Summary

Industry 4.0 aims to transform industrial processes through the integration of ‘smart’ technologies such as AI, automation, and robotics, into manufacturing processes. Integral to many high-value industries are machine vision systems (MVSs) where cameras and sensors are used to monitor production. These systems enable correct part placement during assembly, coordinate robots, and detect defects whilst improving efficiency, increasing productivity, and reducing costs. The integration of ‘digital twins’ could further improve MVSs by providing virtual models of physical objects that use real-time data from sensors to simulate MVSs behaviour and monitor operations. However, metrological standards, calibration methods, traceability, and uncertainty assessment for existing and newly developed MVSs are lacking.

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Project Objectives

The specific objectives of the project are:

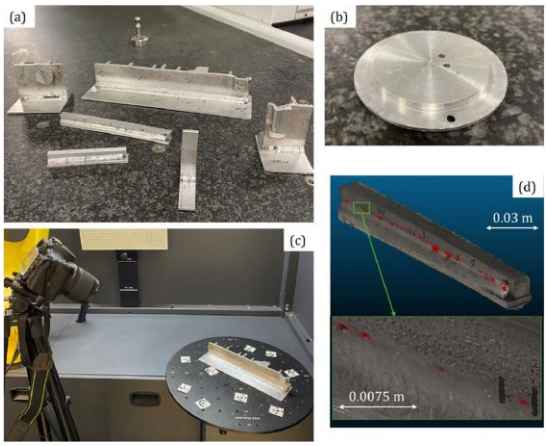
1. To establish the traceability of existing and newly developed industrial MVSs used in (i) dimensional quality, (ii) surface quality, (iii) structural quality, and (iv) operational quality including the development of appropriate material standards with canonical and complex shapes, calibration strategies, traceable identification of MVSs parameters, and uncertainty budgets (target uncertainty 1 µm – 150 µm dependent on MVS application area).
2. To develop Digital Twins (DTs) of selected and newly developed MVSs through physical modelling and/or computational modelling, and to then (i) predict their responses in analysing systematic errors, and to (ii) obtain an optimal measurement strategy in the shortest cycle time. In addition, to develop approaches for the validation of these DTs that include robust methods (e.g., softgauges), and statistical procedures for the assessment of differences between measurements of calibrated standards and corresponding data from their virtual counterparts.
3. To investigate and evaluate novel methods and algorithms for dense image matching (coarse and fine image alignment) of multiple recorded images using ‘softgauges’ (reference data). The algorithms will use external knowledge (e.g. physical markers, contactless tracking systems, precise positioning systems, intrinsic features of the scene) and filtering processes will be considered. Additionally, robust algorithms will be developed and validated for analysing the full 3D reconstruction and uncertainty budgets compiled.
4. To investigate the outputs and outcomes developed in this project while addressing industrial use cases related to dimensional, structural, surface and operational qualities. In addition, the performance of selected traceable MVSs for industrial applications will be tested on industrial freeform artefacts in a round robin comparison exercise. Based on measurement results, training material and a GPG for T-MVS performance assessments (e.g. dimensional, structural, surface and operational qualities) will be produced.
5. To facilitate the take up of the technology, good practice guides and measurement infrastructure developed in the project by the EMNs MathMet, TraceLabMed, AdvManu, the measurement supply chain, standards developing organisations (ISO/TC213 and ASTM), and end users (manufacturers from the automotive, food, pharmaceutical, etc. sectors). This includes demonstrations of the practical application of the developed technology in multiple industrial applications (e.g. automotive, aeronautic, pharmaceutical).

Highlights

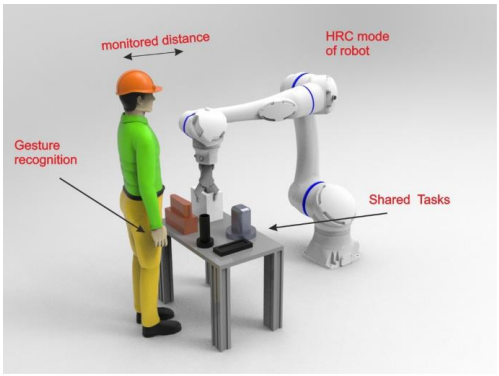
As part of its dissemination activities, the **University of Padua (UNIPD)** brought DI-Vision's latest progress to the precision engineering community at the 25th International Conference & Exhibition euspen 2025 in Zaragoza. During the event, Dr. Sofia Catalucci presented a poster showcasing the project's overall framework, highlighting its methodological approach and development roadmap. Following this contribution, UNIPD submitted two abstracts to euspen 2026, to be held in Krakow, with planned poster presentations by Dr. Sofia Catalucci, and Eng. Dario Pasin.

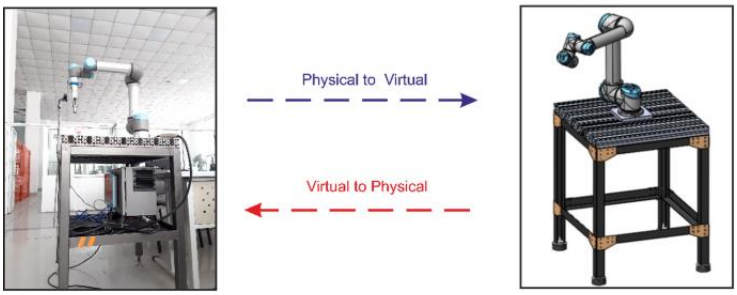
Dario recently joined the team as PhD student, supported by an industry-sponsored scholarship funded by Brevetti CEA, reinforcing the bridge between academic research and real industrial needs (https://www.linkedin.com/posts/brevetti-cea-group_innovation-researchdevelopment-talentgrowth-activity-7401937414195228672-LCFj/). The contributions to the international conference will share the team's next developments and report results in line with the DI-Vision objectives.

In parallel, key research results were consolidated through a peer-reviewed publication: a journal article authored by Dr. Sofia Catalucci and Prof. Enrico Savio has been published in the CIRP Journal of Manufacturing Science and Technology (DOI: https://doi.org/10.1016/j.cirpj.2025.12.002).



Politecnico di Torino (POLITO) developed a methodology for establishing traceability and evaluating measurement uncertainty of machine vision systems for the automatic detection of surface defects. The methodology was applied to a case study aimed at inspecting the surface quality of corner welds in gas metal arc welding of cast and rolled aluminum components for automotive. The work was presented at the 74th General Assembly of the International Academy for Production Engineering (CIRP).



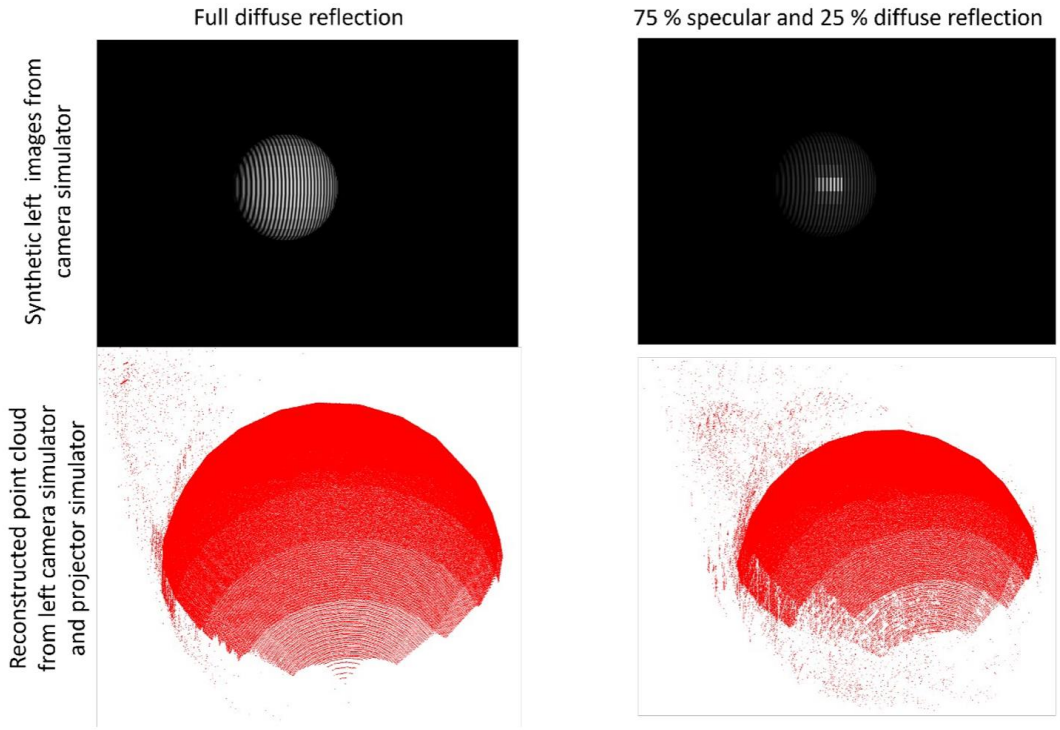


POLITO developed a methodology to establish a traceable digital twin of a robotic arm collaborative robot (cobot). The digital twin leverages a machine vision system, calibrated by laser tracker, to continuously monitor its position and compensate for motion error. The work allowed to evaluate the positioning uncertainty of the cobot reducing the positioning error uncertainty from 2 mm to 0.2 mm.

Polytechnique Montréal (Canada) progress is mainly on creating a digital shadow of ATOS Q 12M and evaluating the scanned points variation inside a part surface. They have achieved the current progress on these two subjects as followings:

1. They presented our poster at the EUSPEN 25th International Conference & Exhibition, on June 6, 2025, in Zaragoza, Spain. The full paper is indexed in the Knowledge Base of EUSPEN. The full paper can be searched online https://www.euspen.eu/knowledge-base/ICE25287.pdf;

2. They applied the calibration parameters to a Digital Shadow of ATOS Q 12 M scanner. The specular and diffuse reflection effects were added in simulating the scanning different material. The reliability of the Digital Shadow is still in testing. The specular and diffuse reflection synthetic images of parts and corresponding reconstructed point cloud can be found in the Figure below.

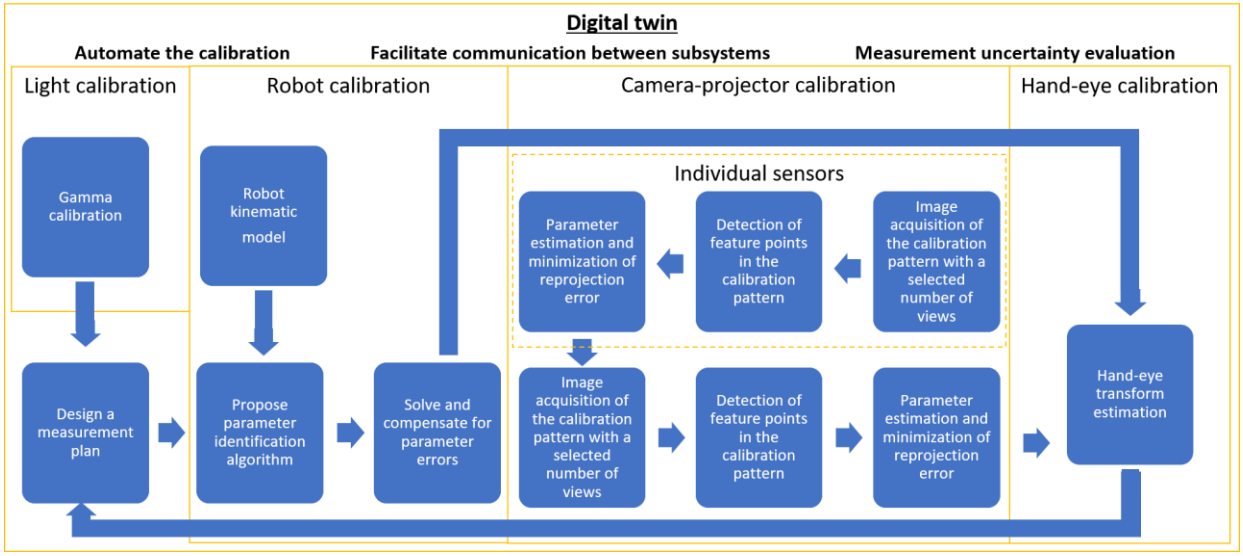


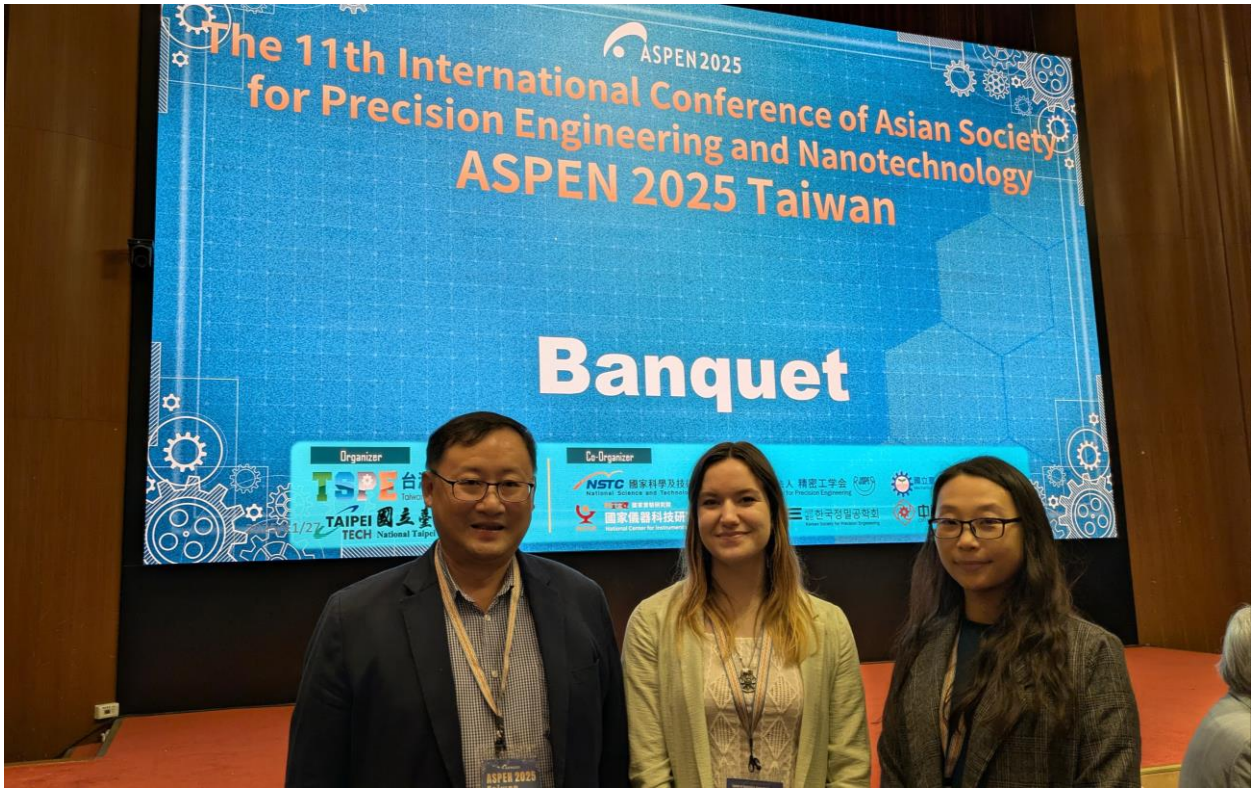
3. They are validating and modelling the scanned points cloud form variation inside a designed surface with respect to proper indicators.

Istituto Nazionale di Ricerca Metrologica (INRiM) attended the MacroScale2025 conference in Buenos Aires presenting an oral contribution titled “Metrological characterisation of Machine Vision Systems for the analysis of surfaces from advanced manufacturing”.
This work addresses the metrological characterisation of a focus variation instrument used for the analysis of surfaces from advanced manufacturing, focusing on the methodologies and challenges associated with quantifying their performance.
Key aspects include instrument characterisation according to two ISO standards.
ISO 25178-600 specifies the metrological characteristics of areal instruments used for measuring surface topography. These parameters are noise, flatness, amplification of X, Y and Z axes, linearity of X, Y and Z axes, mapping deviation of X and Y axes, spatial resolution, and topography fidelity. The quantification of these parameters is achieved by different material measures under varying experimental conditions, including different objectives, measuring positions, and sample orientations.
ISO 25178-700 describes the generic procedures for the calibration, adjustment, and verification of the metrological characteristics of areal topography measuring instruments. The calibration involves the quantification of metrological characteristics, the adjustment describes the correction of systematic errors, and the verification test the validity of the two previous points. The possible subsequent comparison is the performance specification of instrument characteristics.

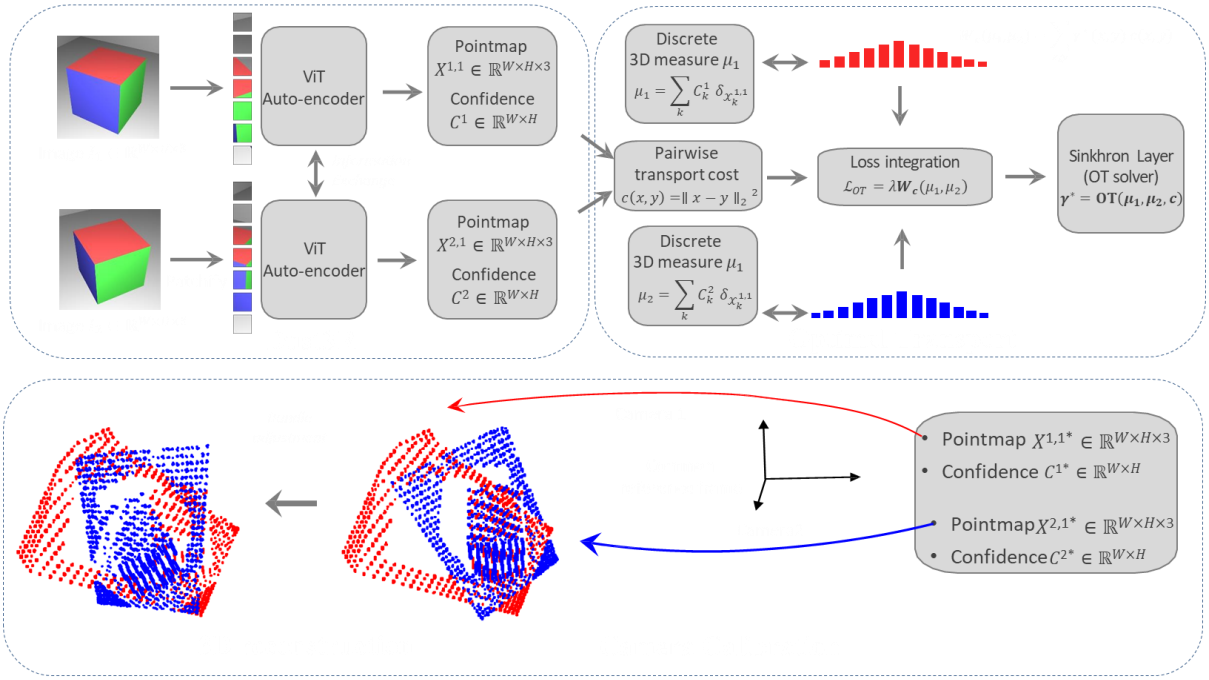
University of Maribor attended the MacroScale2025 conference presenting a poster titled “Metrological set-up for calibration of displacement sensors up to 150 mm”.
This work describes the use of machine vision methods in precision measurements. One of the promising technologies that is increasingly being adopted in the field of precision measurements is the use of vision systems, i.e., cameras. Measurement technology based on machine vision offers numerous advantages, most notably ease of use, a high degree of accuracy, a non-contact approach, and relatively cost-effective implementation. The research is focused on developing vision-based compensation methods for geometrical errors including sensor cosine error, laser beam cosine error and Abbe error offset.

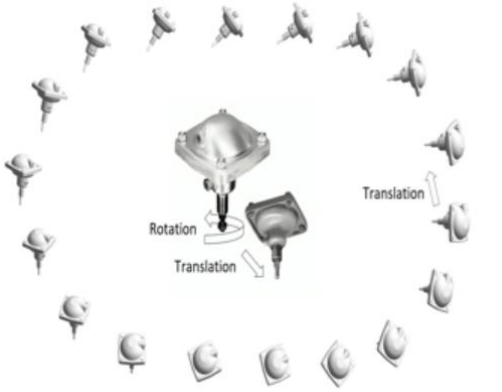
Laboratoire National de métrologie et d'Essais (LNE) developed a framework for digital twins for stereovision systems. This architecture consists of a series of calibrations, outputting extrinsic, intrinsic and distortion parameters, as well as an associated measurement uncertainty. The stereovision system developed at LNE was presented at the 11th International Conference of Asian Society for Precision Engineering and Nanotechnology by a PhD student Katarina Josic.

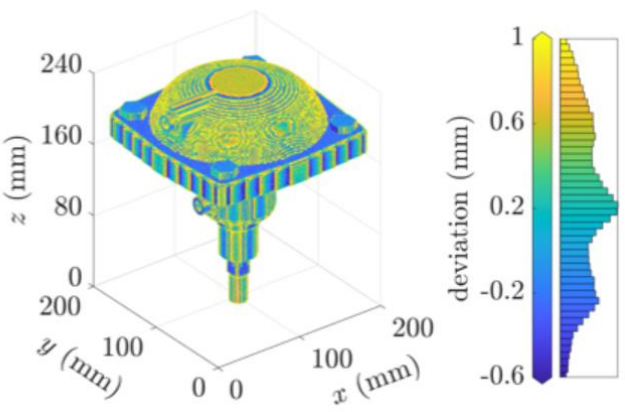




In parallel, **LNE** also developed robust post-processing methods for optical 3D stereovision dedicated to dimensional metrology, focusing on dense image matching, 3D reconstruction, and uncertainty propagation for traceable measurements. These developments were presented at the EUSPEN 2025 conference (Paris-Saclay) and the PTB Macroscale 2025 Conference (Buenos Aires, Argentina) by a PhD student, Ladji Fofana.







Attended Conferences

- International Forum on Digital Twin Design & Operations 2024
- MacroScale 2025
- Light Conference 2025
- Photonics West
- 95th Annual Meeting of the Int. Association of Appl. Mathemetics and Mechanics
- International Conference on Applied Physics & Imaging
- 19th CIRP Conference on Computer-Aided Tolerancing (CAT 2026)
- euspen's 26th International Conference & Exhibition
- Micro/Nano Manufacturing & 6th AET Symposium on ACSM and Digital Manufacturing
- BIPM 150th anniversary
- 11th International Conference of Asian Society for Precision Engineering and Nanotechnology

Scientific Publications

1. Sofia Catalucci, Enrico Savio, Metrological validation of a deep learning pipeline for in-line detection and dimensional quantification of three-dimensional surface defects, CIRP Journal of Manufacturing Science and Technology, Volume 64, February 2026, Pages 107-119, DOI 10.1016/j.cirpj.2025.12.002
2. Giacomo Maculotti, Lorenzo Giorio, Gianfranco Genta, Maurizio Galetto, Traceability and uncertainty of defects automated measurements by CNN-powered Machine Vision Systems, 2025, CIRP Annals, 74:661-665, DOI 10.1016/j.cirp.2025.03.023
3. Giacomo Maculotti, Fazluddin Khusnuddinov, Jasurkhuja Kholkhujaev, Gianfranco Genta, Maurizio Galetto, Traceable digital twin for accurate positioning of industrial robot arms in human–robot collaborative systems, 2025, Flexible Services and Manufacturing Journal, DOI 10.1007/s10696-025-09632-7
4. Louis-Ferdinand Lafon, Alain Vissiere, Charyar Mehdi-Souzani, Nabil Anwer, Hichem Nouira, Reference data generation for evaluating pairwise registration algorithms, Measurement, 15 January 2026, Volume 257, Part B, 118602, DOI 10.1016/j.measurement.2025.118602
5. Louis-Ferdinand Lafon, Alain Vissiere, Charyar Mehdi-Souzani, Hichem Nouira, Nabil Anwer, Multi-sensor data fusion framework and validation of algorithms with reference datasets, Procedia CIRP, Volume 129, 2024, Pages 133-138
6. Rim Bennoune, Gengxiang Chen, Saint-Clair Toguem Tagne, Alain Vissiere, Mohamed Damak, Charyar MehdiSouzani, Nabil Anwer, René Mayer, Hichem Nouira, Advanced ultra-high precision system (NanoCyl) for accurate cylindricity measurements, CIRP Journal of Manufacturing Science and Technology, Volume 59, July 2025, Pages 118-126, DOI 10.1016/j.cirpj.2025.03.005
7. Safouane El Ghazouali, Youssef Mhirit, Ali Oukhrid, Umberto Michelucci, Hichem Nouira, FusionVision: A Comprehensive Approach of 3D Object Reconstruction and Segmentation from RGB-D Cameras Using YOLO and Fast Segment Anything, Sensors2024, 24(9), 2889, DOI 10.3390/s24092889
8. Jean-Michael Muller, Mehdi Daakir, Marc Pierrot Deseilligny, Florian Barcet, Implementation of coded targets for metrology applications in MicMac, a free open-source photogrammetric software, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2024, Volume XLVIII-2/W7-2024, DOI 10.5194/isprs-archives-XLVIII-2-W7-2024-89-2024

Project partners

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For more information, visit our project website https://projects.lne.eu/jrp-di-vision/

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