Digital twins in ensuring human life safety

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Abstract

This article introduces an ontological model of digital twins and explores their classification specifically in the context of ensuring human life safety. The paper delves into how digital twins - virtual replicas of physical systems or processes - can be used to improve safety standards, especially in high-risk industries like oil and gas. By simulating real-world scenarios and potential hazards, digital twins provide valuable insights that can help predict and mitigate risks before they impact human life. The article also highlights various examples of digital twins successfully applied to enhance safety measures, such as monitoring dangerous environments, predicting equipment failures, and providing real-time data to improve decision-making during emergencies. Moreover, the prospects for developing digital twins are discussed, particularly in integrating advanced technologies like artificial intelligence, machine learning, and IoT. These advancements could significantly enhance the capabilities of digital twins in safeguarding human life, making them an indispensable tool in industrial safety and risk management practices.

Keywords

Ontological model, digital twins, ensuring human life safety

1. Introduction

Digital twins have become one of the key technologies in the modern world, particularly in ensuring human safety. They represent virtual models of physical objects or systems that allow for monitoring their status, predicting potential risks, and preventing accidents and emergencies. Various researchers, including Michael Grieves, Edgar Iverson, Frank Pöppelbaum, Feng Tao, Grzegorz J. Nalepa, Julian Gardner, etc., provide deep analyses of digital twins and their significance in the studied fields. Michael Grieves, one of the founders of the digital twin concept [1], describes the key elements and architectural principles of digital twins, emphasizing their importance for industry and production processes. Understanding the application of digital twins [2] in various industries requires building the modeling of digital twins considering multiple aspects.

In this article, the role of digital twins in ensuring human life safety, their classification, and application across different spheres of life will be examined. The creation of digital twins in this field plays a crucial role in improving the quality of training individuals for emergencies, as well as in preventing accidents.

2. Materials and methods

1. Concept and Essence of Digital Twins in Ensuring Life Safety

A digital twin is a virtual copy of a real object or system that synchronizes with it in real time to obtain information about its status and predict possible scenarios. Unlike traditional control methods, a digital twin allows for more accurate and timely analysis.

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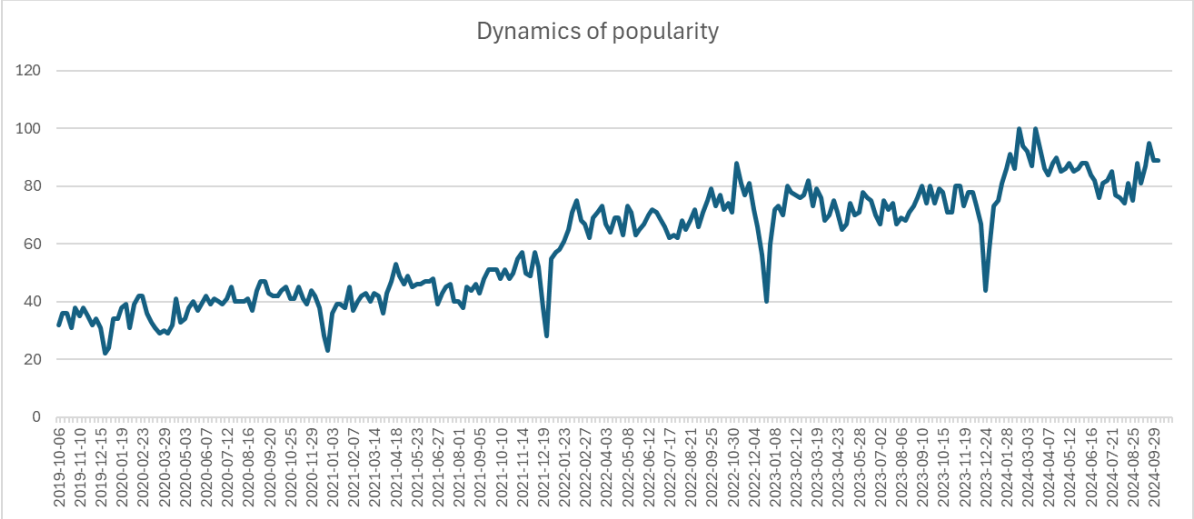

Figure 1: Dynamics of the Popularity of Digital Twins.

Figure 1 shows that the popularity of digital twins is growing worldwide, with demand increasing threefold over the last four years. Digital twins have begun to appear in various economic sectors, and researchers have developed their ontological model. Ontological models help structure data and describe relationships between objects within the context of digital twins.

Many authors [3-5] provide a comprehensive literature review on the creation of the ontology of digital twins, focusing on developing ontological descriptions for automating production and integrating various digital technologies. In their publications [3-5], they discuss the use of ontologies to support digital twins in industry. They emphasize the integration of semantic models and cyber-physical systems, which is directly relevant to the application of digital twins in ensuring human life safety.

The main characteristics of digital twins in safety include continuous monitoring, threat forecasting based on data analysis, modeling reactions to extreme situations, and implementing preventive measures to avoid incidents. Modeling digital twins must start with creating an ontological model.

An ontological model for ensuring human life safety, encompassing health, the environment, safety techniques, physical and psychological protection, and interactions within government regulation, will be built. This model requires structuring key concepts and relationships that reflect the main elements of life safety.

Key categories for creating the ontology structure will be introduced.

A: Human (residents, children, workers, etc.);

D: Hazards (physical, chemical, biological, social, informational threats);

P: Protection measures (first aid, personal protective equipment, etc.);

S: Situations (natural disasters, technological accidents, military conflicts);

G: Government structures (emergency organizations, health institutions, labor protection agencies);

N: Legal norms (safety regulations, including international and national laws);

I: Safety infrastructure (fire alarms, surveillance systems, etc.).

You can describe the relationships between categories as follows:

A - > encounters -> D

D - > causes -> S

G - > manages -> S

P - > protects -> A

N - > regulates -> G

2. Classification of Digital Twins in Safety Digital twins can be classified based on their application area, maturity level, and used models. The main types of digital twins for human safety include:

- Process digital twins (e.g., fire protection systems in buildings);
- Infrastructure digital twins (for smart cities and transport systems);
- Medical digital twins (for monitoring health and preventing diseases) [6].;
- Personal safety digital twins (for smart homes and accident prevention).

3. Here are examples of how digital twins can enhance safety in daily life:

a) Emergency Services: Digital twins are used to create accurate models of buildings and fire safety systems, allowing real-time monitoring of fire sensors and predicting fire developments. Virtual simulations of emergencies (fires, technological disasters, transport accidents) enable responders to practice action scenarios, modeling various critical situations in real time.

b) Personal Safety in Smart Homes: A digital twin can predict potential threats, such as gas leaks or power supply failures, and take preemptive measures. Additionally, digital twins of buildings and individuals can simulate evacuation processes in real time, considering building parameters, people's locations, available exits, and crowd behavior to determine optimal evacuation routes) Industrial safety. In industries, digital twins help minimize accidents related to equipment wear and production efficiency. For example, at dangerous facilities, they can track workplace conditions and predict accidents.

c) Industrial Safety: In the industrial sector, digital twins help minimize accidents related to equipment wear and decreased production efficiency. In hazardous environments (such as chemical and oil and gas plants), digital twins can monitor workplace conditions, predict accidents, and model emergency scenarios. This capability allows employees to train and prevent potential threats before they occur, enhancing overall safety and operational effectiveness. A notable example of a digital twin in the oil and gas sector is the implementation by Tengizchevroil in 2023 of the "Digital Twin of the KTL 1 and KTL 2 Complex Technological Line". This digital representation allows for the exploration of various scenario possibilities, optimizing processes to use existing resources more effectively while reducing waste and environmental harm [7]. The introduction of digital twin systems represents a significant breakthrough into a future where artificial intelligence is key for efficient production in the oil and gas industry.

Additionally, a digital twin of a worker can be used to monitor health status, ensure proper use of personal protective equipment, track the worker's location at the oil field, identify potential hazards, and predict negative outcomes if risks are not addressed promptly.

d) Education in Schools and Educational Institutions: For schoolchildren and students studying safety (such as the Basics of Life Safety), digital twins can be utilized in educational simulations and training exercises.

Feng Tao [8] has researched how digital twins can be applied in smart manufacturing systems and Industry 4.0. He emphasizes the integration of data and process management through these technologies, which is particularly crucial for ensuring safety in industrial settings. By simulating real-world scenarios, students can gain hands-on experience and a deeper understanding of safety protocols, preparing them for future challenges in various fields.

4. Perspectives on the Development of Digital Twins in Human Safety

Modern technologies in artificial intelligence and the Internet of Things (IoT) significantly expand the capabilities of digital twins. The use of AI enables the analysis of vast amounts of data and the prediction of scenarios that are difficult to account for using traditional methods.

According to the Gartner Hype Cycle for Emerging Technologies (see Fig. 2), it is clear that digital twins are trending and are just beginning to develop.

In this regard, the key promising directions include [9]:

- enhancing the accuracy of threat predictions;

- integrating with machine learning technologies for the automatic adaptation of models;
- expanding applications within smart cities and transportation systems to improve public safety;
- developing a digital twin of individuals [10].

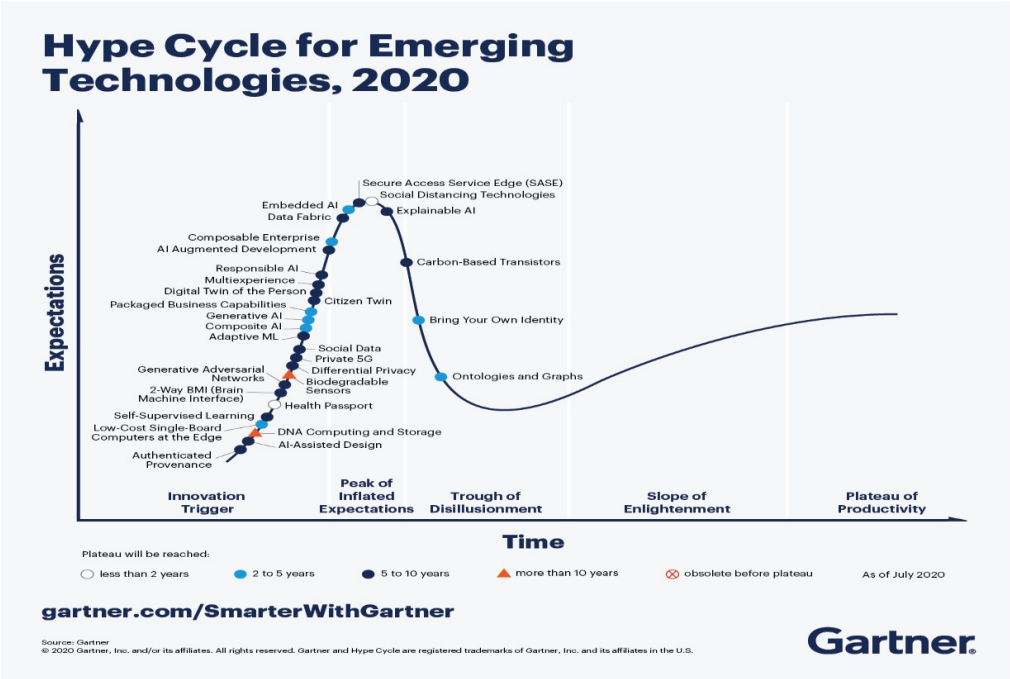

Figure 2: Hype Cycle for Emerging Technologies (Gartner Hype Cycle for Emerging Technologies, 2020) https://www.gartner.com/smarterwithgartner/5-trends-drive-the-gartner-hype-cycle-for-emerging-technologies-2020.

3. Conclusion

Considering the previously mentioned points, it becomes evident that digital twins are evolving into a highly effective tool for ensuring safety across various domains. From fire protection to health condition monitoring and forecasting, this technology is instrumental in minimizing risks, improving control systems, and enhancing overall quality of life. Digital twins allow for the creation of virtual replicas of physical systems or processes, enabling real-time analysis and the prediction of potential failures or hazards before they occur in reality. This proactive approach not only significantly contributes to accident prevention but also instills a sense of confidence in the technology's ability to ensure safety.

In sectors like healthcare, industrial safety, and urban planning, digital twins provide invaluable insights that help optimize operations and ensure safer environments for people. For instance, in healthcare, digital twins can simulate a patient's condition, allowing doctors to predict health outcomes and personalize treatment. In industrial settings, they help monitor equipment, predict failures, and prevent accidents, while in urban environments, digital twins assist in optimizing traffic management and ensuring public safety.

Looking toward the future, we can anticipate even greater integration of digital twins into everyday life. As technology advances, it will likely lead to higher safety, security, and comfort levels in both professional and personal spheres. Integrating artificial intelligence, IoT, and machine learning into digital twin systems will further enhance their capabilities, making them indispensable in safeguarding human life. Ultimately, digital twins have the potential to revolutionize how we manage risks and ensure safety across various industries, contributing to a more secure and comfortable world for everyone.

Declaration on Generative AI

The authors have not employed any Generative AI tools.

References

[1] Grieves M. Digital twin: manufacturing excellence through virtual factory replication. White paper. – 2014. – Т. 1. – №. 2014. – С. 1-7.

[2] Tao F. et al. Digital twin modeling //Journal of Manufacturing Systems. – 2022. – Т. 64. – С. 372-389.

[3] Karabulut E. et al. Ontologies in digital twins: A systematic literature review //Future Generation Computer Systems. – 2023.

[4] Rosen R. et al. About the importance of autonomy and digital twins for the future of manufacturing //Ifac-papersonline. – 2015. – Т. 48. – №. 3. – С. 567-572.

[5] L.V. Massel, T.N. Vorozhtsova. Ontological approach to the creation of digital twins of energy objects and systems// Design ontology.-2020.- T.10. - №3.- C.327-337

[6] Daineko Y. et al. Towards Metahospital: augmented and virtual reality in medicine. Procedia Computer Science. – 2024. – Т. 231. – С. 373-378.

[7] Tengizchevroil told how artificial intelligence is used /https://www.tengizchevroil.com/ru/tco-news/detail/2024/04/06/how-artificial-intelligence-is-used-in-tengizchevroil (viewed 15.09 .2024)

[8] Qi Q., Tao F. Digital Twin and Big Data Towards Smart Manufacturing and Industry 4.0: 360 Degree Comparison //IEEE Access. – 2018. – Т. 6. – С. 3585-3593.

[9] Grieves M. W. Digital twins: past, present, and future //The digital twin. – Cham : Springer International Publishing, 2023. – С. 97-121.

[10] Shengli W. Is human digital twin possible? //Computer Methods and Programs in Biomedicine Update. – 2021. – Т. 1. – С. 100014.