euspen's 25th International Conference & Exhibition, Zaragoza, ES, June 2025
www.euspen.eu

Traceable machine vision systems for digital industrial applications: the DI-Vision project

Sofia Catalucci[1], Katarina Josić[2,3], Ladji Fofana[2,3], Linus Teir[4], Luigi Ribotta[5], Joffray Guillory[2], Charyar Mehdi-Souzani[3], Rok Klobučar[6], Olivier Bruneau[3], Maurizio Galetto[7], Nabil Anwer[3], Enrico Savio[1], Hichem Nouira[2]

[1]*Università degli Studi di Padova, Padova, Italy;* [2]*Laboratoire national de métrologie et d'essais/Conservatoire national des arts et métiers, Paris, France;* [3]*École normale supérieure Paris-Saclay, Paris, France,* [4]*VTT Technical Research Centre of Finland, Helsinki, Finland;* [5]*Istituto Nazionale di Ricerca Metrologica, Turin, Italy;* [6]*Univerza v Mariboru, Maribor, Slovenia;* [7]*Politecnico di Torino, Turin, Italy*

sofia.catalucci@unipd.it

Abstract

In the context of digital transformation and the EU Green Deal, machine vision systems (MVSs) are emerging as key technologies for automated inspection, quality control, and precision measurement across industries such as aeronautics, pharmaceuticals, medical devices, electronics, and semiconductors. Despite their growing adoption, MVSs often lack traceability and standardised calibration methods, making their deployment in manufacturing indispensable for ensuring accuracy and reliability. The DI-Vision project tackles these challenges by developing traceable material standards with prismatic and complex geometries, better representing real-world industrial surfaces. The project also advances the use of Digital Twins (DTs) to enable robust uncertainty evaluations and accurate MVS modelling. Additionally, dense-image matching algorithms, along with defect detection classifiers and analysis tools, aiming at enhancing the reliability of industrial inspections are proposed. To validate these developments, DI-Vision will investigate industrial case studies across 13 applications, spanning multiple sectors. The project will also deliver Good Practice Guides (GPGs) and establish a measurement infrastructure through collaboration with European Metrology Networks (EMNs) MathMet, TraceLabMed, AdvManu, as well as standards organisations (ISO/TC213, ASTM) and key industrial stakeholders. By providing traceable solutions, DI-Vision will drive advancements in industrial automation and precision manufacturing, ensuring greater reliability and efficiency across diverse sectors.

Machine vision systems, traceability, Digital Twins, digital manufacturing

1. Introduction

In the context of Industry 4.0 digital transformation and the EU Green Deal initiative, machine vision systems (MVSs) play a critical role in modern industry, enabling automated fast inspection, quality control, and precision measurement [1]. As digital transformation advances, traceability becomes a major challenge, as MVSs often lack standardised calibration methods and reference data. Current industrial MVSs often operate without a well-defined uncertainty framework, making their results difficult to compare across different systems and industries. The absence of standardised protocols limits their effectiveness, particularly in high-value industries such as aeronautics, pharmaceuticals, medical, electronics, and semiconductor production, where reliability is crucial. Europe remains globally competitive in these sectors, yet further advancements are needed.

The global machine vision market was valued at €13.23 billion in 2021, with projections indicating a compound annual growth rate (CAGR) of ~7% from 2022 to 2030. Europe accounts for approximately one-third of the total market revenue share, highlighting the strategic importance of investing in the advancement of such technologies. As the quality assurance and inspection segment constituted over 50% of the market revenue in 2021, the demand for traceable machine vision systems (T-MVSs) has become indispensable for promoting the zero-defect manufacturing and zero-waste strategies. Thus, ensuring standardised traceability and metrological validation is essential to optimising MVSs performance and enabling reliable deployment across industrial sectors. Despite the urgent demand, traceability of such instruments is yet to be fully achieved.

The DI-Vision project [2] aims to bridge this gap by introducing traceable metrology frameworks for MVSs in tandem with the implementation of ISO 10360-13 [3], incorporating both physical material standards and Digital Twins (DTs) to simulate system behaviour and enable robust uncertainty evaluation methods [4]. Through validated calibration methods, advanced algorithmic solutions, and industrial case studies, the project will ensure that MVSs achieve higher reliability, accuracy, and efficiency in various industrial applications. The ultimate goal is to optimise production processes via enhancing productivity and flexibility, guaranteeing safety, and reducing environmental impact by minimising material waste and energy consumption in industrial applications.

2. Aims of DI-Vision

The overall objective of this project is to ensure the traceability of MVSs deployed in industry for macro- and micro-scale applications. The specific aims are:

1. To establish traceability of existing and newly developed MVSs: the project seeks to enhance the traceability of MVSs by developing material standards with canonical and complex shapes that represent real-world industrial surfaces

and components. These standards will cover various dimensional, structural, surface and operational quality characteristics, ensuring that MVS measurements can be validated against reference artefacts. Additionally, new calibration strategies will be introduced, enabling uncertainty quantification across different MVS applications, with a targeted uncertainty of 1 µm to 150 µm.

2. To develop DTs of existing and newly developed MVSs: to serve as virtual representations of measuring systems, created using a combination of physical modelling and computational techniques. These models enable systematic error analysis to enhance accuracy and reduce measurement cycle times, optimal measurement strategy development, and real-time simulation of MVSs performances. The DTs will be validated statistically by comparing physical and virtual measurement data.
3. To investigate novel methods of image matching algorithms using softgauges (reference data): current image matching and classification techniques often struggle with precise three-dimensional (3D) reconstructions and, in turn, the correct identification and classification of potential defects. To address these limitations, the project will develop robust dense-image matching algorithms to improve the alignment and processing of captured images. By leveraging deep learning techniques, including convolutional neural networks, the project aims to develop robust image processing algorithms with implemented uncertainty evaluation techniques to improve reliability in automated inspection systems. These algorithms will undergo rigorous testing against softgauges to ensure their effectiveness in industrial applications.
4. To investigate and validate while addressing industrial use cases: a key aspect of the project is the industrial validation of the developed T-MVS solutions. The performances of the systems will be tested on a total of 13 real-world industrial scenarios, including applications such as automotive, aerospace, healthcare, and semiconductor industries. More specifically, high-precision inspection of gears, turbine blades, and electronic circuits is essential in automotive manufacturing, in the aerospace sector the validation of freeform surfaces and structural components is paramount, while in the pharmaceutical industry the use of hyper-spectral imaging (HSI) for quality control in drug packaging and diagnostics will be explored. The project will conduct round-robin comparison exercises, where different laboratories and industrial partners will test and validate the developed methods, to verify consistency and repeatability across different facilities.
5. To facilitate the take up of the developed technologies (dissemination and standardisation): the final objective is to ensure the widespread adoption of DI-Vision's findings by engaging with standardization bodies and industrial stakeholders. Collaboration with organizations such as ISO/TC213, ASTM, and European Metrology Networks (EMNs) will facilitate the integration of the project's outcomes into new industry standards. Additionally, the project will produce comprehensive Good Practice Guides (GPGs) and technical reports to support industrial adoption. To promote knowledge transfer, training programs, webinars, and online courses will be made available to researchers, engineers, and quality control professionals, ensuring that the developed methodologies can be effectively implemented across different sectors.

3. Work programme and key deliverables of DI-Vision

The DI-Vision project spans 36 months and is divided into several work packages (WPs), as displayed in Figure 1.

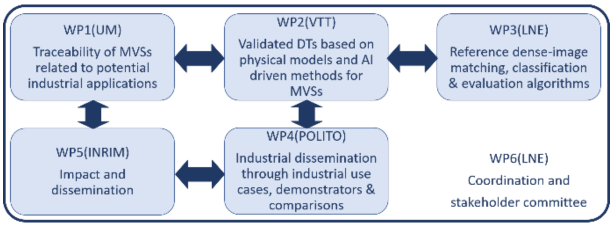

Figure 1: Project structure and subdivision into work packages.

WP1 focuses on the development of material standards and calibration methods, while WP2 is dedicated to the creation of validated DTs for machine vision applications. WP3 advances dense-image matching, defect detection and classification, and uncertainty-aware processing algorithms, and WP4 is dedicated to the validation and dissemination of project results through industrial case studies and round-robin comparisons. Finally, WP5 is responsible for impact creation through training activities, dissemination, and standardisation efforts.
Key deliverables include:

1. new calibration standards for MVS traceability;
2. validated DTs for error analysis and optimisation;
3. GPGs for industrial adoption;
4. technical reports on algorithm development and industrial validation.

4. Outlook

The DI-Vision project is poised to develop the use of MVSs, by addressing the challenges of traceability, validation, and industrial implementation across a range of high-value sectors. The outcomes of this project will directly contribute to the EU Green Deal by enhancing energy efficiency, reducing waste, and promoting sustainable manufacturing. By ensuring that MVSs provide reliable and traceable measurements, industries will benefit from higher productivity, lower defect rates, and improved resource efficiency. The long-term impact of this project extends beyond industrial applications, influencing scientific research, healthcare, and metrology communities worldwide. By providing traceable MVS solutions, DI-Vision will pave the way for the next generation of industrial automation, ensuring accuracy, reliability, and sustainability in digital manufacturing and beyond.

Acknowledgement

Financial support from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and the Participating States (Grant 23IND08 DI-Vision) is greatly acknowledged.

References

[1] Charan A, Chowdary K C, Komal P 2022 The Future of Machine Vision in Industries- A systematic review *IOP Conf. Ser.: Mater. Sci. Eng.* **1224** 012027

[2] https://projects.lne.eu/jrp-di-vision/

[3] ISO 10360 part 13 2021 Geometrical Product Specifications (GPS)—Acceptance and reverification tests for coordinate measuring systems (CMS) - Part 13: Optical 3D CMS *(Geneva: International Organization for Standardization)*

[4] Jones D, Snider C, Nassehi A, Yon J, Hicks B 2020 Characterising the Digital Twin: A systematic literature review *J. Manuf. Sci. Technol.* **29** 36-52