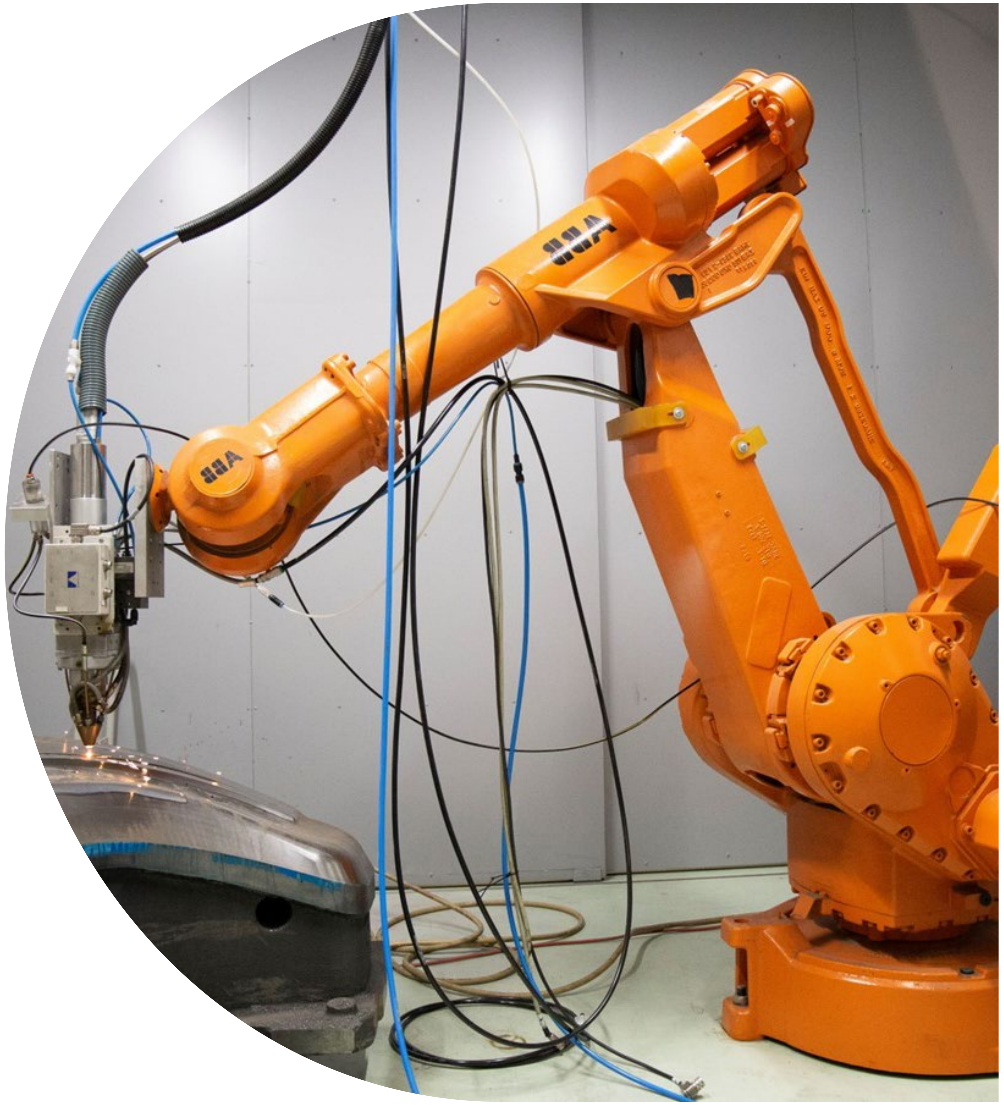
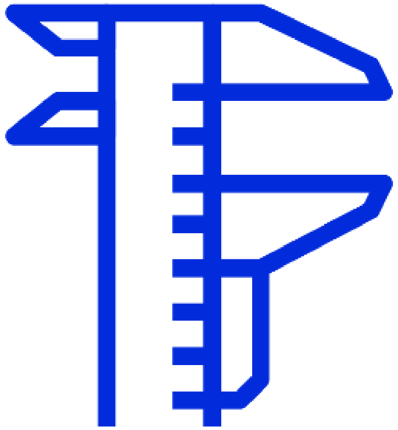
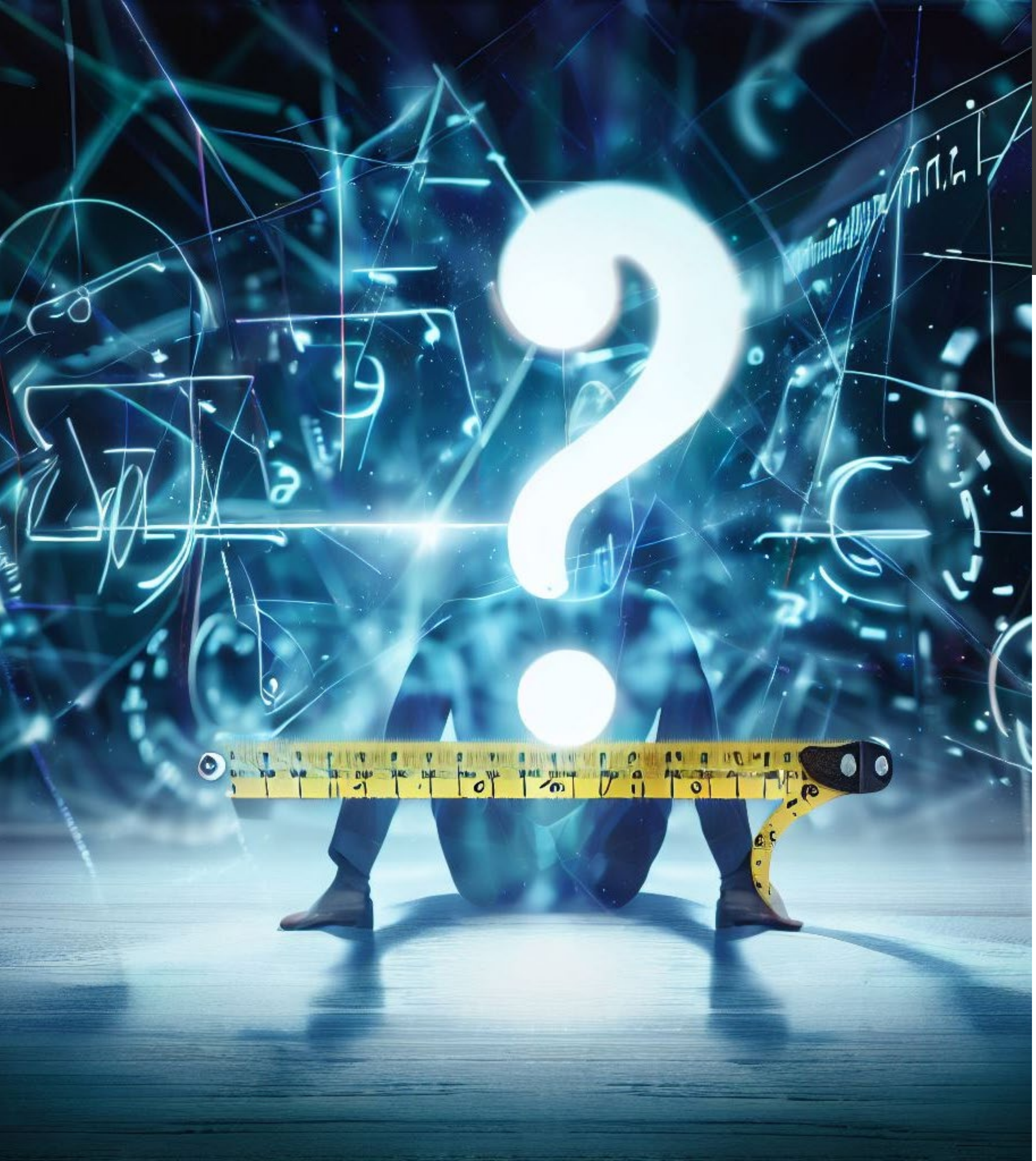
OUTLINES

- FRAMEWORK
- USE CASE
- DEVELOPMENT OF THE TRAZBLE DIGITAL TWIN
- FUTURE WORKS





FRAMEWORK

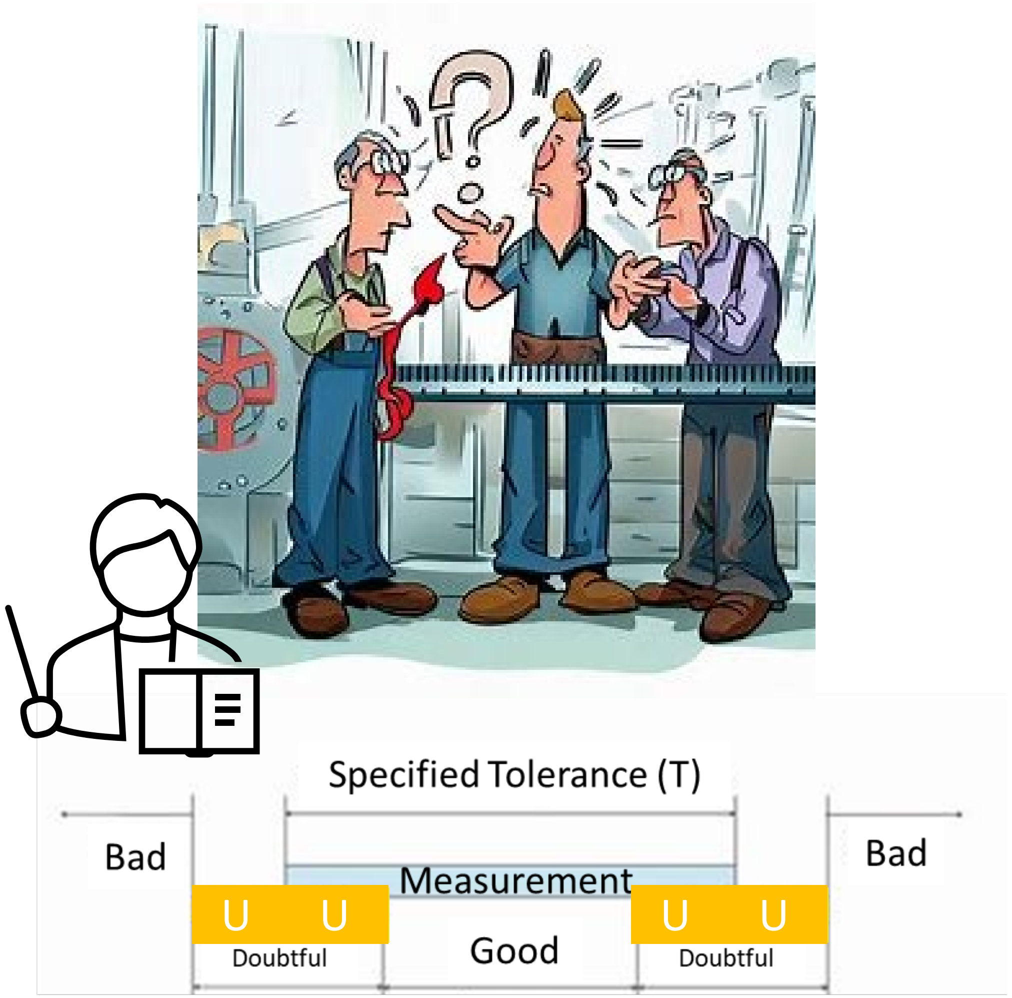


FRAMEWORK

A BRIEF REMINDER:

> “All measurements are subject to uncertainty and a measurement result is complete only when it is accompanied by a statement of the associated uncertainty.”*

* **JCGM 100:2008** GUM 1995



$$3 \leq \frac{T}{2U} \leq 10 \; ^{*}$$

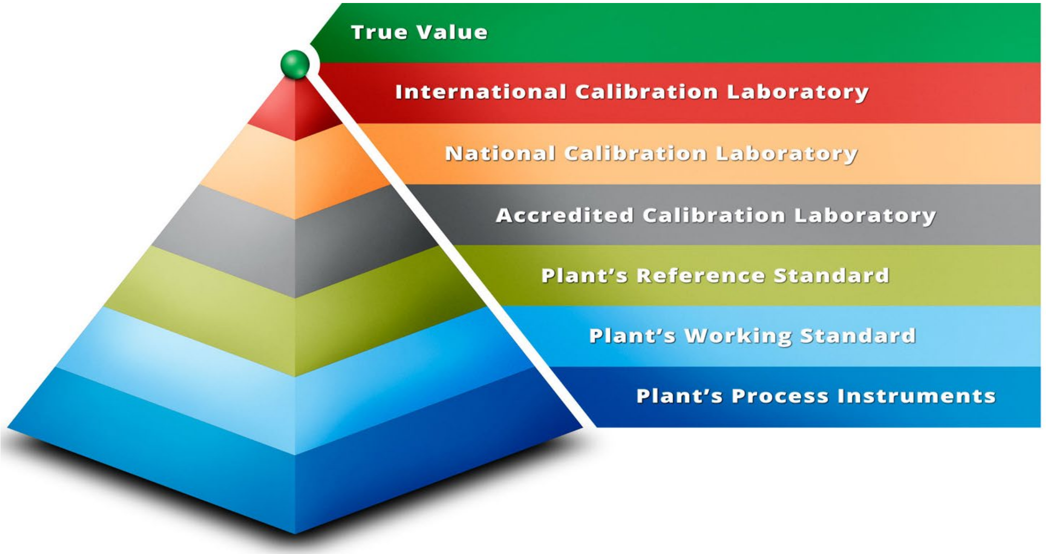
***UNE 66180 recommendation**

FRAMEWORK

DIMENSIONAL METROLOGY IN THE INDUSTRY:

- The core of quality inspection.
- Ensuring tolerances are met.
- Minimizing waste in the manufacturing.
- Improving productivity.
- Providing reliable data for the IA models.

Metrology is a powerful vector to stay competitive in a globalized market.



FRAMEWORK

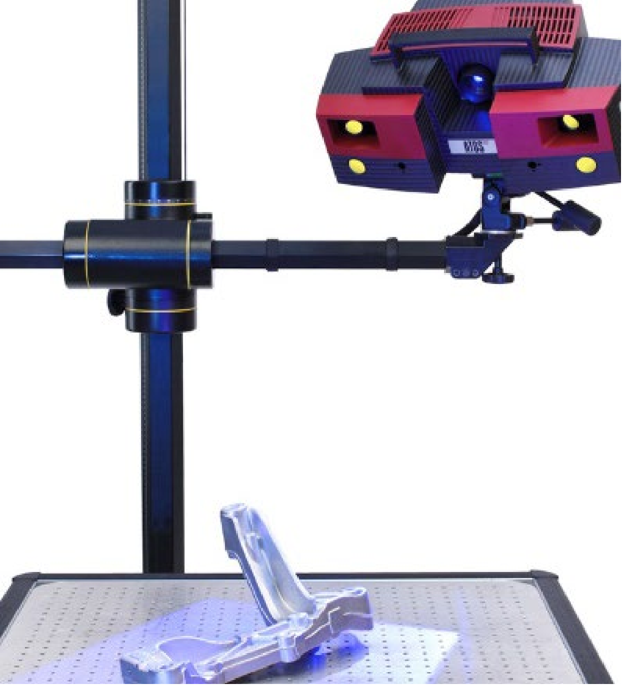
HOW DO WE EVALUATE THE MEASUREMENT UNCERTAINTY?

- Performing the instrument calibration.
- Comparing and correcting of the measurements of the instrument with a standard reference.
- Assuring the traceability chain of the standard reference. Provided by the traceability pyramid from the plant process to the international true value.
- Documented and registered procedure.

FRAMEWORK

HISTORIC IMPLEMENTATION

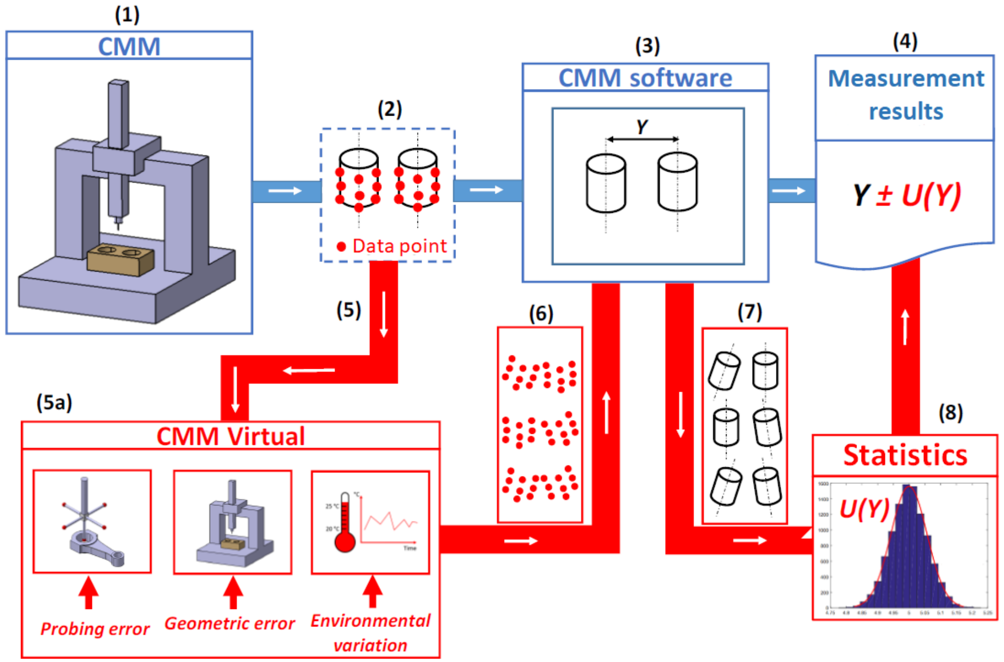
- Calibration in the laboratory.
- Using traditional instruments (Contact technology-based) :
  - Micrometers
  - Calipers
  - CMM
  - ….
- Guided by well-established procedures and normative.
- Inspection process in the laboratory.
- Instrument calibration procedure similar to real use. Intended for non-complex parts.



FRAMEWORK

METROLOGY EVOLUTION.

- Wide range of measuring instruments.
- Non-contact measuring systems:
  - Laser Tracker.
  - Laser triangulators .
  - Fringe projection.
  - Close range photogrammetry.
- Inspection process in the workshop.
- Measurement uncertainty is highly influenced by the part characteristics. Having more complex parts with free forms, and different surfaces finishings.
- The calibration measurements of the instrument are not the same as the actual use case.
- The measurement uncertainty is often not representative of the actual measurement error.



Wahyudin Syam. CMM measurement uncertainty estimation: ISO 15530-4. Wasy Research

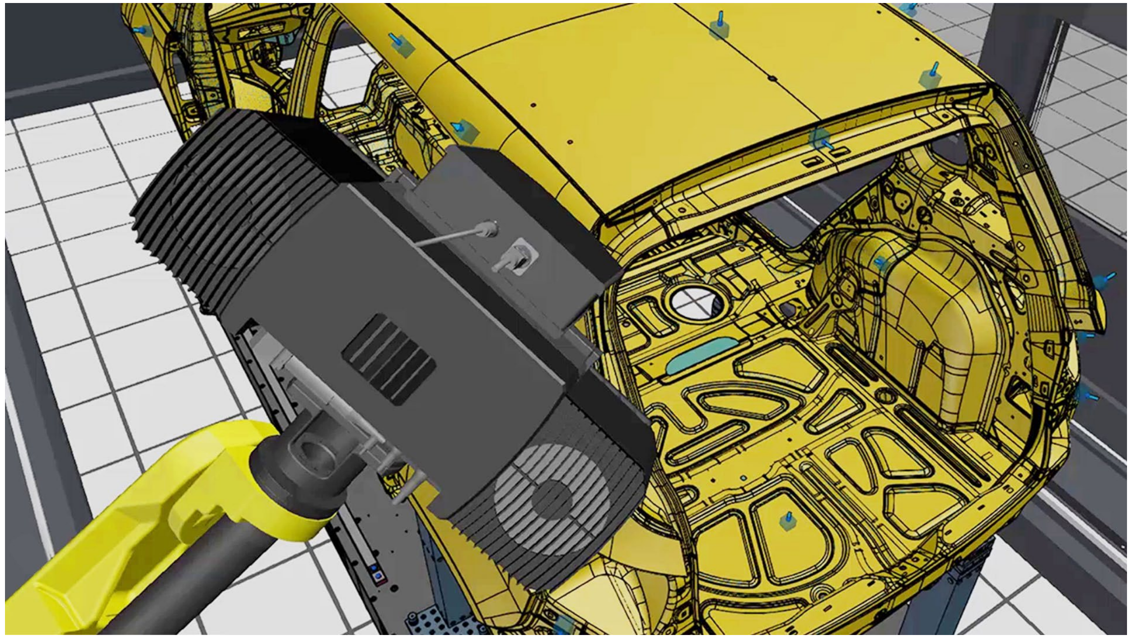
FRAMEWORK

METROLOGY EVOLUTION.

- Digitalization of equipment, processes and components.
  - Virtual Product: Development of simulation models for an optimized design of products and applicability to their entire life cycle.
    - MBD
    - QIF
    - PMI
  - Virtual Manufacturing: Development of simulation models of manufacturing processes, production means and complex systems
  - Smart Product: **Monitoring and control** of manufacturing processes for the acquisition of knowledge and for its prediction and optimization .

VIRTUAL METROLOGY:

- Virtual CMM:
  - More representative uncertainty for the measurements.
  - Determining the optimal measurement strategy.
  - Maximize the measurement accuracy.



FRAMEWORK

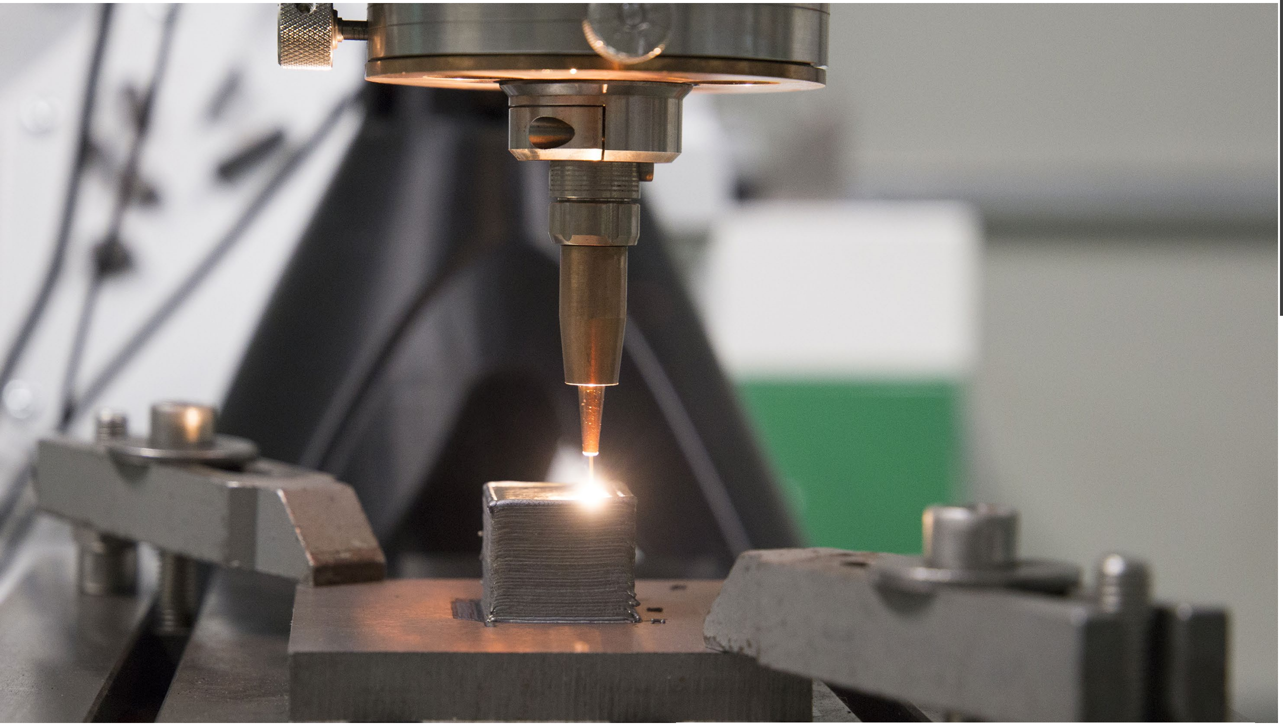
ROBOTIC MEASURING SYSTEMS IN THE INDUSTRY

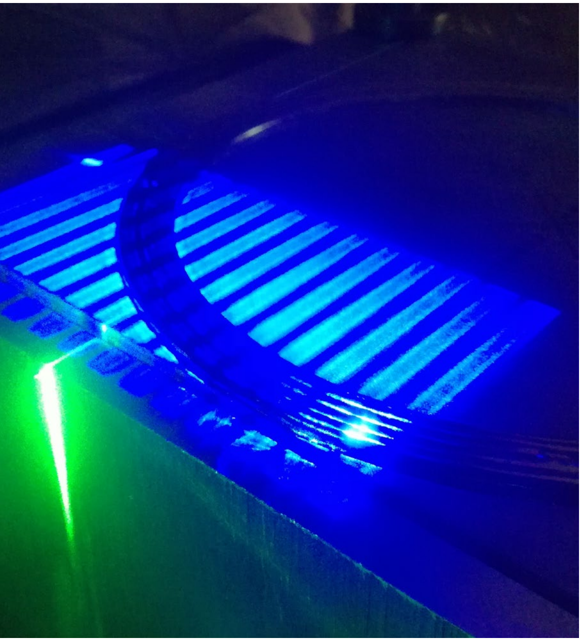
- Integrating different measuring instruments.
- Using the robot just as positioner. Needing markers or external instruments for the complete reconstruction of the scan. Element redundancy
- Inspection out of the manufacturing process (Quality control). Alternative to CMM.
- Measurement uncertainty based on the sensor calibration (MPe). Not considering the measuring procedure.
- Virtual tools only to plan the scanning path, ensuring complete measurement of the work piece. Uncertainty assessment for the measurement procedure is not included.
- The virtual tools do not evaluate the system metrological performance.

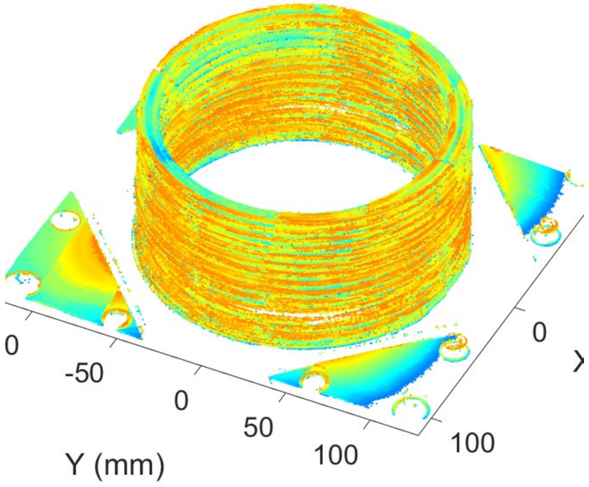
USE CASE

USE CASE

- 3D robotic measurements integrating a structured light sensor.
- Application: Additive Manufacturing

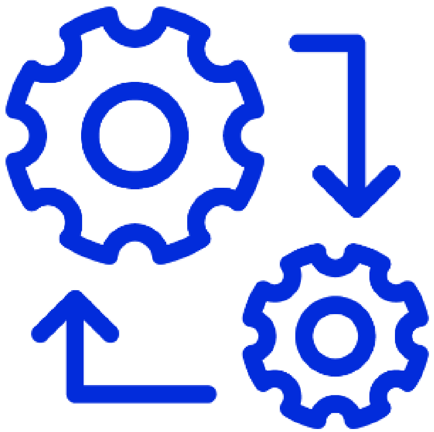




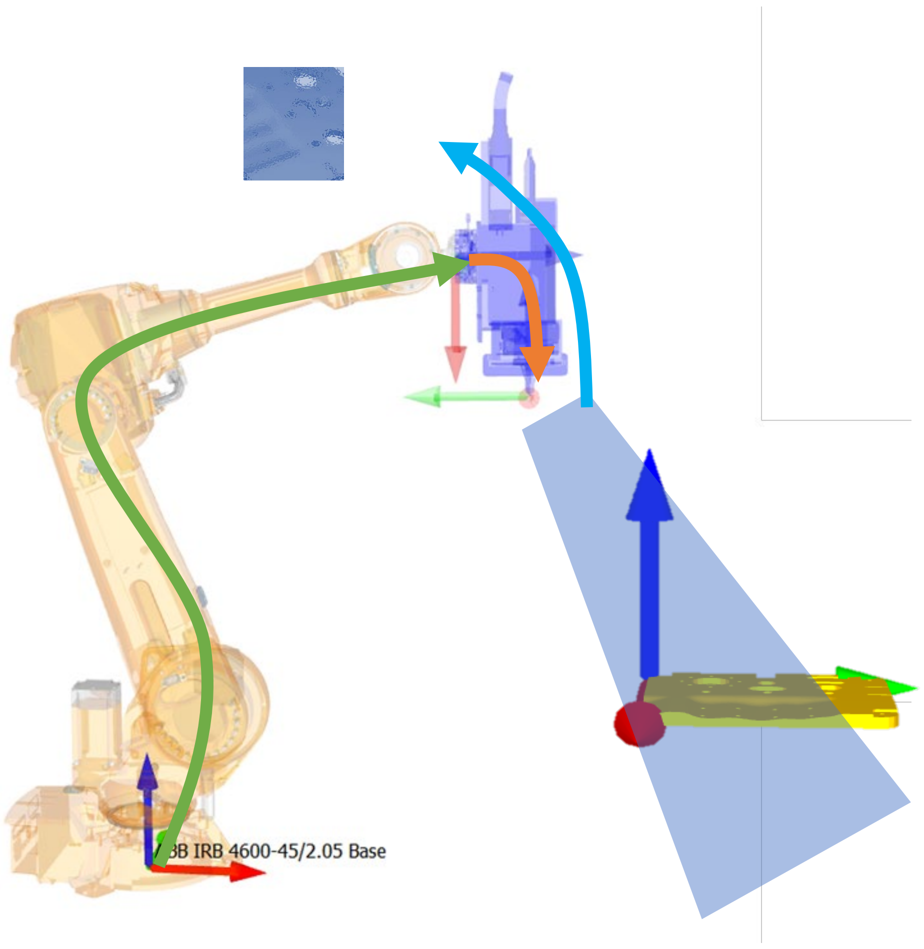


USE CASE

- Additive Manufacturing process :
  - Using thermal energy to fuse materials to create three dimensional objects by depositing materials.
- Measuring requirements:
  - In process requirements for monitoring part distortion, and part growth.
  - Evaluating the machining overthickens, by comparing the final work piece with CAD.
- Benefits of uncertainty evaluation:
  - Assure manufacturing tolerances.
  - Optimizing manufacturing process.
  - Improving **decision-making.**



TRACEABLE DIGITAL TWIN



DEVELOPMENT OF THE DT

ELEMENTS OF MEASUREMENT CHAIN

1. Robot Position: the position of the robot is used for the reconstruction of the measurements.

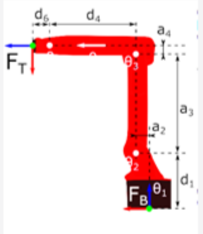
2. Referencing of sensor to robot : the relative transformation from the robot flange to the sensor coordinate system.

3. Sensor acquisition: 3D points measured points in sensor coordinate system.

These are the main sources of uncertainty in the measurement chain.

DEVELOPMENT OF THE DT

ROBOT MODEL



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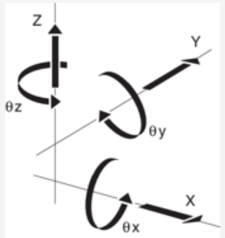
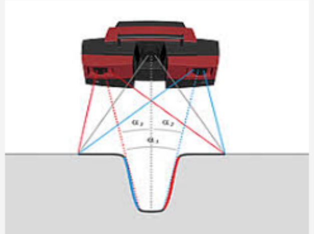


SENSOR MODEL



MEASUREMENT CHAIN

- Kinematic chain for the robot position (Forward kinematic)
- Model defined by the Denavit-Hartenberg **parameters.**

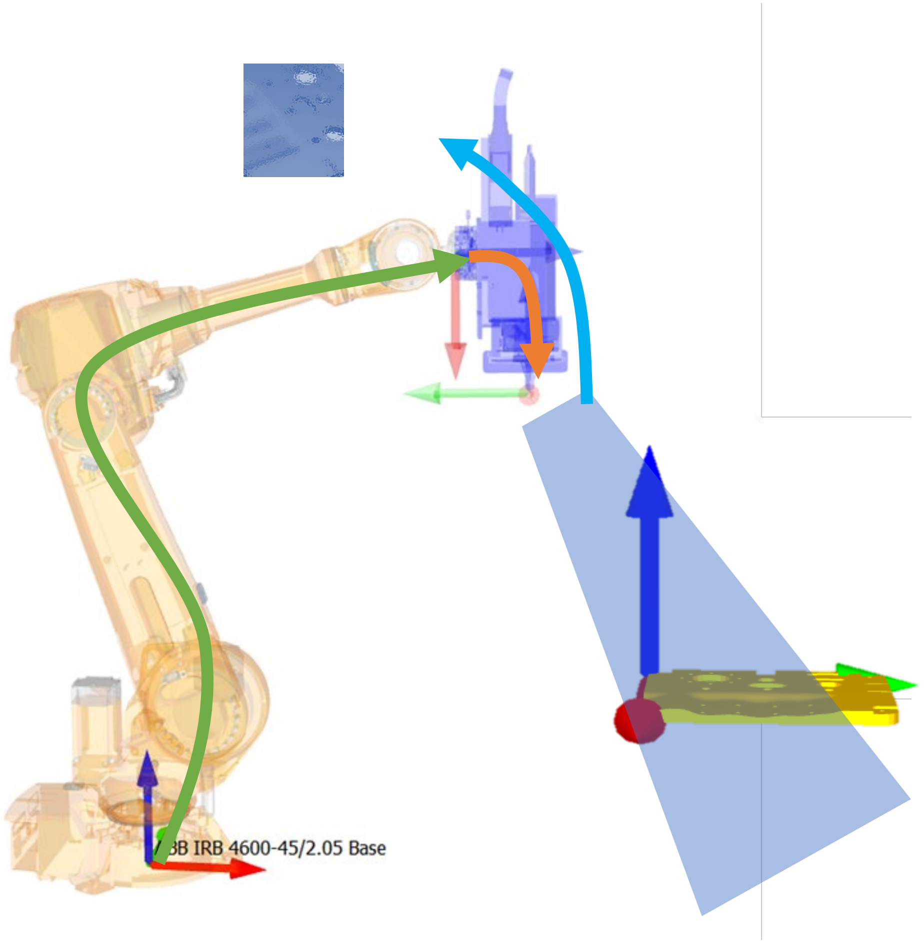
- 6 DoF transformation between coordinate systems.
- Model defined by 3 distance **parameters** and 3 orientation **parameters**

- Stereophotogrammetric model.
- Triangulation technique.
- Model defined by extrinsic and intrinsic **parameters**.

DT PARAMETRIZATION

- The parameters define the model of the DT.
- Applying this parameters in the mathematical model the measurement procedure can be replicated .

DEVELOPMENT OF THE DT



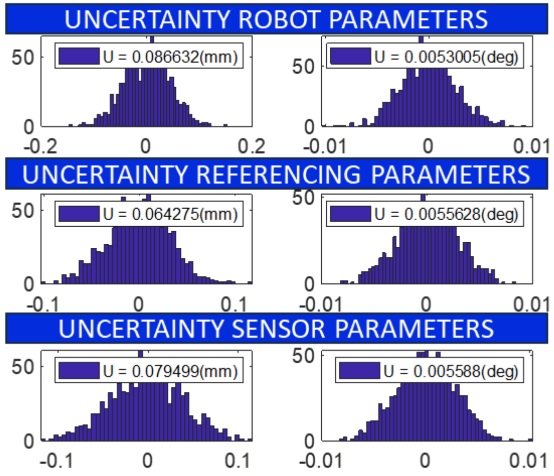
EVALUATION OF THE UNCERTAINTY

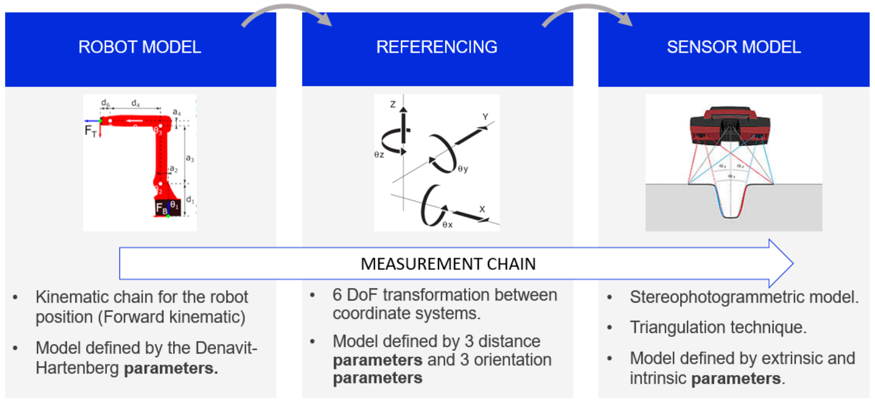
- TYPE A :
  - Based in statistic methods.
  - Measured with a series of repetitions.
  - Needs calibrated artifacts for each different measured part.

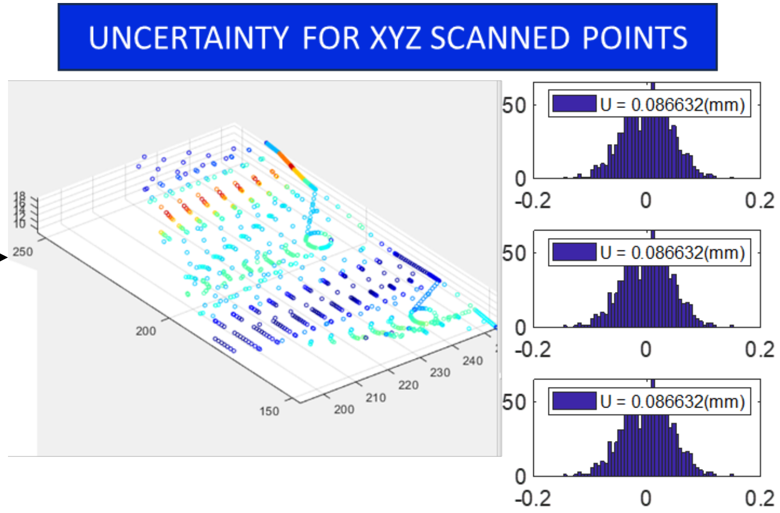
Validating

- **TYPE B:**
  - **Using indirect methods.**
  - **No needs for repetitions.**
  - **Using mathematical models.**
  - **Includes influence parameters**
  - **Consider the measurement procedure**
  - **MONTE CARLO methods**

DEVELOPMENT OF THE DT

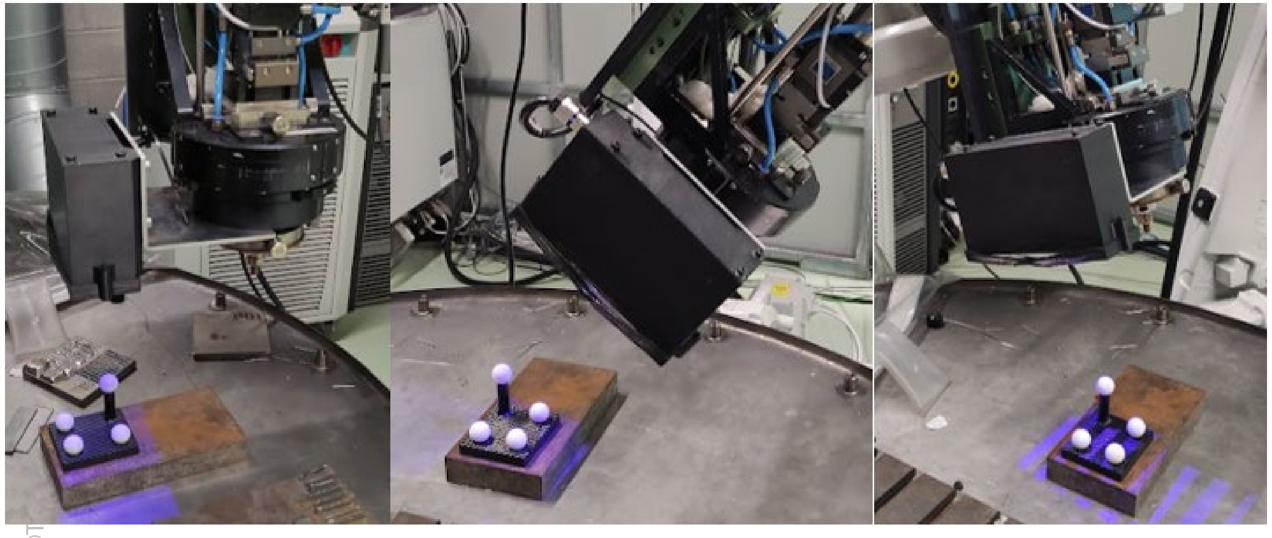






EVALUATION OF THE MEASUREMENT UNCERTAINTY

- Procedure to calibrate the digital twin parameters and estimate the uncertainty (type B Monte Carlo Approach).
- Using the calibrated parameters and its uncertainty to evaluate the uncertainty for the measurements (type B Monte Carlo Approach).
- Uncertainty assessment based on point clouds.

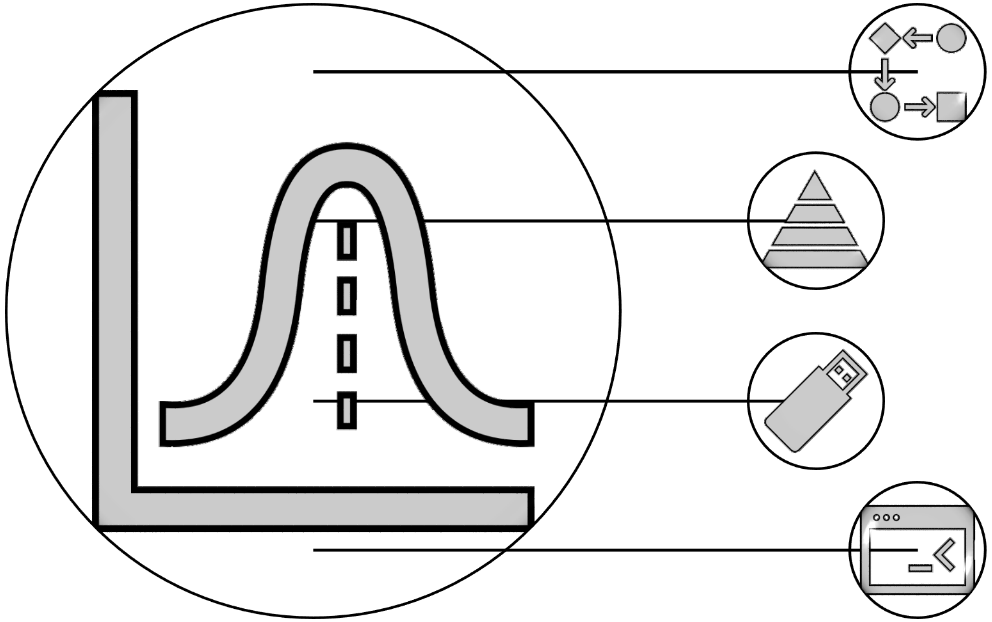


CALIBRATING THE DT

- Robot and referencing parameters (self-calibration).
  - In process calibration.
  - Using calibrated artifact.
  - Scanning in different positions.
  - Automatic and integrated process.
  - Optimized algorithms, based on sensitivity and correlation analysis.

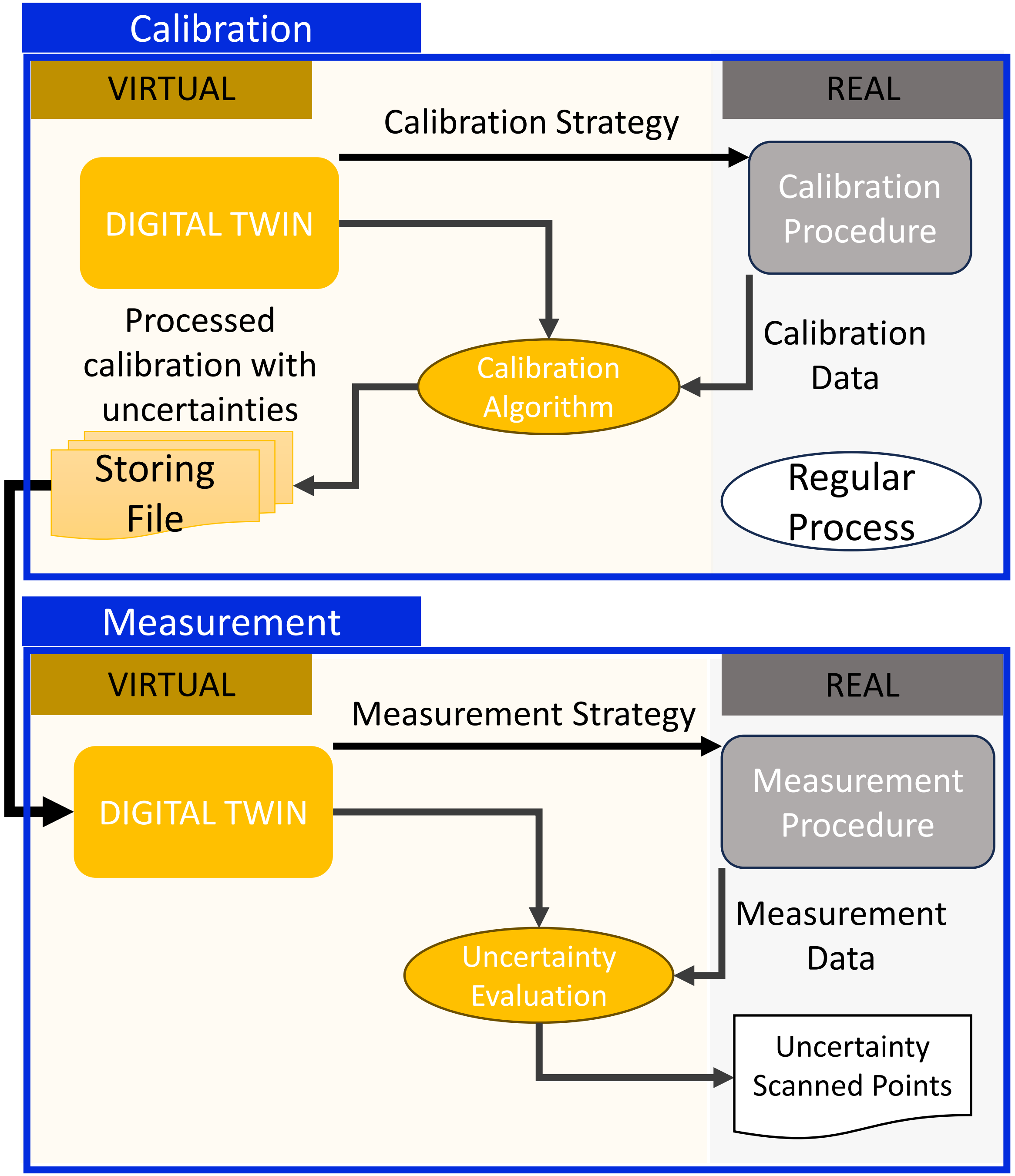
- Sensor parameters:
  - Offline calibration.
  - Using special artifact for vision system.

Periodic updating of the calibrated parameters.



TRACEABILITY OF THE DT

- Establishing the calibration procedure.
- Using traceable calibrated artifact (by the CMM).
- Store and transmit the DT model.
  - Using open standard file (json).
  - Including all the calibrated parameters and their uncertainties.
  - Including used data for the calibration (date info, measurements, operator, procedure…).
- GUI program to estimate the measurement uncertainty applying the DT.
  - Inputs: Calibration file, measurement data.
  - Outputs: Uncertainty for the scanned points.

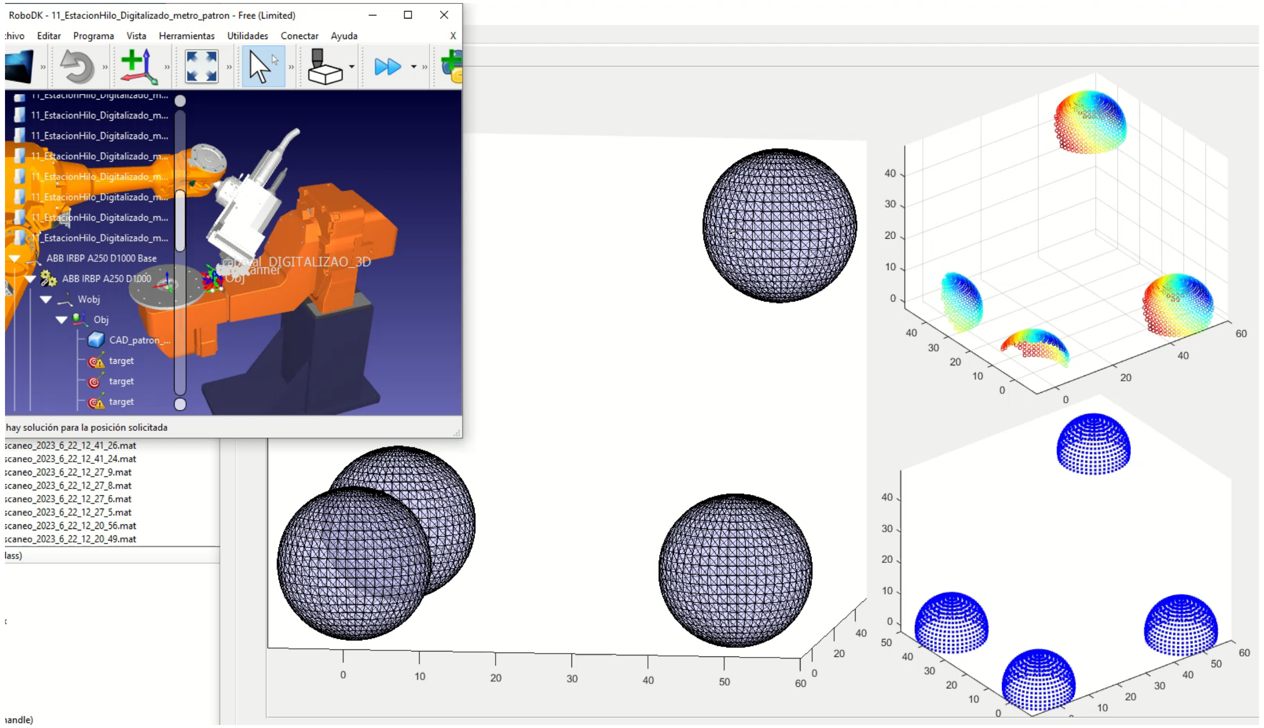


TRACEABILITY OF THE DT

HOW IT WORKS?

- Communication between virtual and real world.
- Updating the DT parameter, performing regular calibrations.
- Estimation of the measurement uncertainty using the calibrated parameters.
- Implementing optimized strategies.
- Decision making.

IMPLEMENTATION OF THE DT



VIRTUAL ENVIROMENT FOR THE 3D ROBTIC MEASUREMENTS.

- TOOLS:
  - MATLAB.
    - Implementing the DT model for the scanning process.
    - Implementing the algorithms for calibration and uncertainty evaluation.
  - Robo DK
    - Virtual representation of the DT.
    - Reproduce the robot's operation in the scanning process.
- FEATURES:
  - Defining the best measurements strategies.
  - Assuring complete measurement of the scanned part.
  - Evaluation of different measurement configurations.
  - Communication with the real system.
- BENEFITS:
  - Minimizing the uncertainty of the measured points, choosing the most suitable strategy.
  - Assuring measurement uncertainties below specified tolerances.
  - Improving system accuracy by applying the calibrated parameters of the robot.
  - Reliable and trustworthily DT for decision making

FUTURE WORKS

FUTURE WORKS

- Validate and verify the uncertainty estimation of the DT with complex geometry calibrated artefact. Comparing with evaluation uncertainty by statistical analysis type A.
- Improving the DT by introducing different factors related to the work piece (reflectiveness, material, shape…).
- Applying surrogate models for agile DT. (Good-Enough)
- Testing the development in aeronautical industrial use case (Aernnova as stakeholder).

FINAL REMINDERS

- DEMO OF THIS DEVELOPMENT IN THE EXHIBITION AREA.

- ACKNOWLEDGMENTS:

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  - **MAY 20**

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