Journal of Emerging Intelligence and Engineering Technologies

Research Article

Artificial Intelligence, Machine Learning, IoT, Robotics, and Digital Twins: A Comprehensive Review of Intelligent Technologies

Preneath Southea[1], Ngoun Sophorn[2]

[1]Research Scholar, Computer Science Studies, College of Science, Norton University, Phnom Penh, Cambodia
[2]Computer Science Studies, College of Science, Norton University, Phnom Penh, Cambodia

Abstract

Artificial intelligence (AI), machine learning (ML), the Internet of Things (IoT), robotics, and digital twin technology together constitute the core technological pillars of the current intelligent systems era, each with a distinct history, methodological foundation, and body of research, yet increasingly studied and deployed in relation to one another. This paper presents a comprehensive review of these five intelligent technologies, examining each discipline in turn before surveying the intersections and synergies between them. For each technology, the review summarizes its conceptual foundations, principal methods and sub-domains, and current market trajectory, drawing on recent industry data: the global AI market, valued at an estimated $757.58 billion in 2025, dwarfs the digital twin market ($21.14 billion in 2025) and the artificial intelligence robotics market ($6.11 billion in 2025) by more than an order of magnitude, even as the underlying physical substrate of these systems, the population of internet-connected IoT devices, is projected to grow from approximately 18.8 billion in 2024 to 40 billion by 2030. The review then examines cross-cutting themes, including AI-augmented IoT (AIoT), digital twin-enabled robotics, and edge intelligence, and surveys representative application domains spanning manufacturing, healthcare, transportation, and smart infrastructure. Critical open challenges are discussed, including data interoperability across technologies, computational and energy constraints, security and privacy risks in interconnected systems, and the widening gap between AI software capability and physical robotics hardware maturity. The paper concludes by identifying emerging directions, including embodied AI, generative AI-augmented digital twins, and standardized cross-technology interoperability frameworks. This review is intended to serve as a consolidated, evidence-based reference for researchers and practitioners across these five intelligent technology domains.

Keywords: Artificial Intelligence, Machine Learning, Internet of Things, Robotics, Digital Twin, Intelligent Systems, Embodied AI, Edge Intelligence.

Received: 12 July 2025
Revised: 08 Au1ust 2025
Accepted: 20 November 2025
Published: 30 December 2025

Introduction

Artificial intelligence (AI), machine learning (ML), the Internet of Things (IoT), robotics, and digital twin technology each represent a substantial, independently developed field of research and practice, with distinct intellectual histories dating from, respectively, the mid-twentieth century origins of AI as a formal discipline, the statistical learning theory underlying modern ML, the early-2000s coining and subsequent commercialization of the IoT concept, decades of industrial and research robotics preceding the current wave of AI-enabled autonomy, and the digital twin concept's origins in aerospace and manufacturing engineering. Each field maintains its own dedicated research communities, conferences, and bodies of literature, and a comprehensive treatment of any one of them individually would constitute a substantial review in its own right.

At the same time, a defining characteristic of the current technological era is the increasing degree to which these five fields inform, depend upon, and are deployed alongside one another. Modern AI and ML systems are frequently trained on and deployed against data generated by IoT sensor networks; IoT platforms increasingly embed AI/ML capability directly at the network edge; robotics has been transformed by the integration of modern AI perception and learning-based control; and digital twins, once primarily geometric and physics-based simulation artifacts, are increasingly AI-augmented, learning-enabled representations that both consume IoT sensor data and inform robotic control. Understanding any one of these technologies in isolation, without reference to this broader intelligent technology landscape, provides an increasingly incomplete picture of the field's current state and trajectory.

This paper adopts a deliberately comprehensive scope, reviewing each of the five technologies in turn before examining their intersections, and grounding the discussion throughout in current market data. As detailed in Section 7, the scale disparity between these technologies as currently commercialized is substantial: the global AI market, valued at an estimated $757.58 billion in 2025, is more than an order of magnitude larger than the digital twin market ($21.14 billion) and nearly two orders of magnitude larger than the artificial intelligence robotics market specifically ($6.11 billion), even as the underlying IoT device population that increasingly feeds these AI systems is projected to more than double from approximately 18.8 billion devices in 2024 to 40 billion by 2030.

This paper presents a comprehensive review of AI, ML, IoT, robotics, and digital twin technology, with the following objectives: (1) to review the conceptual foundations, principal methods, and market trajectory of each individual technology; (2) to examine the cross-cutting intersections and synergies between them; (3) to survey representative application domains; (4) to critically examine open challenges; and (5) to identify promising future research and practice directions.

The remainder of this paper is organized as follows. Section 2 reviews artificial intelligence. Section 3 reviews machine learning. Section 4 reviews the Internet of Things. Section 5 reviews robotics. Section 6 reviews digital twin technology. Section 7 presents comparative market data across all five technologies. Section 8 examines cross-cutting intersections and application domains. Section 9 discusses open challenges. Section 10 outlines future directions, and Section 11 concludes the paper.

Artificial Intelligence

Artificial intelligence, broadly defined as the design of computational systems capable of performing tasks that would typically require human intelligence, encompasses a wide range of sub-disciplines that have risen and fallen in relative prominence over the field's history. Early AI research emphasized symbolic reasoning, search, and expert systems encoding explicit human knowledge as rules. The field's current dominant paradigm, statistical and neural machine learning, is treated as a distinct technology in Section 3 given its methodological centrality to nearly all other technologies reviewed in this paper. Beyond machine learning specifically, the contemporary AI field additionally encompasses generative AI, including large language and multimodal foundation models capable of producing novel text, code, images, and other content; autonomous agents capable of planning and executing multi-step tasks with limited human supervision; and a substantial applied research literature addressing AI safety, alignment, and explainability, motivated by the field's rapidly expanding real-world deployment. As detailed in

Section 7, the AI market's scale, an estimated $757.58 billion in 2025, substantially exceeds that of the other technologies reviewed in this paper, reflecting both its broad applicability across virtually every industry sector and its increasingly foundational role in the other four technologies.

Machine Learning

Machine learning, the dominant methodological engine of contemporary artificial intelligence, encompasses algorithms that learn patterns and decision rules directly from data rather than through explicit, manually authored programming. Supervised learning, in which models learn to map inputs to known output labels, underlies the majority of commercially deployed predictive and classification systems. Unsupervised learning, including clustering and dimensionality reduction, extracts structure from unlabeled data. Reinforcement learning, in which an agent learns a decision policy through interaction with an environment guided by a reward signal, underlies much of contemporary robotics control and sequential decision-making research, discussed further in Section 5. Deep learning, employing multi-layer neural network architectures, has driven the majority of recent breakthroughs across each of these paradigms, from convolutional networks for computer vision to transformer architectures underlying modern generative AI and large language models. Machine learning's centrality to the other four technologies reviewed in this paper, providing the perception and decision-making capability within IoT, robotics, and digital twin systems alike, is a recurring theme throughout this review.

Internet of Things

The Internet of Things refers to the network of physical devices, embedded with sensors, processors, and network connectivity, that collect and exchange data, extending network connectivity and computational capability beyond traditional computing devices into the physical environment. IoT architectures typically span a device layer of sensors and actuators, a connectivity layer employing protocols such as low-power wide-area networks, cellular, or short-range wireless connectivity suited to differing latency, bandwidth, and power constraints, and a

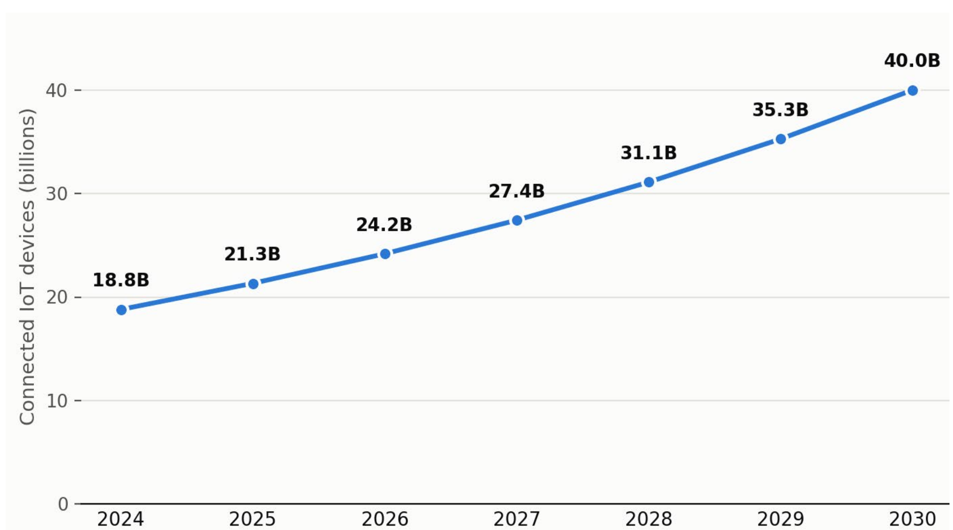

Figure 1: Projected worldwide IoT-connected devices, 2024–2030. Source: IoT Analytics.

platform layer aggregating and processing device data, increasingly incorporating AI/ML capability directly at the network edge to enable low-latency local decision-making without continuous cloud connectivity.

The physical scale of global IoT deployment continues to expand rapidly and is presented in Figure 1: the population of connected IoT devices worldwide is estimated at approximately 18.8 billion in 2024 and projected to reach 40 billion by 2030, driven by continued deployment across industrial, consumer, healthcare, and smart infrastructure applications. This sustained device growth underlies much of the data volume that feeds AI and ML model training and inference across the other technologies reviewed in this paper, and increasingly informs the real-time state synchronization underlying digital twin systems, discussed in Section 6.

Robotics

Robotics, the engineering discipline concerned with machines capable of sensing their environment, making decisions, and physically acting upon the world, has a research and industrial history predating the current AI era by several decades, rooted in industrial manipulator arms and early mobile robotics research. Contemporary robotics has been substantially transformed by the integration of modern AI and ML capability: computer vision-based perception has replaced or augmented earlier rule-based sensing approaches; reinforcement learning increasingly trains robotic control policies directly, particularly for manipulation and locomotion tasks difficult to specify through explicit programming; and large multimodal foundation models are increasingly explored as a basis for more general-purpose, instructable robotic behavior, an emerging sub-field often termed embodied AI. Despite this substantial capability advance, the artificial intelligence robotics market, valued at an estimated $6.11 billion in 2025, remains, as shown in Figure 2, dramatically smaller in commercial scale than the broader AI software market, reflecting the higher capital cost, slower deployment cycles, and greater physical-world engineering complexity characteristic of robotics hardware relative to software-only AI deployment.

Digital Twin Technology

A digital twin is a continuously synchronized virtual representation of a physical asset, process, or system, maintained through real-time or near-real-time data exchange with its physical counterpart, typically via IoT sensor data. Originating in aerospace and manufacturing engineering as primarily geometric and physics-based simulation models, digital twin technology has increasingly incorporated AI and ML capability, enabling predictive analytics, anomaly detection, and increasingly generative scenario simulation within the virtual environment, in addition to its traditional role in visualization and physics-based simulation. Digital twins serve an increasingly central role in validating and training robotic control policies in simulation prior to physical deployment, discussed further in Section 8, and in supporting predictive maintenance and process optimization decisions informed by IoT sensor data. The digital twin market, valued at an estimated $21.14 billion in 2025, sits at an intermediate scale between the broader AI software market and the more nascent AI robotics hardware market, as shown in Figure 2, and has been among the fastest-growing segments of the broader intelligent technology landscape in recent market forecasts.

Comparative Market Data Across the Five Technologies

Table 1 summarizes the conceptual foundation, principal methods, and 2025 market size across the five technologies reviewed in this paper, and Figure 2 visualizes the substantial scale disparity between the three technologies for which

Table 1: Overview of the Five Intelligent Technologies

Technology	*Conceptual Foundation*	*Principal Methods/Sub-domains*	*2025 Market Size*
Artificial Intelligence	Systems that perform tasks requiring human-like reasoning	Search/planning, expert systems, generative AI, agents	$757.58 billion
Machine Learning	Learning patterns from data rather than explicit programming	Supervised, unsupervised, reinforcement, deep learning	Subsumed within AI market
Internet of Things	Networked physical devices that sense and exchange data	Sensor networks, edge gateways, device connectivity protocols	18.8B devices (2024)
Robotics	Physical machines that perceive, decide, and act in the world	Manipulation, mobile robotics, human-robot interaction	$6.11 billion (AI robotics)
Digital Twin	Synchronized virtual replica of a physical system or process	Physics-based modeling, real-time state synchronization	$21.14 billion

comparable market-size data is available: the global AI market ($757.58 billion), the digital twin market ($21.14 billion), and the AI robotics market ($6.11 billion), plotted on a logarithmic scale given the more than two-order-of-magnitude range spanned by these figures. This disparity reflects the differing maturity, deployment cost, and breadth of applicability across the three markets: AI, and increasingly generative AI specifically, has achieved broad, relatively low-marginal-cost software deployment across nearly every industry sector, while digital twin and robotics technologies remain comparatively more capital- and integration-intensive to deploy, particularly at the physical hardware layer represented by robotics.

Cross-Cutting Intersections and Application Domains

Cross-Cutting Intersections

AI-Augmented IoT (AIoT): The integration of AI/ML capability directly within IoT devices and edge gateways, enabling local perception and decision-making without continuous cloud connectivity, represents one of the most actively developing intersections among the five technologies, driven by the growing device population documented in Figure 1 and the increasing availability of compressed, edge-deployable AI models.

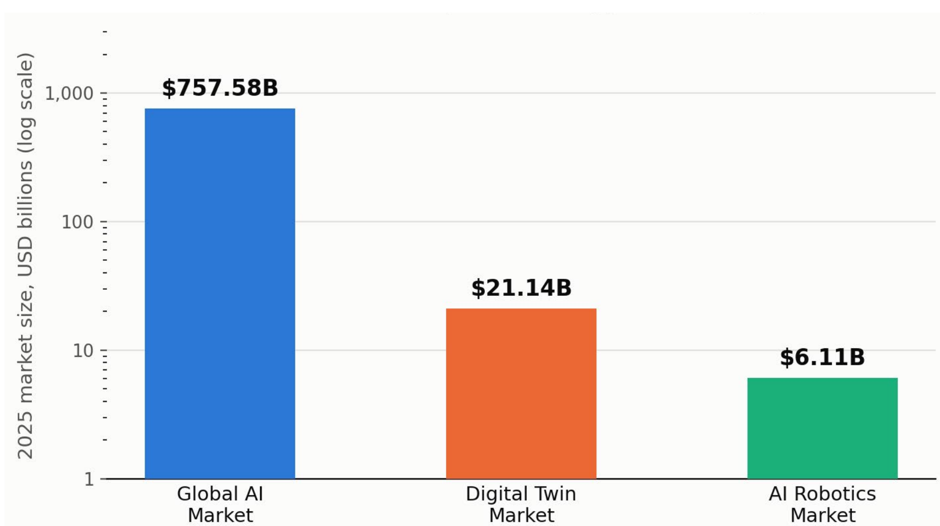

Figure 2: 2025 market size by technology pillar, log scale. Source: market forecast data compiled from industry analyses.

Digital Twin-Enabled Robotics: The use of digital twins to simulate, train, and validate robotic control policies before physical deployment, discussed in Section 6, represents a critical intersection that substantially reduces the real-world data collection and physical risk associated with training AI-driven robotic behavior, particularly for reinforcement learning-based control approaches.
Edge Intelligence: The broader movement of AI/ML inference and, increasingly, training capability from centralized cloud infrastructure toward IoT devices, edge gateways, and robotic platforms themselves cuts across all five technologies, driven by latency, bandwidth, privacy, and connectivity-reliability requirements common to real-time autonomous and IoT applications alike.

Representative Application Domains

Manufacturing: Smart factory deployments integrate IoT sensor networks, AI/ML-driven predictive maintenance and quality inspection, digital twin-based process simulation, and increasingly AI-enabled robotic automation, representing the most mature convergence application domain across all five technologies.
Healthcare: Applications span AI/ML-driven diagnostic and clinical decision support, IoT-based patient monitoring devices, digital twins of individual patients or organs for treatment planning, and increasingly autonomous or semi-autonomous surgical and care robotics.
Transportation: Autonomous vehicle development integrates dense onboard and infrastructure IoT sensing, AI/ML-driven perception and planning, digital twin-based simulation for training and safety validation, and the vehicle itself as a robotic platform, representing a domain in which all five technologies are simultaneously essential.
Smart Infrastructure and Cities: Municipal deployments integrate IoT sensor networks monitoring traffic, utilities, and environmental conditions, AI/ML-driven analytics and optimization, and increasingly digital twins of urban infrastructure supporting planning and emergency response simulation, with robotics playing a more limited but growing role in infrastructure inspection and maintenance.

Open Challenges

Data Interoperability Across Technologies: IoT, AI/ML, robotics, and digital twin platforms frequently employ distinct data formats, protocols, and vendor ecosystems, and achieving seamless data interoperability across this heterogeneous landscape remains a persistent engineering and integration challenge, echoing similar interoperability concerns documented in related enterprise AI and data intelligence literature.
Computational and Energy Constraints: Deploying capable AI/ML models directly on resource- and power-constrained IoT and robotic edge devices requires substantial model compression and efficient hardware, an active research area with meaningful trade-offs between model capability and deployment feasibility, particularly for battery-powered or energy-harvesting IoT devices.
Security and Privacy in Interconnected Systems: The interconnection of AI, IoT, robotics, and digital twin systems substantially expands the potential attack surface relative to any single technology deployed in isolation, and securing this interconnected landscape against both traditional cybersecurity threats and AI-specific risks, such as adversarial manipulation of sensor data or model outputs, remains an area of active concern.
The Software-Hardware Capability Gap: The substantial market-scale disparity documented in Figure 2 reflects a broader capability gap between rapidly advancing AI software capability and the comparatively slower-advancing, more capital-intensive physical robotics hardware required to fully realize AI-driven physical autonomy, a gap that industry analysts consistently identify as a key

constraint on the pace of real-world autonomous system deployment.

Standardization and Governance: The rapid, largely independent evolution of standards, protocols, and governance frameworks across AI, IoT, robotics, and digital twin domains complicates the development of coherent, cross-technology governance approaches, particularly as increasingly autonomous, interconnected systems raise novel safety and accountability questions that single-technology governance frameworks do not fully address.

Future Directions

Embodied AI: Continued research into general-purpose, instructable robotic behavior grounded in large multimodal foundation models represents a rapidly emerging direction with the potential to narrow the software-hardware capability gap discussed in Section 9, by enabling more flexible, less task-specific robotic AI capability.

Generative AI-Augmented Digital Twins: The integration of generative AI capability into digital twin platforms, enabling more flexible scenario generation, natural-language interaction with simulation environments, and synthetic data generation for training AI/ML and robotics systems, represents a promising and rapidly advancing research direction.

Standardized Cross-Technology Interoperability Frameworks: The development of standardized protocols and data models spanning AI, IoT, robotics, and digital twin platforms represents an important direction for reducing the integration burden identified in Section 9 and accelerating the practical realization of cross-technology intelligent systems.

Continued Edge Intelligence Advancement: Ongoing advances in model compression, efficient neural architectures, and specialized edge AI hardware are likely to continue narrowing the gap between cloud-scale AI capability and what can be deployed directly on IoT devices and robotic platforms, expanding the range of feasible real-time, autonomous edge applications.

Convergent Market Maturation: As digital twin and AI robotics markets continue to grow at CAGRs substantially exceeding that of the broader AI market, as documented in related market analyses, the current scale disparity shown in Figure 2 is likely to gradually narrow over the coming decade, reflecting the increasing commercial maturation of the physical and simulation layers of the intelligent technology stack.

Conclusion

Artificial intelligence, machine learning, the Internet of Things, robotics, and digital twin technology each represent substantial, independently developed fields, yet the current era of intelligent systems is increasingly defined by their interconnection rather than their separate advancement. This review has examined each technology's conceptual foundations, principal methods, and market trajectory in turn, finding a striking scale disparity, an AI market of $757.58 billion in 2025 against a digital twin market of $21.14 billion and an AI robotics market of just $6.11 billion, even as the underlying IoT device population continues to expand toward a projected 40 billion devices by 2030. The review has further examined the cross-cutting intersections, including AI-augmented IoT, digital twin-enabled robotics, and edge intelligence, through which these technologies increasingly depend upon and reinforce one another, alongside representative applications spanning manufacturing, healthcare, transportation, and smart infrastructure. While persistent challenges around data interoperability, computational constraints, security, the software-hardware capability gap, and governance remain significant, continued progress toward embodied AI, generative AI-augmented digital twins, and standardized cross-technology interoperability is likely to define the next phase of intelligent technology development, and the current market-scale disparities documented in this review are themselves likely to narrow as these currently smaller markets mature.

References

[1] S. Russell and P. Norvig, Artificial Intelligence: A Modern Approach, 4th ed. Boston, MA, USA: Pearson, 2021.
[2] T. Mitchell, Machine Learning. New York, NY, USA: McGraw-Hill, 1997.
[3] L. Atzori, A. Iera, and G. Morabito, “The Internet of Things: A survey,” Computer Networks, vol. 54, no. 15, pp. 2787-2805, 2010.
[4] R. Siegwart, I. R. Nourbakhsh, and D. Scaramuzza, Introduction to Autonomous Mobile Robots, 2nd ed. Cambridge, MA, USA: MIT Press, 2011.
[5] M. Grieves and J. Vickers, “Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems,” in Transdisciplinary Perspectives on Complex Systems, Springer, 2017, pp. 85-113.
[6] R. S. Sutton and A. G. Barto, Reinforcement Learning: An Introduction, 2nd ed. Cambridge, MA, USA: MIT Press, 2018.
[7] Precedence Research, “Artificial Intelligence (AI) Market Size and Trends, 2026-2035,” 2025. Available: https://www.precedenceresearch.com/artificial-intelligence-market
[8] MarketsandMarkets, “Digital Twin Market Size, Share, Latest Trends & Growth Analysis, 2025-2030,” 2025. Available: https://www.marketsandmarkets.com/Market-Reports/digital-twin-market-225269522.html
[9] MarketsandMarkets, “Artificial Intelligence (AI) Robots Market Report 2025-2030,” 2025. Available: https://www.marketsandmarkets.com/Market-Reports/artificial-intelligence-robots-market-120550497.html
[10] IoT Analytics, “Number of Connected IoT Devices Growing 14% to 18.8 Billion,” 2024. Available: https://iot-analytics.com/number-connected-iot-devices/
[11] “Toward Intelligent AIoT: A Comprehensive Survey on Digital Twin and Multimodal Generative AI Integration,” Mathematics, vol. 13, no. 21, p. 3382, 2025. Available: https://www.mdpi.com/2227-7390/13/21/3382
[12] “From Simulation to Autonomy: Reviews of the Integration of Artificial Intelligence and Digital Twins,” International Journal of Precision Engineering and Manufacturing-Green Technology, Springer Nature, 2025. Available: https://link.springer.com/article/10.1007/s40684-025-00750-z