Digital twin for integration of design, manufacturing, and maintenance

Design, manufacturing, and maintenance of industrial equipment are usually managed separately, making them inefficient in terms of time and cost. Dr Ming-Liang Zhu, Dr Fu-Zhen Xuan and colleagues at East China University of Science & Technology develop the concept of digital twin technology to increase the efficiency of all phases that make up a product's lifecycle. Their research offers a practical solution for continuous lifecycle integration. They also identify the key challenges to developing a unified, intelligent design–manufacturing–maintenance platform that combines physical and virtual information.

Although it might seem counter-intuitive, the design, manufacturing, and maintenance of industrial equipment are usually managed independently; each task occurs separately and is guided by its own regulations. This disconnect makes these processes inefficient, both in terms of time and cost, and there is little reuse of design information. In addition, data collected from manufacturing processes and equipment maintenance rarely supports optimal design.

Traditionally, industrial maintenance and its safety assessments – including measures of structural integrity and life prediction – rely on simplified models. The complexity involved in the physical modelling of engineering equipment at a high level of accuracy adds to the challenge of integrating the design, manufacturing, and maintenance processes into any real-world model.

Dr Ming-Liang Zhu and Dr Fu-Zhen Xuan, professors at the School of Mechanical and Power Engineering, East China University of Science & Technology, and colleagues, note that so far, the application of cyber-physical systems in industrial equipment design-manufacturing-maintenance has received little attention. In their recent research, they investigate the use of digital twins to address this inefficiency. This leads them to highlight the need for a unified, intelligent design–manufacturing–maintenance platform.

WHAT IS A DIGITAL TWIN?

A digital twin is a virtual model that accurately represents a product. In the industrial field, this could be anything from an engine for an aeroplane to complex engineering equipment. The digital twin can be used throughout all phases of a product's lifecycle, from the initial design and simulation to integration, testing, monitoring, and maintenance. This digital simulation can integrate multiple data with attributes and potential applications, while also providing real-time feedback. It bridges the gap between physical products and virtual products, enabling the two to feed back to one another.

Digital twin technology accurately represents products in a virtual arena.

Engineers can also merge information from the virtual representation with data from expert databases to analyse and optimise the manufacturing process, letting each product work smarter and more efficiently. The digital twin can be used to inform maintenance decisions, enabling maintenance tasks to be virtualised with digital representations, so engineers can determine an asset's condition and performance, update and amend them, all without touching the physical asset. Optimal maintenance schedules can be established, reducing unplanned downtime and costs. Applications range from micro-manufacturing to engineering smart buildings and smart cities.

For example, researchers in Finland have developed a micro-manufacturing unit: a digital twin research facility where they investigate the construction and behaviour of a digital model of micro-manufacturing. Another example is the digital twin-based construction of a large eco-green hospital with continuous lifecycle integration in China. A digital twin software system was developed, providing managers with details of the whole hospital from design through to management. Suggestions for improvement are automatically generated from the digital building which can then be used to improve the real one. As a result, energy consumption, facility faults, and repairs have all been reduced.

A DEEP DIVE INTO DIGITAL TWIN DEVELOPMENT

In their study, the research team explore the evolution of digital twin technology, through the four developmental stages since its inception in 2002, which started with the information-mirroring models that offered digital twin concepts for workstations and servers. These include 3D modelling and analysis, computer numerical control (CNC), remote computing, and robotics. This was superseded by the second stage (2003–2014) that included digital design, 3D printing, and virtual assembly, and includes global business-to-business cooperation network access.

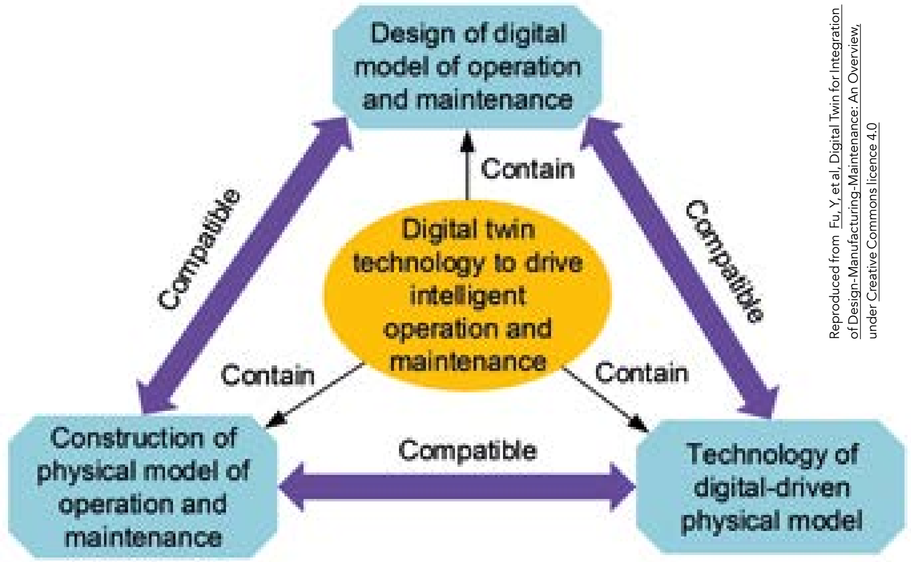
The third phase (2015–2016) followed with intelligent and connected internet of things (IoT) services which provided rapid feedback on design manufacturing and maintenance with the advent of big data and cloud computing. Since 2017, digital twins have involved mixed reality (augmented reality and virtual reality), together with cognitive services of artificial intelligence (AI), and the development of both human–computer interaction and collaboration applications.

THREE ESSENTIALS OF DIGITAL TWIN-DRIVEN INTELLIGENCE

The three core elements making up an intelligent design-manufacturing-maintenance digital twin are:

- designing virtual models of manufacturing operations and maintenance
- building the physical operations and maintenance models
- designing the information-fusion technology required to blend the digital and physical models together.

The researchers note that these three components must be compatible with one another, and the merging of the human, cyber, and physical systems is the central feature of digital twin technology. All through the product lifecycle, interaction, and collaboration between various entities are required, such as human–machine and machine–machine, both cross-platform and cross-industry. This multidisciplinary crossover digital twin technology combines and connects physical and virtual equipment data supporting the design, manufacturing, and maintenance of industrial equipment.



Digital twin technology allows for real-time feedback throughout a product's life cycle.

SUPPORTING DESIGN

The aerospace industry was an early adopter of digital twin technology. In 2011, the US Air Force Laboratory proposed the use of digital twins to predict the structural life of aircrafts and ensure their structural integrity. In 2016, they created a digital twin analysis framework that provides engineering analysis together with decision support throughout the lifecycle of an aeronautical system.

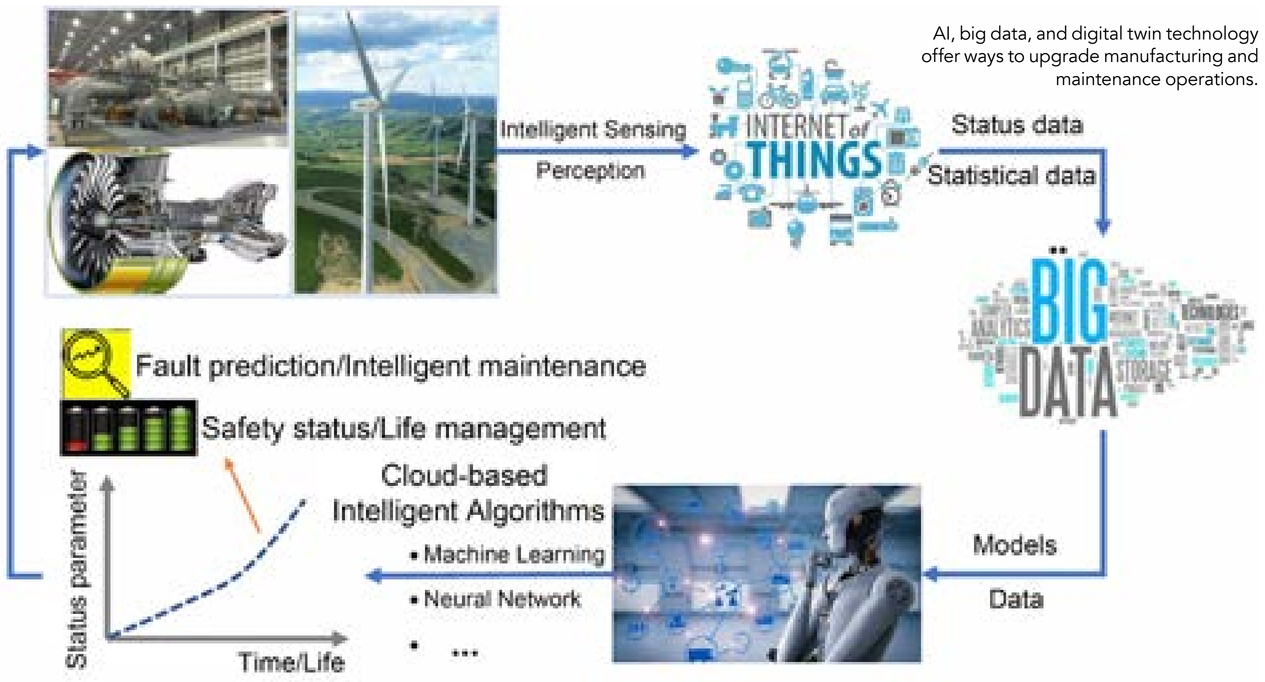
This digital simulation can integrate multiple data with attributes and potential applications, while providing real-time feedback.

Importantly, digital twin technology lets designers quickly identify and evaluate design flaws. Intelligent design requires the combination of digital twins with next generation information technology, including deep learning, machine learning, big data, and cloud computing. Machine learning can result from digital twin simulations capable of simple learning, while cloud computing offers multi-dimensional data computing and storage technology. The integration of cloud technology reduces computation time and solves the storage issues concerning large quantities of data. Businesses including General Electric, Tesla, and Siemens are using next-generation information technology in their application scenarios to enrich their digital twins. Agriculture and animal husbandry are also exploring the use of digital twins in the promotion of smart farming.

Zhu, Xuan and colleagues remark that a real-time, systematic, bi-directional, and transparent consideration of design–manufacture performance can only be achieved with full digital twin technology. This would enable the construction of the numerous models and associated data required, including models of digital products, digital designs, digital manufacturing, and digital performance.

SUPPORTING MANUFACTURING

Industry is evolving away from traditional labour-intensive product manufacturing.



AI, big data, and digital twin technology offer ways to upgrade manufacturing and maintenance operations.

Intelligent manufacturing has come to the forefront with the introduction of AI, big data, and digital twin technology, while electronic, digital, and virtual manufacturing systems offer ways to upgrade manufacturing operations. The research team has completed a detailed review of the key digital twin technologies developed over the past decade. They discuss how traditional manufacturing and its production of physical prototypes has given way to simulation assisted by computer-aided design software.

Computer-aided inspection and quality-control techniques mean that products can be inspected at every stage during the manufacturing process without the need for costly and time-intensive physical models. This digital twin approach combines manufacturing with advances such as the IoT and cloud computing. Importantly, this saves both cost and design time, as smart manufacturing becomes more adaptive, responsive, and predictive.

Digitally driven manufacturing established with digital twin technology allows manufacturers to manage co-evolving and bi-directional information mappings between the physical products and their digital representations in real time. This opens the door for deep cyber-physical integration.

SUPPORTING MAINTENANCE

Predictive maintenance has replaced both retrospective and preventive maintenance. It also paves the way for precision maintenance. Digital twin supports maintenance using five technologies: data collection, data modelling, twin data application, AI, and human–computer interaction. Intelligent maintenance involves damage perception, evolution, and prediction models, combined with diagnosis and decision intelligence. Extending this to intelligent lifetime maintenance means incorporating big data, AI, and diagnostics. In addition to improved efficiency, automatic verification systems employing intelligent operation and maintenance technology can have social and economic benefits too. The researchers show how applying intelligent technologies including AI, augmented reality, and robotics, together with online monitoring can considerably reduce both the operation and maintenance costs of large machinery, turbines, and power stations. These cases highlight the need for predictive maintenance solutions that combine augmented reality with digital twins.

Digital twin-based maintenance replaces the dependence on downtime inspection maintenance decisions with a combination of simulation and online testing. It is not simply a simulation, however, as consideration must be given to the underlying technological innovations, such as digital model building and high-fidelity sensing technology.

WHAT'S NEXT?

Through their detailed investigation of design–manufacturing–maintenance digital twins, Zhu, Xuan and colleagues demonstrate that this offers a practical solution for integrating design, manufacturing, and maintenance throughout a product's entire life span. The researchers also identify key challenges that must be overcome to advance the integration of design-manufacturing-maintenance based on digital twin technology.

Moving forward, the researchers envisage the development of a framework for combining physical and virtual information. This platform will offer a more precise design, manufacturing that is free of defects, smarter maintenance, and superior sensing technology.

The merging of the human, cyber, and physical systems is the central feature of digital twin technology.

Behind the Research

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Personal Response

What has been the most rewarding outcome of this research so far and what plans do you have to further develop your work on digital twin technology?

"This work proposes a conceptual digital twin model for the integration of design-manufacturing-maintenance. In the years ahead, the research group will focus on data science, advanced sensing and perception, artificial intelligence in structural integrity, modelling of digital twin with design, manufacturing and maintenance cross-linked. This will fulfil the development of engineering equipment with high performance, longer lifetime, and the best reliability, and to realise a more intelligent, safe and sustainable industry and life."