

Literature Survey on Secure and Scalable Digital Twin Architecture for Industrial IoT-Based Smart Manufacturing Systems

¹Dr. Pravin Latane

¹Professor and Dean Academics, Dr. D. Y. Patil College of Engineering and Innovation,
Department of Computer Engineering, Varale, Talegaon, Pune., Lincoln University College, Malaysia
pclatane@gmail.com, pdf.pravin@lincoln.edu.my,

Abstract: Industry 4.0 has completely changed how factories work by bringing together cloud computing, artificial intelligence (AI), cyber-physical systems, and the Industrial Internet of Things. A big part of this change is digital twin technology. This technology creates a live, virtual copy of physical systems. It can monitor things in real time, predict how things will behave, analyze what's happening, and control them smartly. Even though digital twins show a lot of promise, there are still many challenges to using them in real factories. These include making them bigger, getting them to work across different systems, dealing with delays in communication, and making sure they are secure. This study suggests a digital twin system based on IIoT ideas to help make smart workplaces of the future safer, easier to expand, and better at making quick decisions.

Keywords: Digital Twins, Industry 4.0, Blockchain, Technology trends, Industrial Internet of Things.

Introduction

New Industry 4.0 technologies are quickly changing how industries work today. We're moving from old-fashioned factories that relied a lot on people to smart production systems that use a lot of data. This shift is happening because of things like the Industrial Internet of Things (IIoT), cyber-physical systems, cloud computing, and artificial intelligence. Digital Twin (DT) technology is a big part of this. It creates a very accurate virtual model of something real. Digital Twins help us watch things in real time, run advanced simulations, predict what might happen, and make decisions based on the situation. This connects physical things with digital data, making manufacturing much more efficient and productive.

But even with these advancements, there are still several problems that limit how much we can use digital twins in factories. The main worries are whether these systems can handle huge amounts of data, if they can keep real-time information perfectly synced, if they can work well with different kinds of platforms, and how strong their cybersecurity is against growing threats. Also, it's hard to combine IIoT and digital twins because there aren't many agreed-upon standards or secure ways for them to talk to each other. On top of that, it's complex to manage many different data sources and make sure everything works together smoothly from start to finish, especially in systems that are far apart.

Related Work

Other research has looked at how supply chain management has moved from old, rule-based ways to new systems that use data from IoT sensors and AI. Using IoT devices at the edge along with digital twins powered by machine learning has made supply chains much clearer, improved how well we can predict demand, and made operations more flexible [1-3].

Some papers also talk about the move from Industry 4.0 to Industry 5.0. This next stage focuses more on people and being environmentally friendly in areas like managing water. Technologies like IoT sensor networks, blockchain records, AI for smart processes, and advanced data analysis make it possible to monitor the environment in real time, fix infrastructure predictively, and use resources more efficiently [4-5].

Digital twins are seen as key to connecting Industry 4.0's focus on automation with Industry 5.0's focus on sustainability and people working with machines. Digital twins linked with IIoT have been shown to help track assets, figure out why things went wrong, and make decisions based on facts in industrial processes [6-8].

In the oil and gas industry, there's a growing use of AI and blockchain technology. This shows a bigger need for smart systems that are secure and where data can't be tampered with. It's been confirmed that combining AI and blockchain makes supply chains more open, reduces transaction costs, and keeps data accurate across different industrial operations [9-10].

Another study highlights how important digital twins are for making manufacturing processes better, especially when it comes to sustainable development. By combining engineering knowledge with data science, digital twins can significantly improve energy efficiency, how resources are used, and reduce waste in manufacturing [11].

Overall, this study covers topics from data science, artificial intelligence, mechanical, industrial, electrical, and electronic engineering, to how manufacturing operations are managed. We've looked at what other studies focused on, what they contributed, what they found, and what questions they left unanswered. Comparison of Related Literature which covers Focus Areas, Key Contributions, Insights, and Research Gaps are presented in table 1.

Table 1. Comparison of Related Literature: Focus Areas, Key Contributions, Insights, and Research Gaps

No.	Author & Year	Focus Area	Key Contribution	Key Insight	Research Gap
[1]	Iranshahi et al. (2025)	DT Trends	Future DT directions	Multi-domain DT usage	It has Integration challenges
[2]	Kabir & Ray (2025)	DT Tools	Use of scalable DT tools	Real-time CPS integration	It has Limited interoperability
[3]	Massaro (2025)	AI + DT	AI-integrated DT	Industry 5.0 shift	Security is not addressed
[4]	Sitahong et al. (2025)	Optimization	DT scheduling models	Real-time optimization	It has scalability issues
[5]	Liu et al. (2022)	DT Systems	DT-driven manufacturing	Improved efficiency	It has latency issues
[6]	Xu et al. (2022)	DT + Industry 4.0	Architecture review	CPS integration	It has standard gaps
[7]	Rasheed et al. (2022)	DT Challenges	DT challenges review	Value-driven DT	Implementation issues
[8]	Wang et al. (2023)	Smart Factory	IIoT-based factory models	Improves automation	High implementation cost
[9]	Bi et al. (2022)	Smart Manufacturing	Advanced manufacturing systems	Supports smart factory vision	Lack of DT integration
[10]	Lu et al. (2023)	Industry 4.0	Support IIoT framework	Drives digital transformation	Security gaps

No.	Author & Year	Focus Area	Key Contribution	Key Insight	Research Gap
[11]	Zhang et al. (2023)	IoT Systems	IoT-based manufacturing	Enables real-time monitoring	Data overload

Methods, Experiments, and Results

Based on our review of earlier research, this study proposes a complete, layered Digital Twin system. We designed it to fix problems with security, how easily systems can grow, and how quickly they respond in smart manufacturing settings that use IIoT. This suggested system brings together four linked parts into one, expandable whole: connecting physical devices, syncing digital twins in the cloud, processing data at the edge, and smart features at the application level as shown in fig 1.

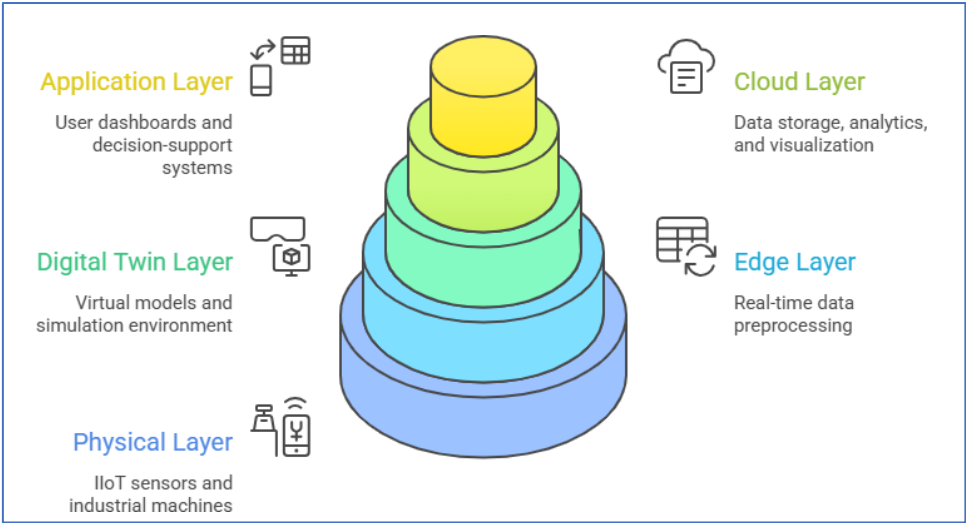


Figure 1: Overview of IIoT-enabled Digital Twin Architecture

This system starts with a small network of IIoT sensors and actuators built into the factory. These devices use common ways to communicate, like MQTT, OPC-UA, and CoAP, to send a steady stream of data. This data includes things like temperature, humidity, how much things vibrate, how much energy is being used, and how much is being produced. This raw data is first handled by the edge computing part before it's sent to the cloud. The cloud synchronization part keeps the digital twin's status updated by constantly matching data from physical sensors with the virtual model. Blockchain technology is used to create secure records of all changes and updates. This creates a permanent history that meets both legal requirements and industry security standards by documenting all state transitions and configuration modifications. This part also uses machine learning models to help improve processes on the fly, check quality, and schedule maintenance before things break. Finally, the application intelligence part lets both people and automated systems use dashboards to help with decisions, simulation tools, and automated control panels.

Results

We created a new and secure digital twin system for IIoT. This system includes a real-time synchronization feature that works with improved speed. We also developed a way to predict when industrial equipment needs maintenance using artificial intelligence. Figure 2a and 2b illustrates a new and safe Digital Twin architecture for IIoT.

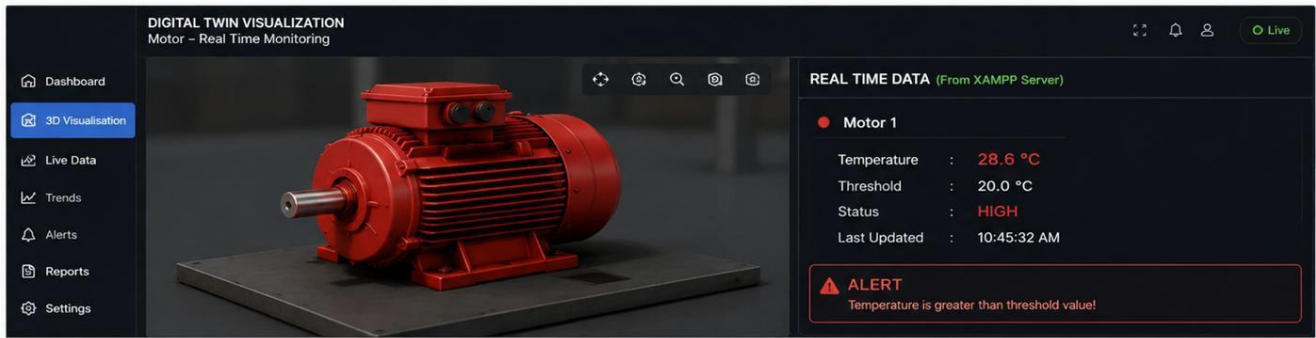


Figure 2a: Digital twin interface displays a temperature-triggered threshold-triggered state shift.

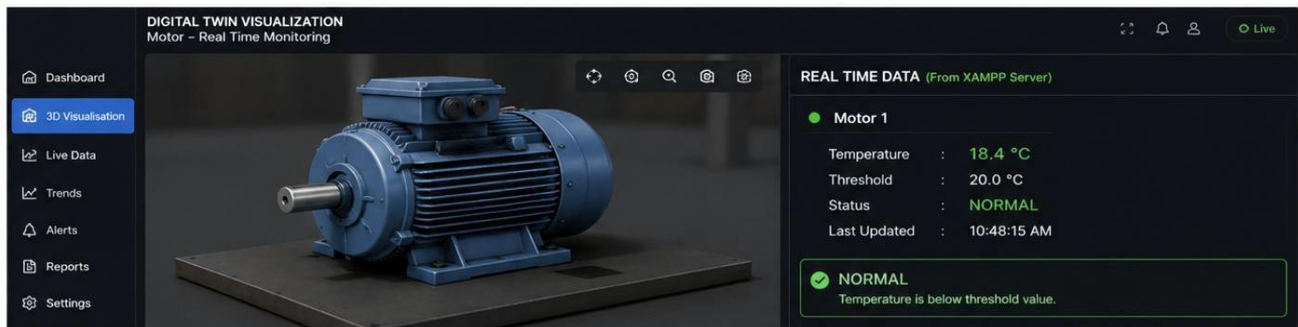


Figure 2b: Digital Twin interface displays Normal (Temperature) state transition

Discussion

The research we looked at shows that digital twin technology can really change how industrial applications work, especially those using IIoT. These systems are moving faster towards being able to grow easily, work on their own, and be good for the environment, fitting into Industry 5.0. This is happening because digital twins are coming together with AI analysis, secure blockchain systems, computing that spans from edge devices to the cloud, and combining data from many different kinds of sensors. We've seen clear evidence that digital twin systems are flexible and make good business sense. They improve how different areas are managed, make processes better throughout their whole lifespan, and help predict when maintenance is needed.

Conclusions

We've carefully reviewed a lot of recent, expert-checked research. This review shows how much digital twin technology is changing smart industrial systems that use IIoT. Most of this research confirms that digital twins greatly improve how accurately we can monitor things in real time, how well we can predict maintenance needs, how effective process optimization is, and how completely we can manage the entire life of products across different industries. Digital twin systems are moving much faster towards becoming self-operating, scalable, and sustainable for Industry 5.0. This is thanks to combining them with AI analysis, secure blockchain systems, edge-to-cloud computing, and advanced ways to analyze data. All in all, the information we've shared here proves that digital twin technology has huge potential. It can help build smart manufacturing systems that are effective, strong, and good for the environment, especially when designed with IIoT connections, AI features, and strong cybersecurity. Because of this, digital twin technology will become an even more important part of the bigger move towards the next generation of smart industrial systems.

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