Robot on-board self-calibration by vision system through pose uncertainty assessment

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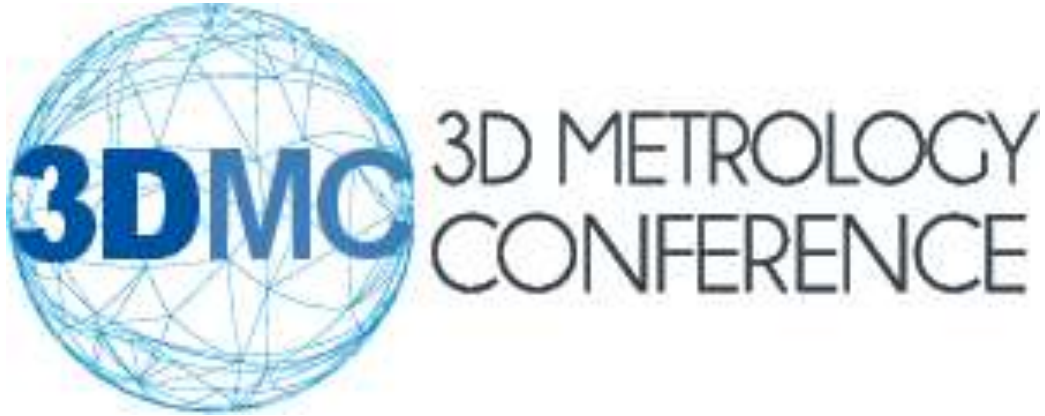
Collaborative project PRECITEK
(Funded by Grupo SPRI).



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IDEKO
MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

OUTLINES

- Robot calibration overview
- Vision Proposal
- Accuracy Requirements
- Digital simulation environment
- Simulation Results
- Experimental results
- Conclusions

BRTA

- **TEKNIKER** and **IDEKO** are a member of the
- Basque Research & Technology Alliance, BRTA;
- with 16 agents belonging
    - to the Basque Network of Science, Technology and Innovation;
- in addition to SPRI and the Provincial Councils of Gipuzkoa, Bizkaia and Araba.

ROBOT CALIBRATION

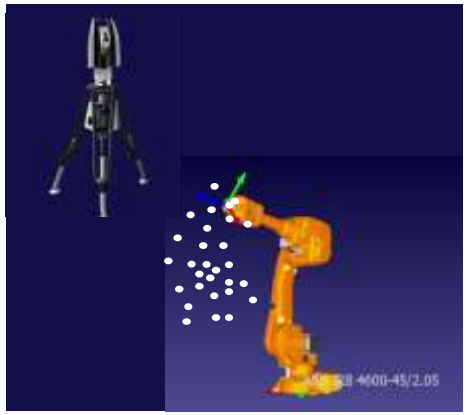
OVERVIEW

Determination of the real DH kinematic parameters

Using an external metrology framework

(ISO 9283)

Demanding robot-based manufacturing applications



VISION PROPOSAL

WHY?

Alternative to an external measuring instrument

Flexible on-board and external solution

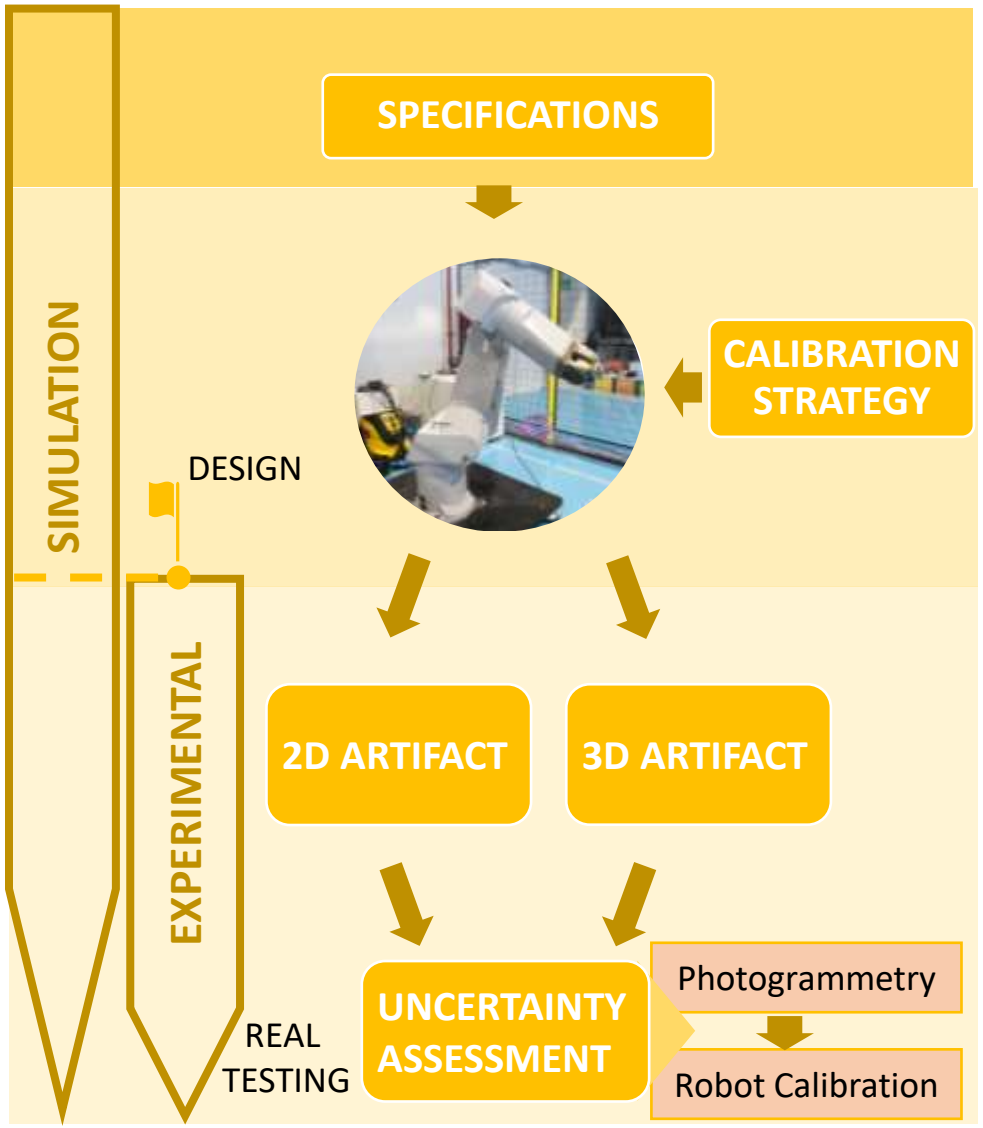
Economic and fast solution

HOW?

Single camera (mono camera)

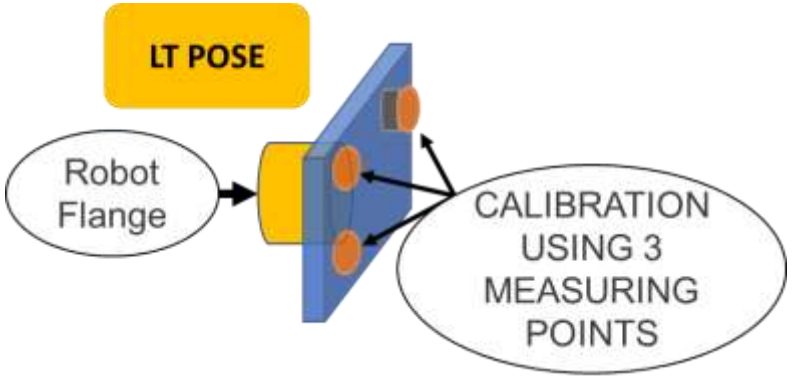
On board embedded Solution

2D or 3D Artifact

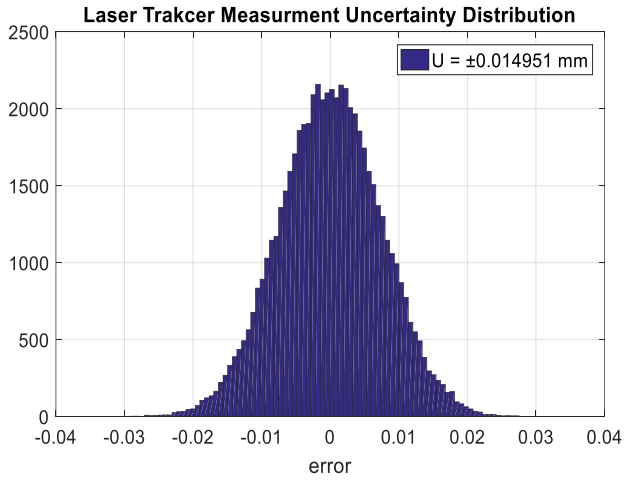


ACCURACY REQUIREMENTS

THEORETICAL LEVEL



U tracker:
± 15 µm
± 20 µm
± 50 µm



ACCURACY REQUIREMENTS

MONTE CARLO APPROACH

U tracker:
± 15 µm
± 20 µm
± 50 µm

Calibration Points Uncertainty (3 Points)

Robot Pose Uncertainty

Laser Tracker Pose Uncertainty

ACCURACY REQUIREMENTS

MONTE CARLO APPROACH

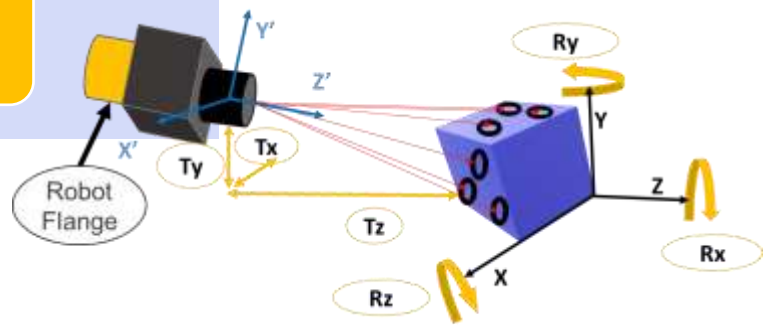
U tracker:
± 15 µm
± 20 µm
± 50 µm

Calibration Points Uncertainty (3 Points)

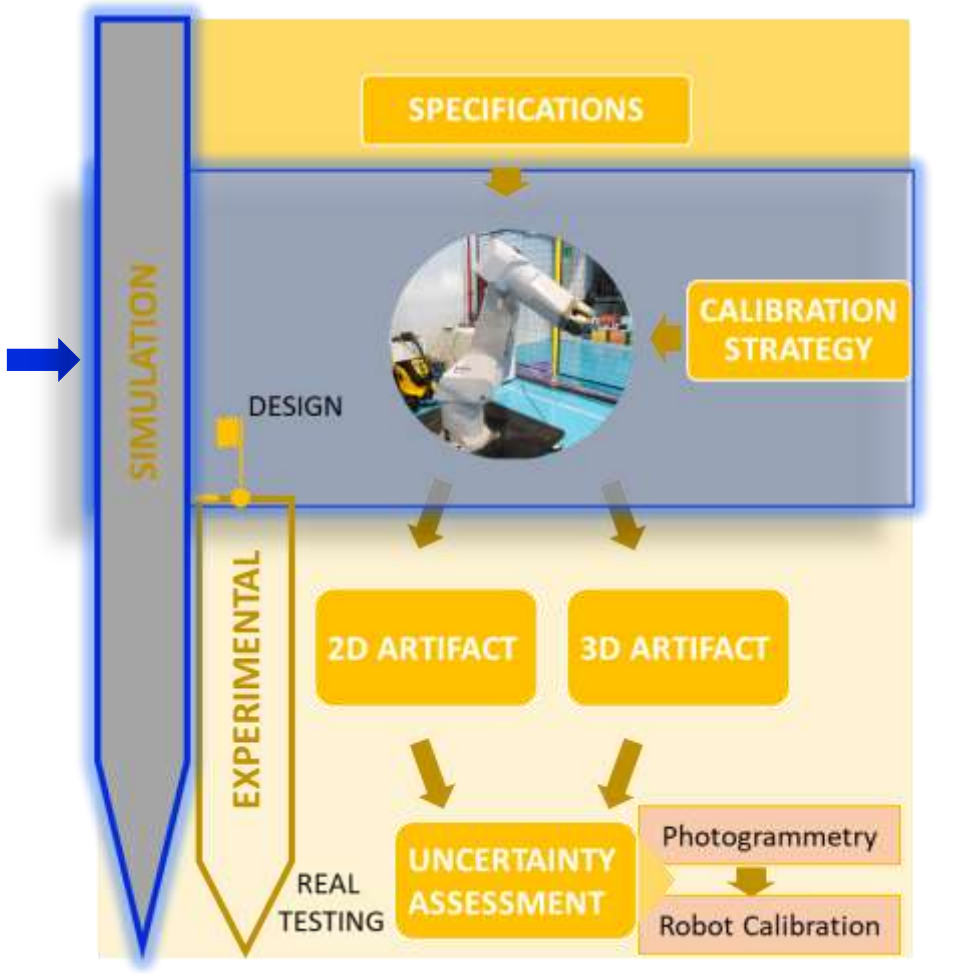
Robot Pose Uncertainty

Laser Tracker Pose Uncertainty = Vision Pose Uncertainty

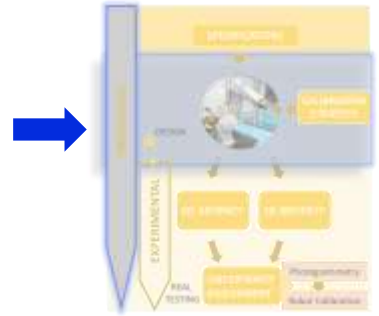
Pose Uncertainty For 50 µm						
	Rx	Ry	Rz	Tx	Ty	Tz
	arc-sec			µm		
Robot	30	35	40	170	160	140
Vision	120	119	85	65	65	20



DIGITAL SIMULATION ENVIROMENT



DIGITAL SIMULATION ENVIROMENT



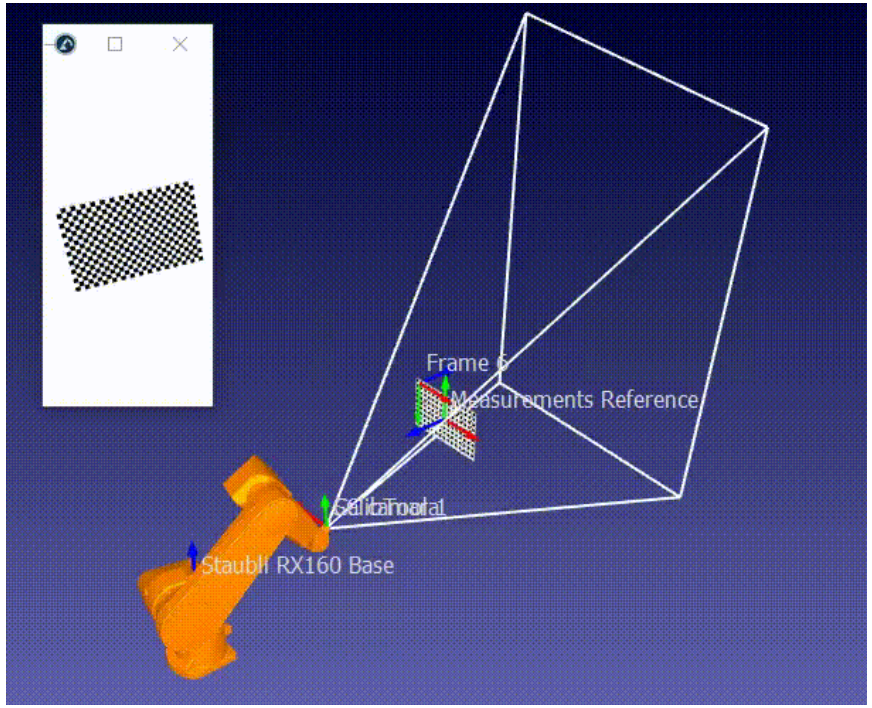
Simulation flow

- Pose generator
- Synthetic Images
- Camera Pose
- Referencing
- Robot Calibration

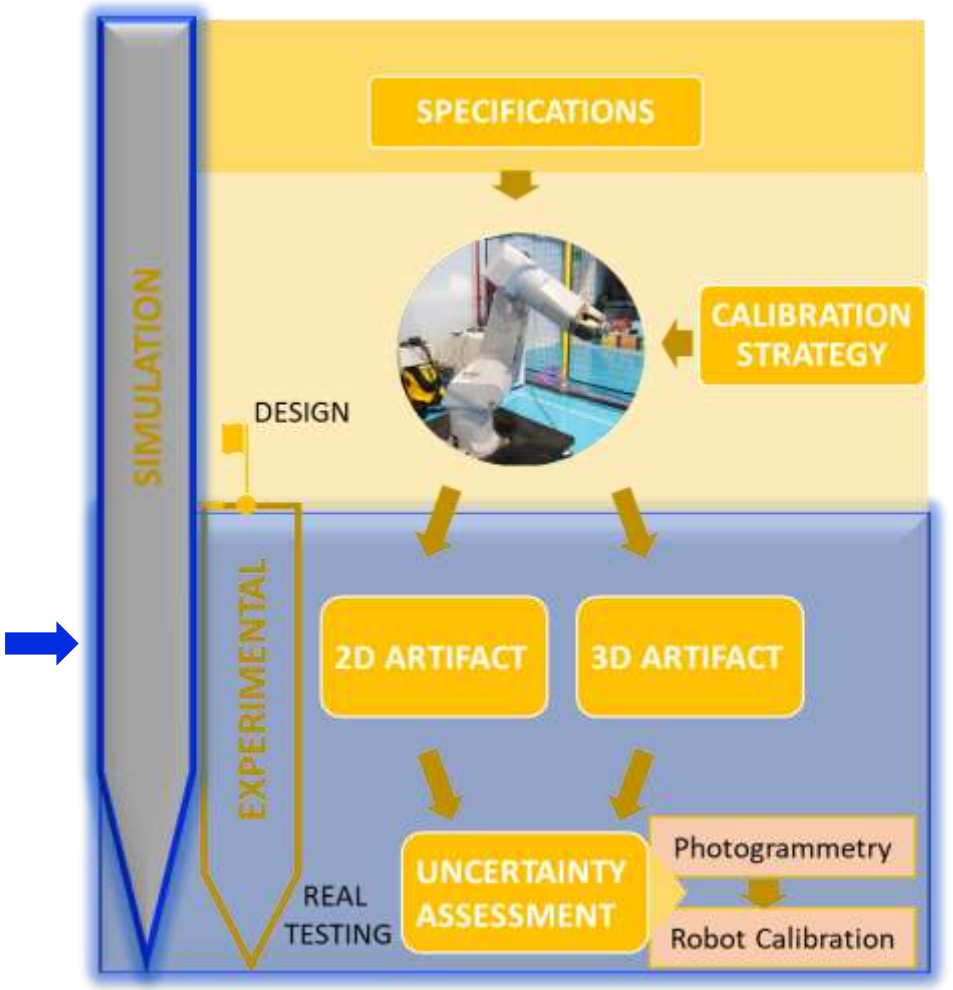
MATLAB

RoboDK

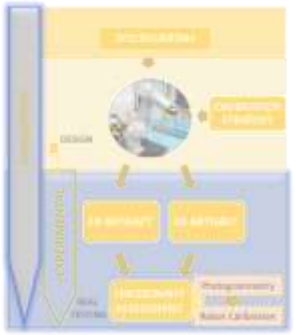
MULTI camera



SIMULATION RESULTS

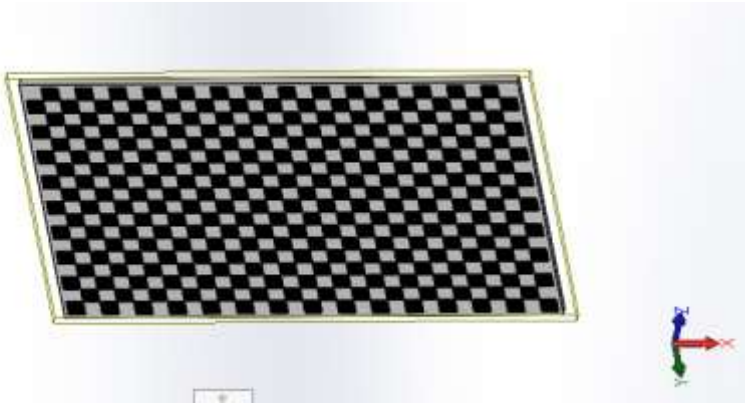


SIMULATION RESULTS

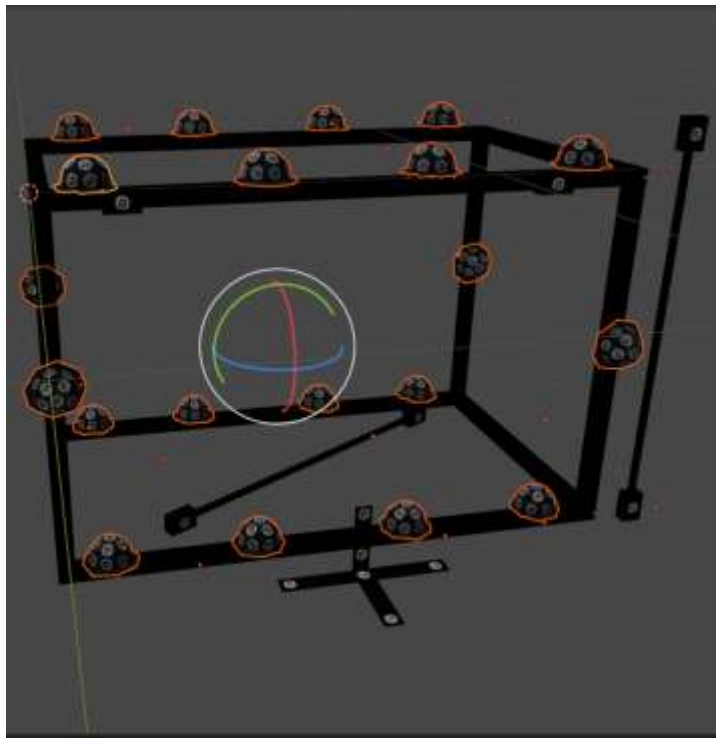


Calibration Artifacts

2D



3D

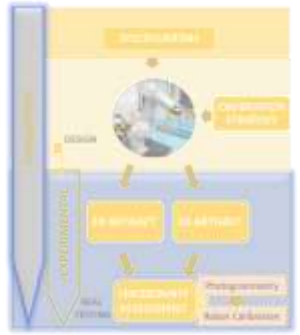


SIMULATION RESULTS

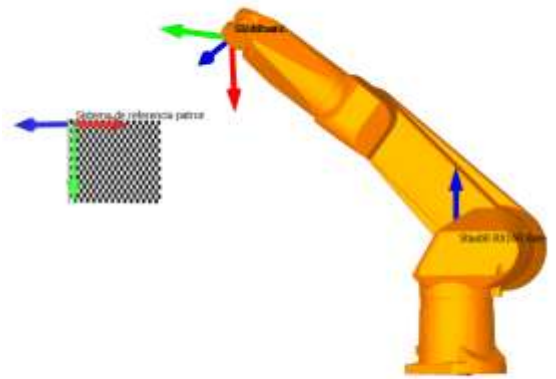
3D Pattern shows the least uncertainty

2D Pattern for big size (Back plane) is acceptable

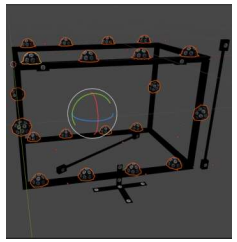
U K=1	σ α (rad)	σ β (rad)	σ γ (rad)	σX (mm)	σY(mm)	σZ(mm)
2D Front plane	0.00023	0.00022	0.00002	0.230	0.239	0.366
2D Back plane	0.00005	0.00005	0.00001	0.134	0.133	0.237
3D	0.00001	0.00001	0.00001	0.012	0.036	0.023

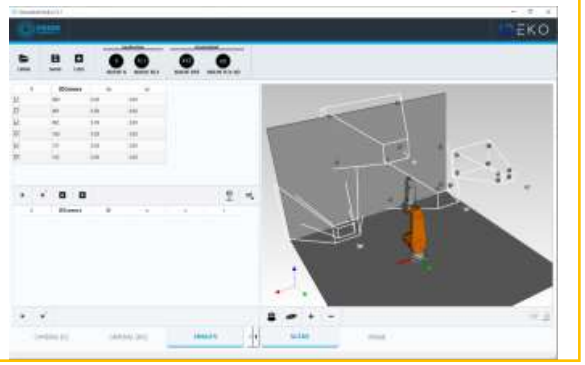


2D

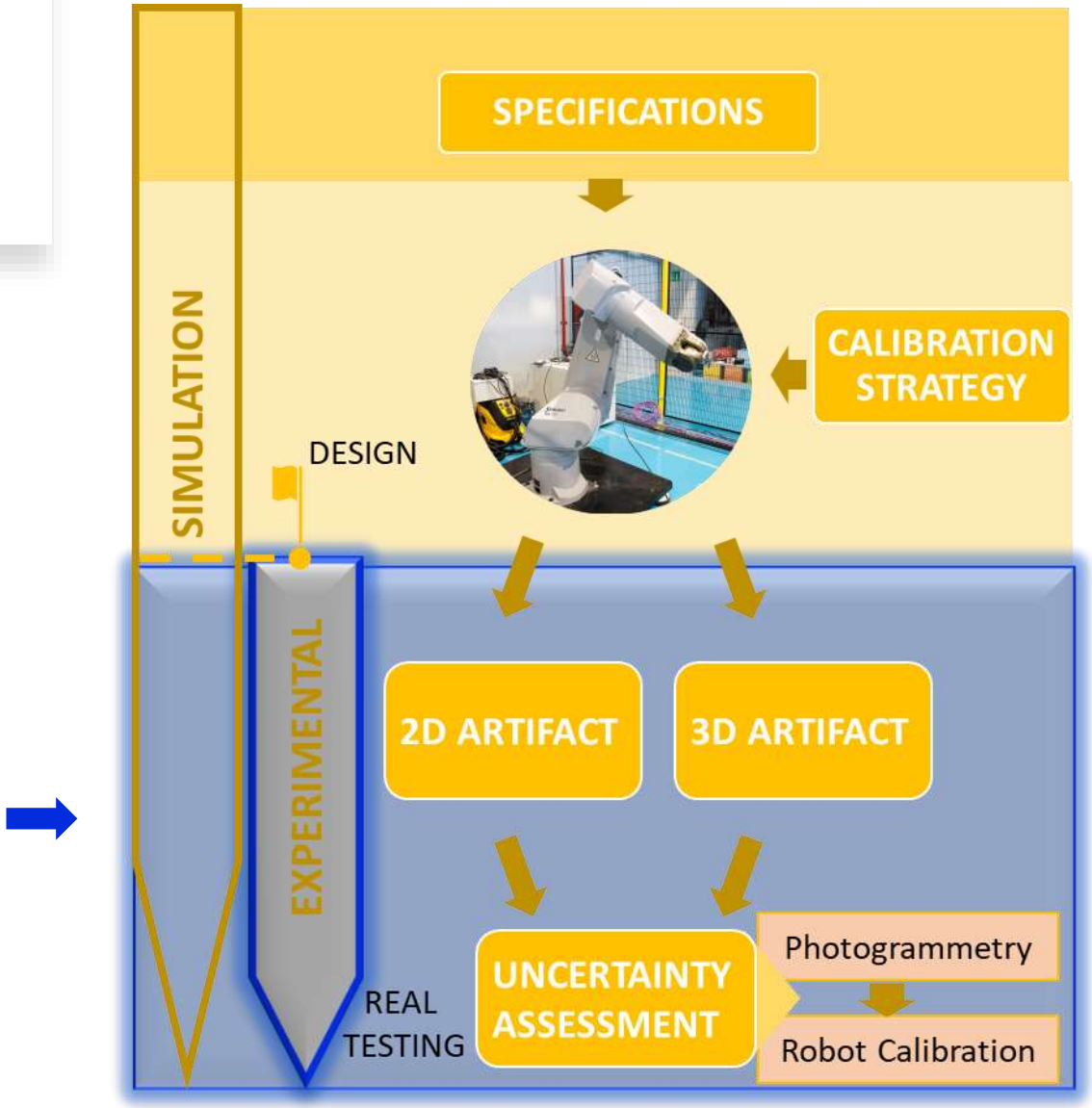


3D

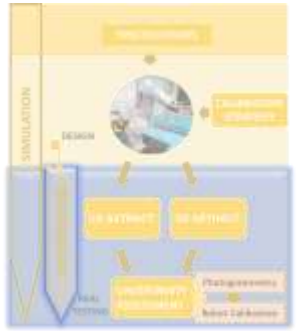




EXPERIMENTAL RESULTS



EXPERIMENTAL RESULTS



CAMERA ROBOT INTERFACE

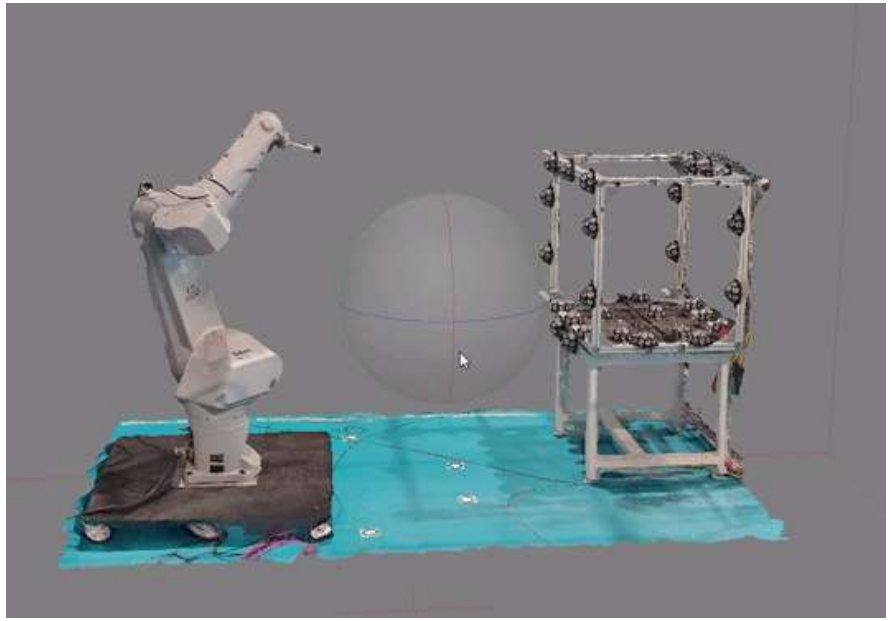
3D ARTIFACT CONFIGURABLE SOLUTION

(BUNDLE)

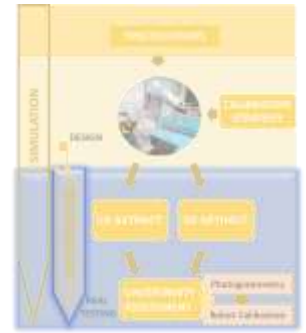
2D ARTIFACT CHESS BOARD

(RESECTION)

Test Materialization



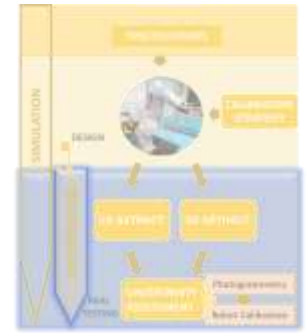
EXPERIMENTAL RESULTS



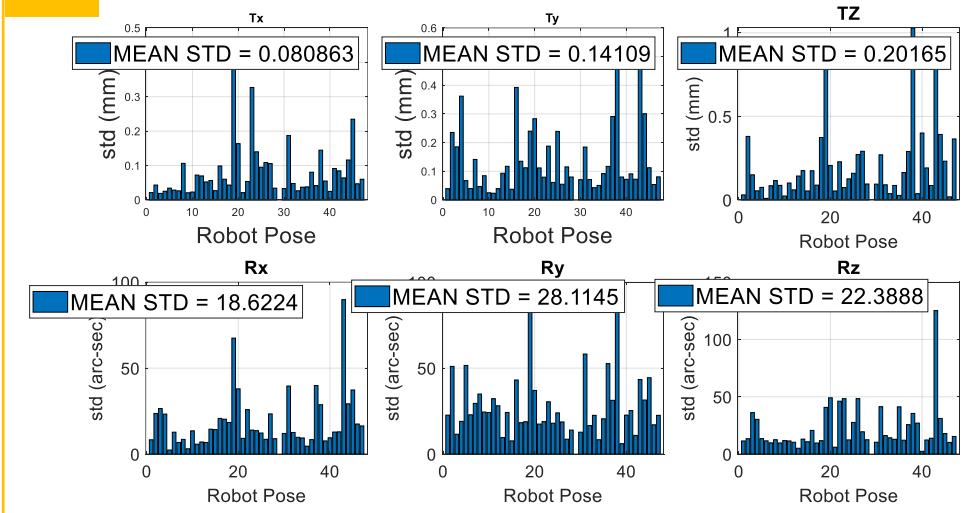
Vision 6 DOF Performance

- Photogrammetry repeatability evaluation.
- Estimation of the camera poses
- 5 repetitions

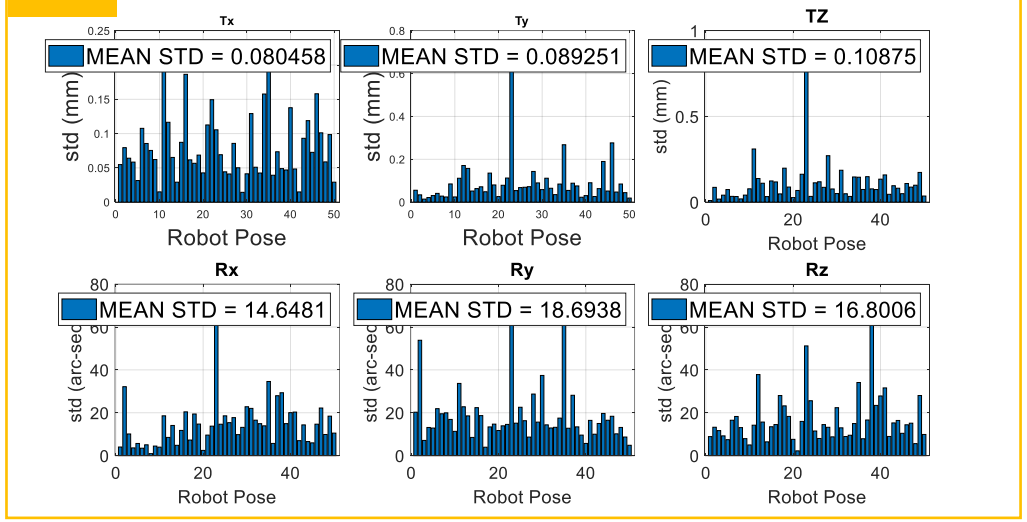
EXPERIMENTAL RESULTS



2D



3D



	2D Pattern	3D Pattern
	mean	mean
Translational (mm)	0,140	0,092
Orientation (arc-sec)	23,0	16,7

EXPERIMENTAL RESULTS

Referencing Process

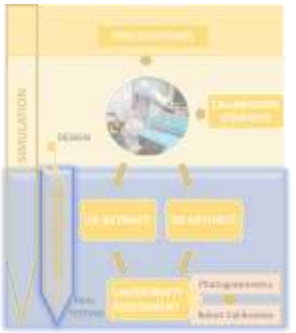
- Camera to robot reference frame
- Nominal values as initial input
- Referencing algorithms
- Adjusting the definition of Artifact and Camera

$$ {}^{Camera}T_{Robot} = {}^{Robot}T_{Artifact} * {}^{Artifact}T_{Camera} * {}^{Camera}T_{TCP} $$

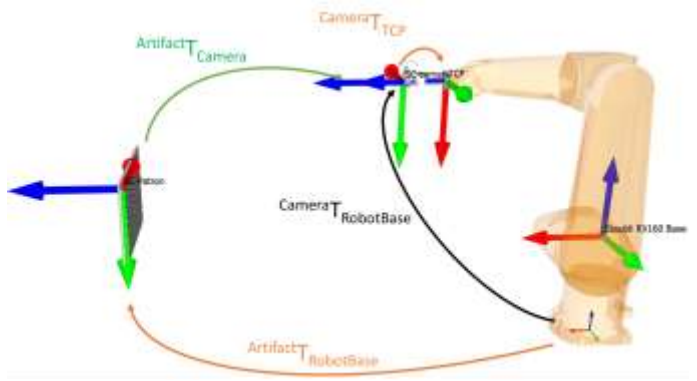
Referenced Poses

Input Poses

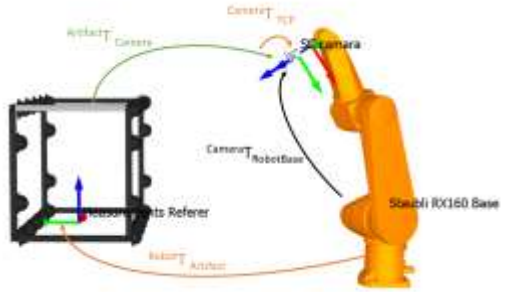
Unknowing Transformation



2D



3D



EXPERIMENTAL RESULTS

Robot 6 DOF Performance Results

- Using the referenced transformation of the camera in TCP
- Using the camera definition in base frame as ground truth

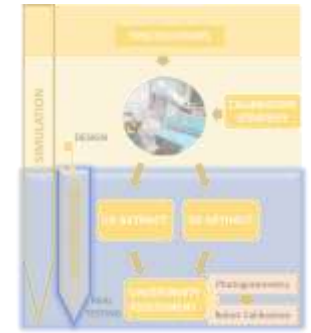
Error Evaluation

- Differences between robot nominal poses, using nominal DH
- Error sources:
  - Photogrammetry
  - Robot

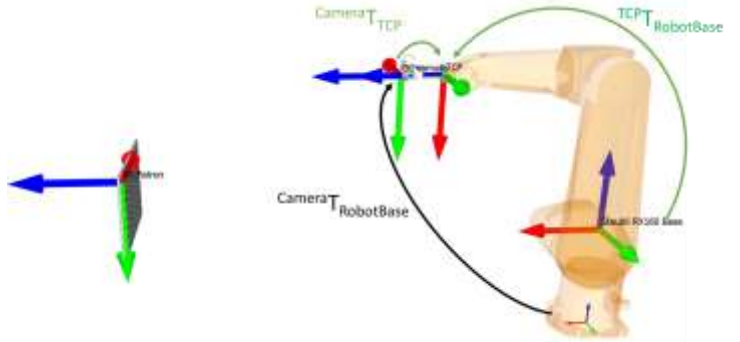
$$\text{Evaluated Error} = {}^{\text{Camera}}\mathbf{T}_{\text{Robot}} - ({}^{\text{TCP}}\mathbf{T}_{\text{Robot}} * {}^{\text{Camera}}\mathbf{T}_{\text{TCP}})$$

Referenced Poses

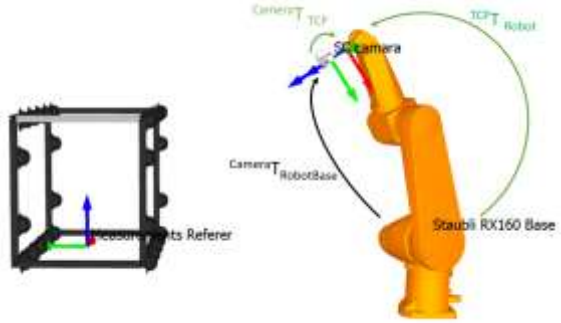
Input Poses



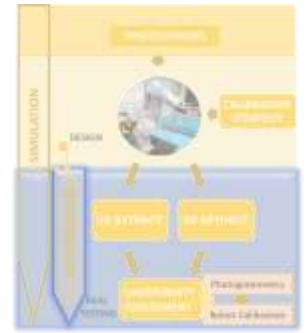
2D



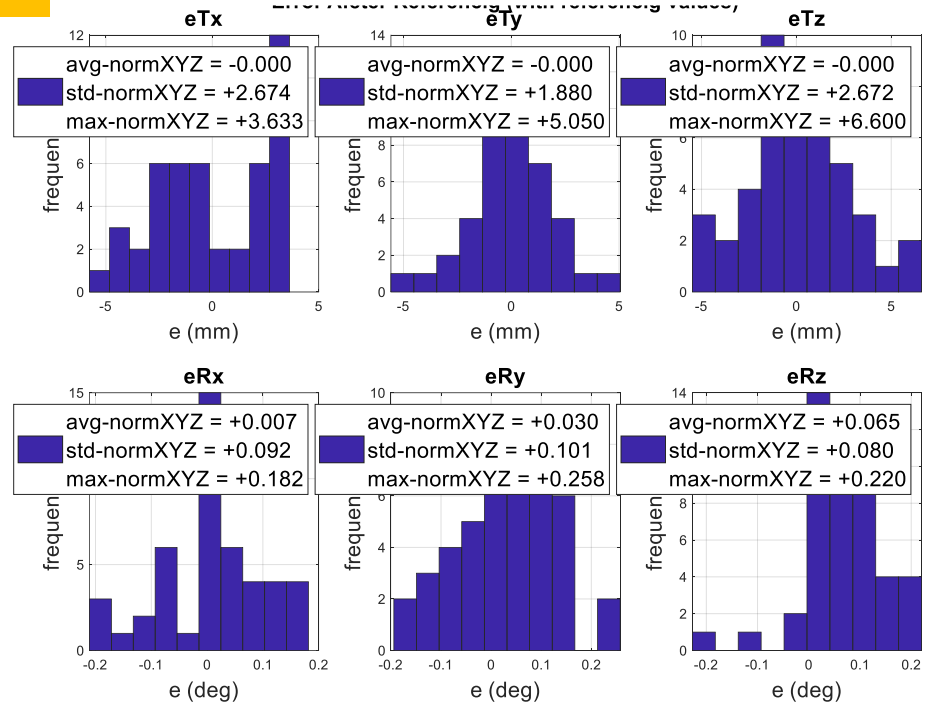
3D



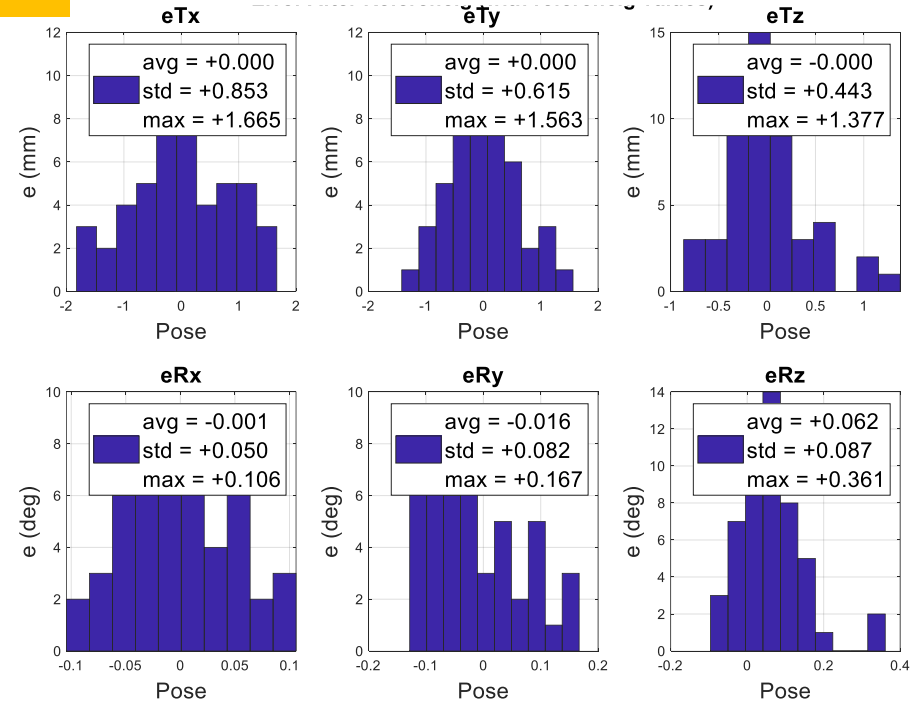
EXPERIMENTAL RESULTS



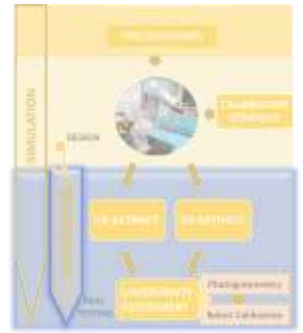
2D



3D



EXPERIMENTAL RESULTS



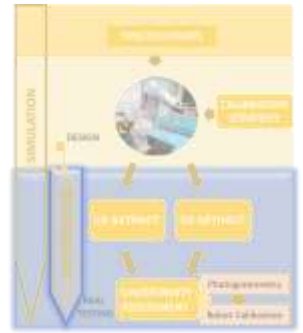
Robot 6 DOF Calibration

- Using the camera referenced poses as Ground Truth
- Adjusting the real DH Parameters and Referencing values
- Improvement of the robot accuracy

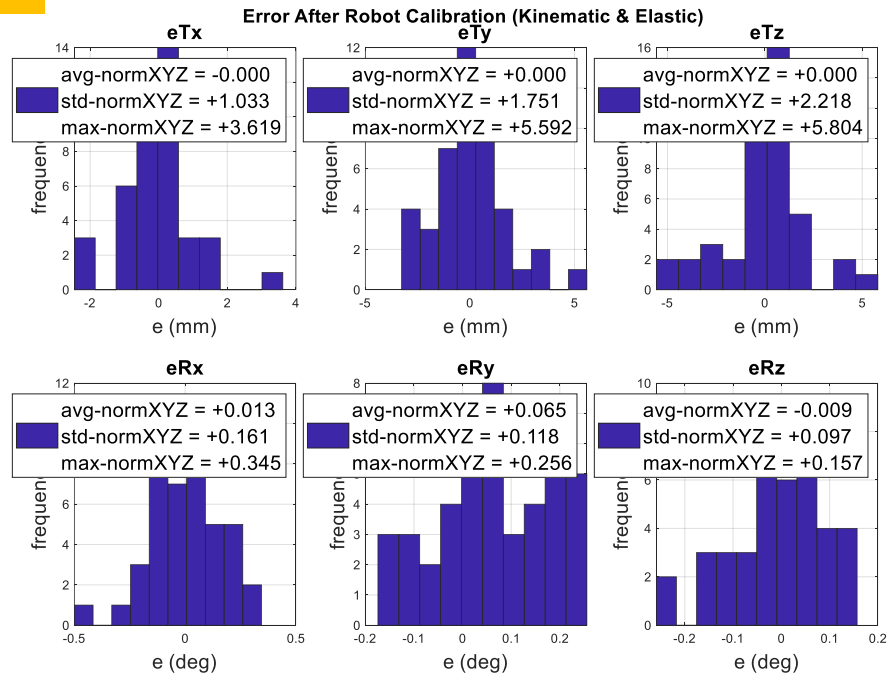
2D

3D

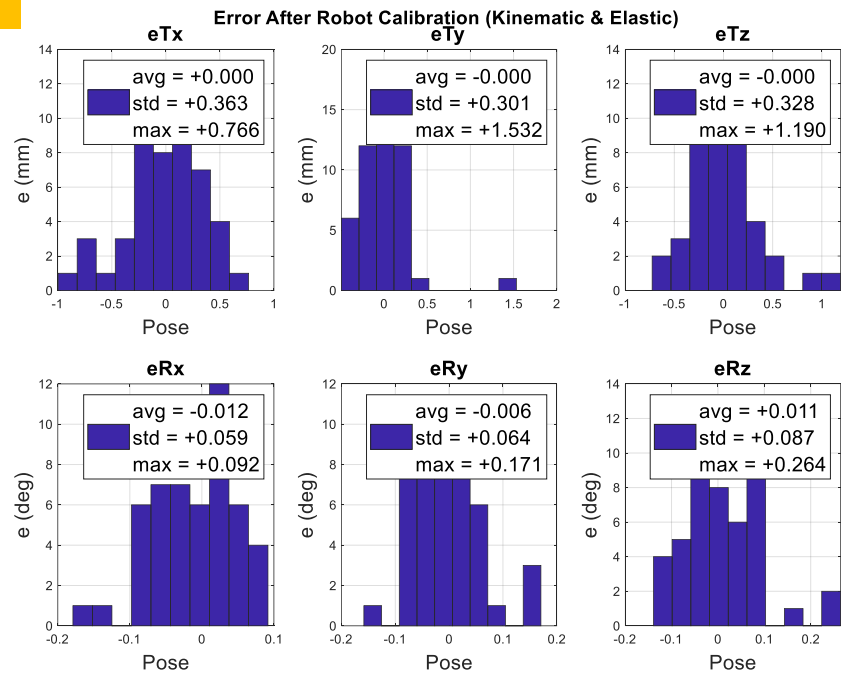
EXPERIMENTAL RESULTS



2D



3D

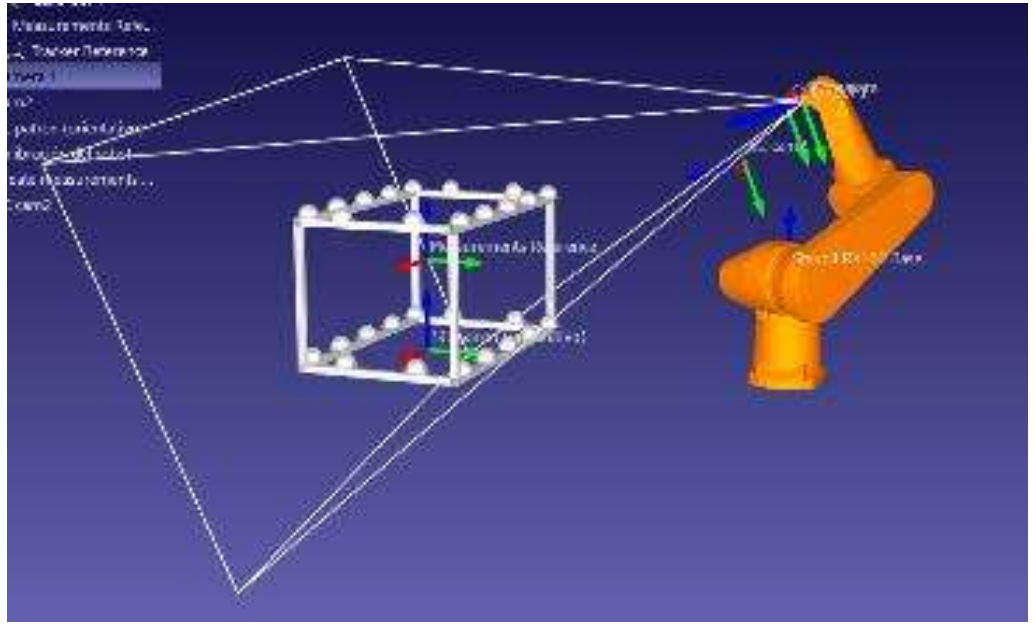


CONCLUSIONS

A useful simulation methodology to assist in robot calibration before the materialization of the experiment set-up.

Experimental **results demonstrate the feasibility of a single-camera vision system for on-board robot calibration**

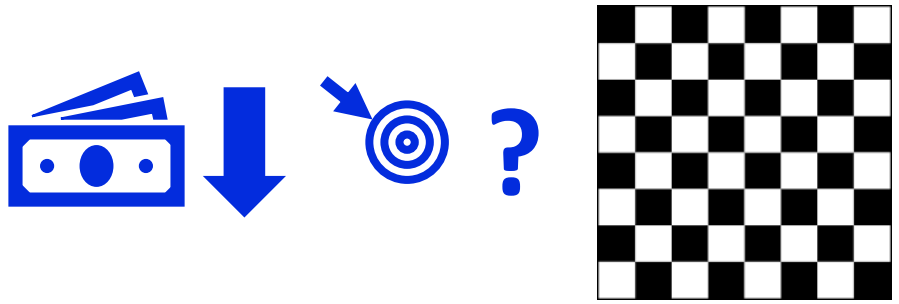
2D artifact and resection: easy-to-use;
3D artifact and mobile photogrammetry bundle: higher accuracy potential



FUTURE WORKS

Further improve the photogrammetric approach: new 3D artifact design for being as usable as the 2D approach, **adopt onboard ilumination for optimizing image quality**, etc.

Robot **calibration** and **verification** trials (laser-tracker) for **assessing the whole** photogrammetric process**, extending** the approach also to **other robot models** and working volumes.



Collaborative project PRECITEK
(Funded by Grupo SPRI).

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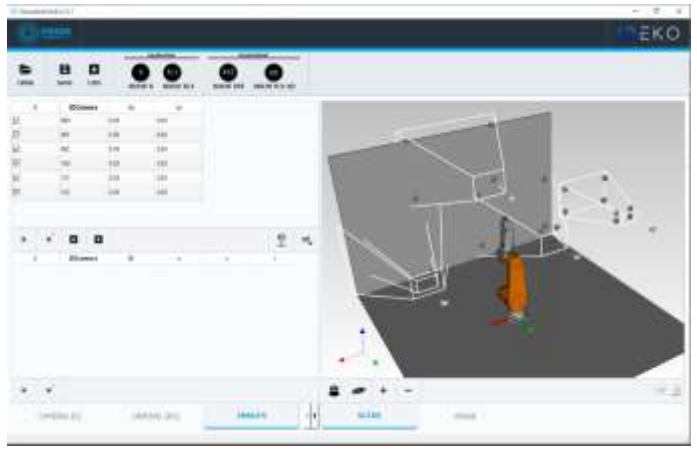
Annexes

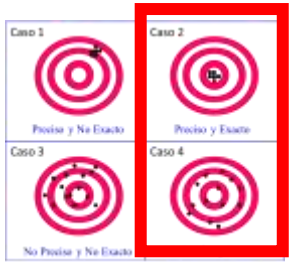
SIMULATION RESULTS

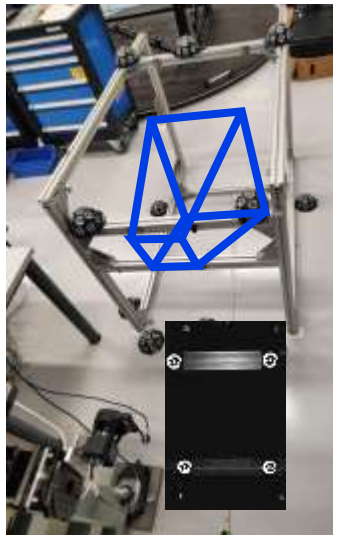
- 3D Pattern shows the least uncertainty
- 2D Pattern for big size (Back plane) is acceptable
- Test shows similar trend than simulation
- Simulation overestimates values

U K=1	σ α (rad)	σ β (rad)	σ γ (rad)	σX (mm)	σY(mm)	σZ(mm)
2D Front plane	0.00023	0.00022	0.00002	0.230	0.239	0.366
2D Back plane	0.00005	0.00005	0.00001	0.134	0.133	0.237
3D	0.00001	0.00001	0.00001	0.012	0.036	0.023

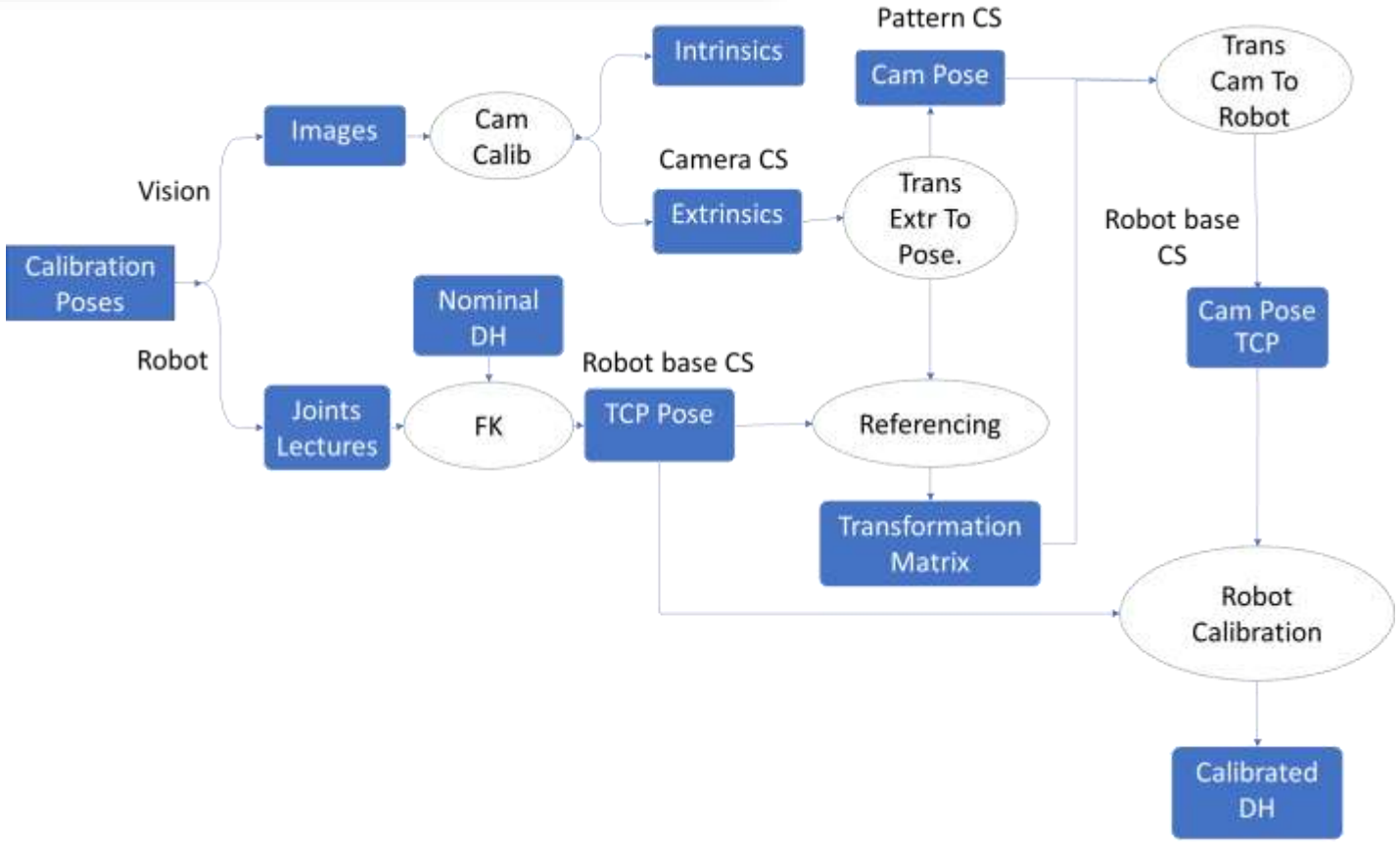


Repeatability





Tests Materialization



Pattern Characterization

2D Pattern

Commercial equipment

Uncertainties in micron order

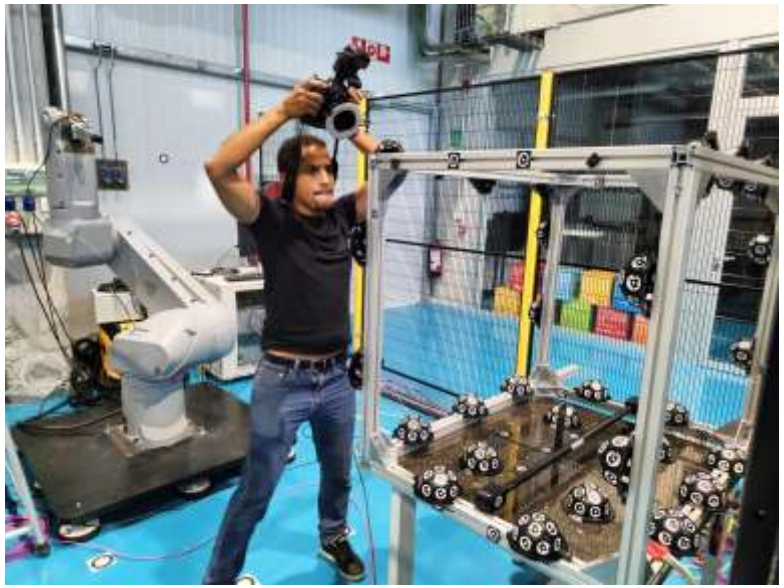
3D Pattern

Adjustable solution

On-site characterization

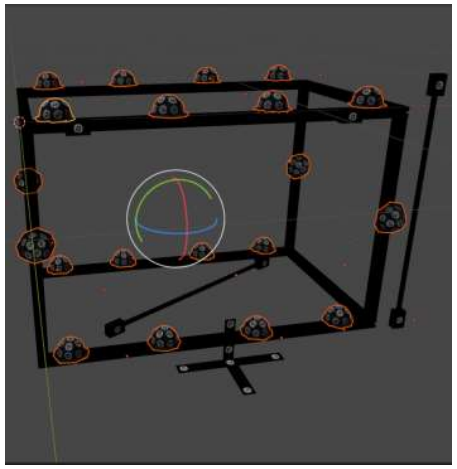
Repeatability testing

Bench marking comparison



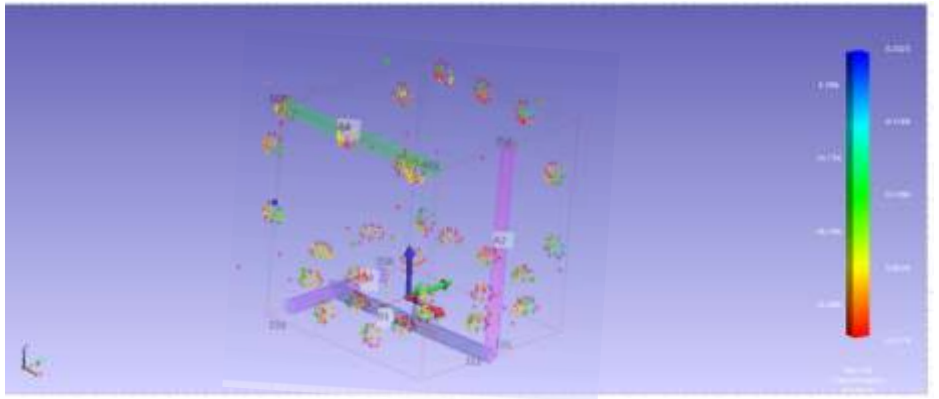
3D artifact Characterization

Repeatability	3 repetition	Tritop ± 20 µm
		VSET ± 50 µm
Accuracy	Scale bars differences	± 90 µm



VSET

TRITOP Professional



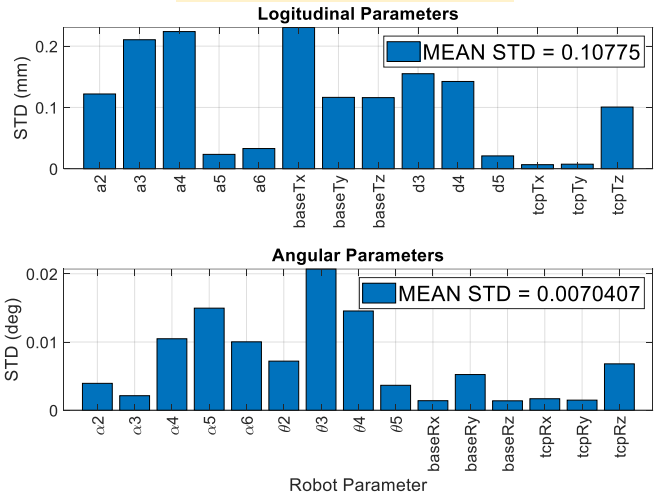
Robot Calibration Results

Process repeatability

- Evaluation the repeatability of the estimation in the vision poses, 5 repetitions
- Evaluation of the repeatability in the estimation of calibrated parameter

	2D Pattern	3D Pattern
	mean	mean
Longitudinal Parameters (mm)	0,108	0,143
Angular Parameters (arc-sec)	25,2	24,5

2D Pattern



3D Pattern