euspen's 26th International Conference & Exhibition, Krakow, PL, June 2026
www.euspen.eu

Digital metrological twins for stereovision systems - A literature review

Katarina Josic[1,2,3], Ladji Fofana[1,2,3], Louis-Ferdinand Lafon[1], Charyar Mehdi-Souzani[2], Romain Brault[3], Nabil Anwer[2], Olivier Bruneau[2], Hichem Nouira[1]

[1] *Laboratoire national de métrologie et d'essais/Conservatoire national des arts et métiers, 1 Rue Gaston Boissier, 75015 Paris, France*
[2] *Université Paris-Saclay, ENS Paris-Saclay, LURPA, 91190 Gif-sur-Yvette, France*
[3] *Centre technique des industries mécaniques, 52 Avenue Félix Louat, 60300 Senlis, France*

katarina.josic@lne.fr

Abstract

Stereovision can be defined as a measurement process reliant on multiple images taken from different perspectives to estimate three-dimensional dense informations and parameters, thereby enabling the metrological evaluation of form errors and surface texture parameters. Digital Metrological Twin is defined as a numerical model that depicts a specific measurement process and indicates an associated measurement uncertainty for a specific measurement value, which is traceable to the units of the international system of units. A comprehensive literature review on the integration of stereovision systems and digital metrological twins has been conducted using a PRISMA methodology, exploring different applications, frameworks and challenges. Digital twins of stereovision systems could be useful tools for developing, modeling, testing, and optimizing the usage of stereovision in many industrial contexts. By bridging the gap between the digital and physical domains, they enable virtual testing and validation and pave the way for the more accurate, effective and efficient implementation of stereovision technologies in the real world. This review reveals a major barrier to the integration of digital twins and stereovision systems for industrial applications in terms of availability of standards among hardware, software, and data layers. Achieving high accuracy in intelligent industrial settings is limited due to increased complexity, expenses and lack of calibration standards for stereovision systems. Future efforts to resolve these gaps will aid in promoting widespread adoption. This research is beneficial for the creation of a digital twin for a stereovision 3D scanning system being developed at LNE in the scope of the 23IND08 Di-Vision project.

Systematic literature review, stereovision, digital twins, metrology

1. Introduction

Stereovision allows visual feedback of spatial connections and distances, and comprehension of complex object geometry by recreating three-dimensional information from two-dimensional images using the principle of triangulation. This feature, which provides rich 3D information with basic and affordable sensor technology, has become a fundamental component in disciplines including autonomous navigation, collaborative robots, and intelligent manufacturing. Stereovision has become even more relevant in recent years due to its integration with digital twin technologies. Digital twins are digital representations of real-world entities constantly fed by dynamic, bidirectional communication and updates throughout the lifecycle of these sophisticated paired systems [1]. Since digital twins depend on accurate, real-time representations of observable entities, stereovision provides an effective method of 3D reconstruction of these entities. The development of a digital twin for a structured light stereovision 3D scanning system at the French National Metrology Laboratory (LNE) as part of the 23IND08 Di-Vision [2] European project benefits from this study.

2. Methodology

This literature review was conducted using the PRISMA methodology [3] and the scientific database Google Scholar. Publications from 2018 to 2025 were included in a thorough preliminary search for literature on the integration of digital twins and stereovision systems, as a rapid growth in the number of publications was noted beginning from 2018. The assessment focused on keywords "digital twin," "stereovision," "industry," and "production" .

Out of the 200 materials that were found, 63 were eliminated because they lacked citations, as to ensure the review's credibility. After the 137 remaining records were screened, 124 resources were eliminated because they did not fall inside the review's scope for a variety of reasons, mostly because they addressed digital twins and stereovision systems in unrelated contexts. Finally, 13 materials were selected and reviewed. The selection process is illustrated in **Figure 1**.

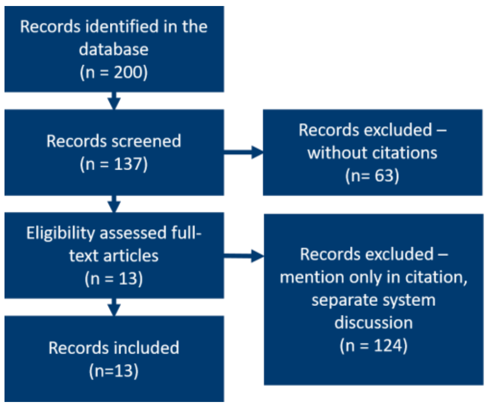

Figure 1: Resource selection

3.Stereovision

Stereovision is a measurement technology used for 3D reconstruction and depth perception, applicable in many industrial fields [4]. It is based on stereo correspondence, which is the method of creating a 3D representation of an item from two or more images of the same scene. According to the literature [4, 5, 6], this technology is divided into two types: passive stereovision, which uses ambient light and features to find correspondences, and active stereovision, which projects structured light (such as grids or coded patterns) onto objects to aid in the matching process, particularly for featureless or smooth surfaces. Passive stereovision scanners use two cameras [4], whereas active stereovision systems combine cameras and projectors [7], as illustrated in **Figure *2***. The difference between modeling these two systems is that the projector is treated as an inverted camera, transmitting rather than receiving light. A single camera is limited in terms of depth information, as many 3D points might correspond to the same pixel point on the image [8]. While active techniques are more robust in poor visibility conditions [6] and provide easier height measurement through laser triangulation [9], they can sometimes be burdened by outlier points caused by interreflection, whereas passive systems may provide denser and cleaner point clouds if a scene is naturally rich in detail [6, 10]. Complementary and integrated use of both passive and active stereovision systems as a strategy to overcome the constraints of each individual approach is explored [4, 6, 9]. A common issue with passive stereo vision is the "false boundary problem" [4]. When a stereovision sensor's two cameras see a smooth and curved surface, each camera's inspection of the surface's border may differ from the surface's real boundary. Consequently, the surface boundary that is retrieved by comparing these two artificial borders in the two cameras will be inaccurate. A combined technique employs passive stereovision to identify rough surface borders and active stereovision to detect interior curvatures and surface features [4]. This problem is effectively resolved by calibrating structured light in active stereovision and dynamically positioning the cameras in passive stereovision. Moreover, systems can benefit from the consistent surface coverage and texture independence offered by active techniques in low visibility situations while taking use of the high point density frequently observed in passive techniques by combining a point cloud collected by both passive and active approaches.

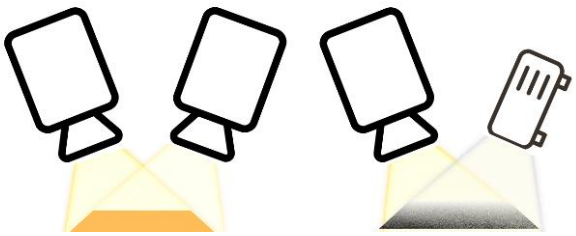

Figure 2: Passive stereovision (left) and active stereovision (right)

4. Digital twins

The digital twin was first presented by NASA as a *"an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin*" [11]. Michael Grieves expanded this idea beyond aerospace by defining the digital twin as the "*a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro-atomic level to the macro-geometrical level*" [12]. The digital twin was formalized specifically for manufacturing by the ISO 23247 as a "*fit for purpose digital representation of an observable manufacturing element with synchronization between the element and its digital representation*" [13]. This standard provided a reference architecture for digital twins widely used today, displayed in **Figure *3***.

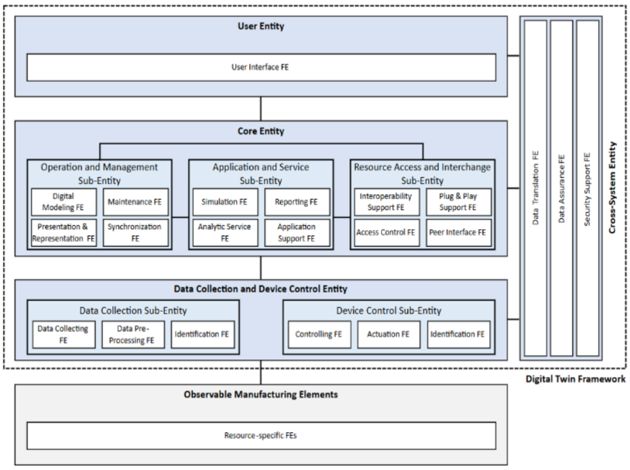

Figure 3: Reference architecture [12]

This term was formalized again when ISO/IEC 30173 provided a domain-agnostic definition of a digital twin as a "*a digital representation of a target entity with data connections that enable convergence between the physical and digital states at an appropriate rate of synchronization*" [14]. In a metrological context, a Digital Metrological Twin is defined as "*a numerical model that depicts a specific measurement process and indicates an associated measurement uncertainty for a specific measurement value, which is traceable to the units of the international system of units*" [15]. It is possible to expand these concepts to suggest a digital twin in metrology as "*a digital model of a measurement process connected to the physical system by a closed loop, then providing the associated measurement uncertainty for a given measured value traceable to the meter unit definition*".

5. Integration of digital twins and stereovision systems

The integration of digital twins with stereovision systems provides significant value by offering a high-fidelity simulation environment that enables for the safe testing and validation of complicated navigation and safety algorithms without endangering actual hardware or human lives [16]. Before any software is installed on the actual machine, digital twins enable the validation of navigation algorithms and safety features in a risk-free virtual environment [17]. Virtual stereoscopic cameras and environmental factors are simulated by engines such as Gazebo [10, 17]. Researchers can test localization and navigation algorithms in a virtual operating environment when the environment is not available for testing by replicating the system's operational environment as part of the digital twin using this tool. The digital twin is becoming more and more used in the digitization and automation of production processes [18]. Digital twins can be used for virtual simulation and testing of vision-based systems with an infinite number of design options [19]. The system can look for ideal topologies and parameters that meet certain job requirements using different deep-learning methods for various metrological purposes[19]. To increase inference speed and matching accuracy, digital twins can be programmed to tune the underlying neural networks of stereovision systems, such as those used for stereo matching or depth estimation [19].

In mixed reality (MR) contexts, digital twins can enable real-time distance measurement and collision detection between virtual components and unknown real-world objects [20]. The virtual world mesh and the scene mesh captured by the stereovision system can be intersected to accomplish this [20]. Digital twins also assist to reduce the load of streaming high-resolution 3D point clouds. In order to minimize interruptions to crucial control links, engineers can detect network bottlenecks and split visual data to different networks by modeling sensor data flows [17]. Through the integration of MR goggles and stereovision concepts, the digital twin can allow operators to use natural human motions to operate a physical robot. These systems make use of imitation-based motion mapping, which tracks the user's hand motions and translates these into orders for the robot's tool center point's spatial velocity. The digital twin makes it easier for novel users to use this technology [20]. Digital twins facilitate the generation of precise virtual coordinates for camera frames by visualizing hand-eye calibration data, thus enabling system traceability. This allows virtual sensors to be calibrated with identical distortion coefficients and focal lengths as their physical counterparts, ensuring accurate visual feedback [16]. Moreover, by allowing the user to interact with the system's replica in MR while concurrently viewing real-time sensor data from the remote site, the digital twin helps address problems with virtual transparency [20]. Virtual transparency is the degree to which the MR interface allows the user to "see through" the virtual layer in order to fully understand the actual or simulated system underlying it, rather than the interface limiting that insight.

6. Industrial applications

Stereovision combined with digital metrological twins provides precise three-dimensional information about objects, processes, and surroundings, reflecting real-world situations more realistically and responsively. In industrial settings, where accurate spatial awareness and real-time updates are crucial for various processes, this combination is especially beneficial. Stereovision systems integrated with digital metrological twins offer a diverse range of high-precision industrial applications.

6.1. Autonomous navigation

In the field of mobile robotics and logistics, these integration enables autonomous navigation and "virtual docking" by providing a Digital World Model that allows robots to plan collision-free paths and adjust their behavior to dynamic shopfloor changes without disrupting active production [16]. "Virtual docking" is a localization method where the mobile robot uses fiducial markers (like AprilTags) to precisely locate itself in front of a workstation. This increases shopfloor flexibility by eliminating the requirement for physical clamping devices. Although the stereo camera used for these tasks had 3D capabilities, only 2D data was used for the localization, achieving good results with a smaller amount of data to create a real-time map for collision-free trajectory planning.

6.2. Manufacturing systems

Stereovision systems have been shown to contribute to the efficiency and precision of weld route recognition [9], particularly for complex welds during production [21]. Active stereovision (projecting structured light, such as dot matrices or laser lines) is used for weld seam tracking and bead inspection because the regular patterns make it easier to retrieve height and contour information independent of the metal's surface roughness [9]. For weld pool monitoring, passive stereovision is used since it offers trustworthy geometric characteristics like width, length, and convexity to forecast penetration states. Digital twins serve as visual monitors for robotic arc welding, using multi-sensor fusion to estimate weld pool penetration and track seams in real time [21].

Robotic manipulators rely on stereovision systems for accurate identifying, grasping, and placing objects, which is essential for robust manufacturing [16]. To guarantee safe handling, systems employ CAD matching and 3D point-cloud matching to determine the posture of complex objects. Stereovision was utilized for the localization and grasping of dampers in an automobile vehicle front-axle assembly, illustrating its potential to improve assembly line reconfigurability. Integrated digital twins provide real-time distance assessment between virtual robot components and unknown real-world barriers using MR goggles [20]. Moreover, automation of sorting tasks can be performed using cognitive cells which feature stereovision technology [22]. A cognitive cell is made up of two components: a cooperative robot acting as an actuator and a passive stereovision system carrying out sensor operations. The cognitive cell could determine the height where the object is placed via computer vision triangulation to determine depth using two cameras in full high definition. A monochrome cube served as the object in this piece. Furthermore, the cameras recognized each object's color individually and compared the results to improve accuracy. The cell's cognitive abilities were improved by this stereovision system [22]. Digital twins for these systems enable task flexibility, allowing for adaptation to changes in the environment or production, as well as rapid task planning [10].

6.3. Harsh environments

Stereovision is a useful technique in marine biology and archaeology for digitizing items that cannot be transported [6]. Active stereovision produces more stable 3D coordinates in unclear water than passive stereovision, which is limited by poor contrast and scattering. However, in clear water, passive stereovision can generate denser point clouds. A combination of 3D point clouds obtained using both stereovision methods results in higher point density from the passive technique and more coverage of the object surface from the active technique [6]. In hazardous situations like deep-sea research, space repair, nuclear rehabilitation, and remote robotic surgery, stereoscopic vision combined with a digital twin provides critical depth signals for operators operating robots remotely [21]. These signals eliminate the uncertainty present in standard 2D displays, where operators struggle to estimate the distance between a robotic gripper and a target.

7. Challenges

The literature points to certain research gaps that impact the integration of digital twins with stereovision systems. One of the main issues is a lack of consistent standards, design patterns, and universal IT tools [1, 17], [18]. These limits make it difficult to apply digital twins in real-world industrial environments. Every digital twin implementation in industry needs to be handled differently due to the low degree of universalism and the absence of approved design patterns. Design teams have to develop their own programming libraries and IT tools from scratch. This increases the time it takes to popularize such solutions in the commercial environment and raises the cost of implementing digital twins. Moreover, current systems have poor generalization in unforeseen circumstances [1], as certain frameworks based on neural networks created for one environment frequently fail when presented with various lighting or textures in the field [19]. Furthermore, certain resources highlight that communication latency and real-time synchronization problems make it challenging to maintain a zero-delay link. Broadcasting high-resolution 3D point clouds also puts a significant demand on industrial network capacity, frequently mandating the separation of vision data to prevent control system failures [16]. Time is an important factor in measurement processes and improving the communication between the virtual and physical systems is critical for the reduction of measurement uncertainty of stereovision systems.

8. Conclusion

The convergence of stereovision and digital metrological twins systems is a big step toward safer, more reliable, adaptable and accurat physical assets and processes. Without endangering actual hardware or interfering with ongoing manufacturing lines, digital twins offer a high-fidelity simulation and decision-making environment for the secure testing and validation of algorithms. They provide more accurate measurement, monitoring, process optimization, and automation in industry. However, research findings suggest that in order to proceed, important gaps including the absence of uniform standards, communication latency problems, and the severe network load associated with streaming high-resolution 3D point clouds need to be tackled.

Acknowledgment

This work is part of the project 23IND08 DI-Vision, which has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

References

[1] N. Anwer, R. Stark, F. Tao, and J. A. Erkoyuncu, 'Developing and leveraging digital twins in engineering design', *CIRP Ann.*, vol. **74**, no. 2, pp. 843–868, Jan. 2025, doi: 10.1016/j.cirp.2025.05.002.

[2] 'DI-VISION'. Accessed: Jan. 04, 2026. [Online]. Available: https://projects.lne.eu/jrp-di-vision/

[3] M. J. Page *et al.*, 'The PRISMA 2020 statement: an updated guideline for reporting systematic reviews', *BMJ*, vol. **372**, p. n71, Mar. 2021, doi: 10.1136/bmj.n71.

[4] C. Chen and Y. F. Zheng, 'Passive and active stereo vision for smooth surface detection of deformed plates', *IEEE Trans. Ind. Electron.*, vol. **42**, no. 3, pp. 300–306, Jun. 1995, doi: 10.1109/41.382141.

[5] D. Beltran and L. Basañez, 'A Comparison between Active and Passive 3D Vision Sensors: BumblebeeXB3 and Microsoft Kinect', in *ROBOT2013: First Iberian Robotics Conference: Advances in Robotics, Vol. 1*, M. A. Armada, A. Sanfeliu, and M. Ferre, Eds, Cham: Springer International Publishing, 2014, pp. 725–734. doi: 10.1007/978-3-319-03413-3_54.

[6] G. Bianco, A. Gallo, F. Bruno, and M. Muzzupappa, 'A Comparative Analysis between Active and Passive Techniques for Underwater 3D Reconstruction of Close-Range Objects', *Sensors*, vol. **13**, no. 8, Art. no. 8, Aug. 2013, doi: 10.3390/s130811007.

[7] I. Martynov, J.-K. Kamarainen, and L. Lensu, 'Projector Calibration by "Inverse Camera Calibration"', in *Image Analysis*, A. Heyden and F. Kahl, Eds, Berlin, Heidelberg: Springer, 2011, pp. 536–544. doi: 10.1007/978-3-642-21227-7_50.

[8] R. Hartley, 'Triangulation, Computer Vision and Image Understanding', *Comput. Vis. Image Underst.*, 1997, Accessed: Apr. 12, 2025. [Online]. Available: https://www.semanticscholar.org/paper/Triangulation%2C-Computer-Vision-and-Image-Hartley/77f0fc6beb53d96c1f9e38a57ba6fc74f939982b

[9] F. Xu, Y. Xu, H. Zhang, and S. Chen, 'Application of sensing technology in intelligent robotic arc welding: A review', *J. Manuf. Process.*, vol. **79**, pp. 854–880, Jul. 2022, doi: 10.1016/j.jmapro.2022.05.029.

[10] X. Yang, Z. Zhou, J. H. Sørensen, C. B. Christensen, M. Ünalan, and X. Zhang, 'Automation of SME production with a Cobot system powered by learning-based vision', *Robot. Comput.-Integr. Manuf.*, vol. **83**, p. 102564, Oct. 2023, doi: 10.1016/j.rcim.2023.102564.

[11] E. Glaessgen and D. Stargel, 'The Digital Twin Paradigm for Future NASA and U.S. Air Force Vehicles', in *53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference*, American Institute of Aeronautics and Astronautics. doi: 10.2514/6.2012-1818.

[12] M. Grieves and J. Vickers, 'Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems', in *Transdisciplinary Perspectives on Complex Systems*, F.-J. Kahlen, S. Flumerfelt, and A. Alves, Eds, Cham: Springer International Publishing, 2017, pp. 85–113. doi: 10.1007/978-3-319-38756-7_4.

[13] 'ISO 23247-1:2021', ISO. Accessed: Dec. 26, 2025. [Online]. Available: https://www.iso.org/standard/75066.html

[14] 'ISO/IEC 30173:2023(en), Digital twin — Concepts and terminology'. Accessed: May 22, 2025. [Online]. Available: https://www.iso.org/obp/ui/en/#iso:std:iso-iec:30173:ed-1:v1:en

[15] O. Baer *et al.*, 'Digital Twin concept of a force measuring device based on the finite element method', *Acta IMEKO*, vol. **12**, pp. 1–5, Mar. 2023, doi: 10.21014/actaimeko.v12i1.1404.

[16] A. C. Bavelos *et al.*, 'Enabling Flexibility in Manufacturing by Integrating Shopfloor and Process Perception for Mobile Robot Workers', *Appl. Sci.*, vol. **11**, no. 9, p. 3985, Apr. 2021, doi: 10.3390/app11093985.

[17] P. Stączek, J. Pizoń, W. Danilczuk, and A. Gola, 'A Digital Twin Approach for the Improvement of an Autonomous Mobile Robots (AMR's) Operating Environment—A Case Study', *Sensors*, vol. **21**, no. 23, p. 7830, Nov. 2021, doi: 10.3390/s21237830.

[18] L. Zhou, L. Zhang, and N. Konz, 'Computer Vision Techniques in Manufacturing', *IEEE Trans. Syst. Man Cybern. Syst.*, vol. **53**, no. 1, pp. 105–117, Jan. 2023, doi: 10.1109/TSMC.2022.3166397.

[19] W. Li *et al.*, 'Modular design automation of the morphologies, controllers, and vision systems for intelligent robots: a survey', *Vis. Intell.*, vol. **1**, no. 1, p. 2, May 2023, doi: 10.1007/s44267-023-00006-x.

[20] K. Lalik and S. Flaga, 'A Real-Time Distance Measurement System for a Digital Twin Using Mixed Reality Goggles', *Sensors*, vol. **21**, no. 23, p. 7870, Nov. 2021, doi: 10.3390/s21237870.

[21] Y.-P. Su, X.-Q. Chen, C. Zhou, L. H. Pearson, C. G. Pretty, and J. G. Chase, 'Integrating Virtual, Mixed, and Augmented Reality into Remote Robotic Applications: A Brief Review of Extended Reality-Enhanced Robotic Systems for Intuitive Telemanipulation and Telemanufacturing Tasks in Hazardous Conditions', *Appl. Sci.*, vol. **13**, no. 22, p. 12129, Nov. 2023, doi: 10.3390/app132212129.

[22] W. A. A. Cotta, S. I. Lopes, and R. F. Vassallo, 'Towards the Cognitive Factory in Industry 5.0: From Concept to Implementation', *Smart Cities*, vol. **6**, no. 4, pp. 1901–1921, Aug. 2023, doi: 10.3390/smartcities6040088.