Digital Twin KR3

Usecase and Application

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1 Introduction

Digital Twin (DT) technology represents the creation of a virtual replica of a physical object or system that is used to simulate, monitor, and optimize its real-world counterpart. DTs integrate real-time data from the physical entity, utilizing advanced simulation, machine learning, and reasoning techniques to enhance decision-making and operational efficiency. [1]
Efforts to advance the key technologies that underpin the primary capabilities of mirroring, shadowing, and threading are actively progressing in DT-driven industries. These capabilities are critical for the effective deployment and utilization of digital twins in various sectors. [1]
Mirroring involves the creation of an exact virtual replica of a physical object or system in real-time. This capability is essential for applications such as real-time monitoring and diagnostics, virtual prototyping, and pre-production testing of products. Industries such as manufacturing, healthcare, and aerospace benefit significantly from precise replication and analysis, which ensures quality and efficiency in their operations. [1]
Shadowing focuses on continuously updating the digital twin with real-time data from its physical counterpart. This real-time data integration is vital for predictive maintenance, real-time performance optimization, and condition monitoring. Sectors like energy, utilities, and smart cities leverage shadowing to maintain system efficiency and predict potential failures, thereby avoiding downtime and reducing maintenance costs. [1]
Threading entails the integration and synchronization of multiple digital twins across different systems and processes. This capability is crucial for complex system simulations, supply chain management, and coordinated operations across multiple locations. Industries such as logistics, large-scale manufacturing, and integrated urban infrastructure rely on threading to coordinate various elements seamlessly, ensuring smooth and efficient operations. [1]
In summary, the principles of mirroring, shadowing, and threading are fundamental to the key use cases and applications of digital twin technology. These concepts enable comprehensive and integrated approaches to monitoring, optimizing, and managing complex systems across a wide range of industries.

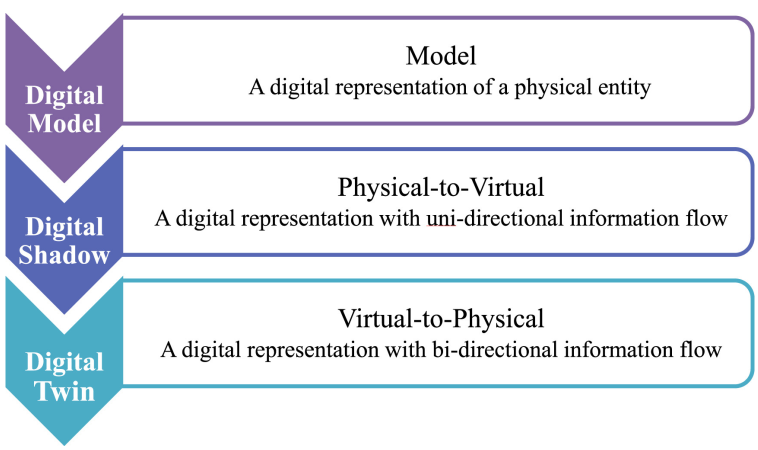

Figure 1: Levels of integration

2 Industry 4.0 and DT

In most industries, the development of Digital Twins is linked to the concept of Industry 4.0, i.e. the implementation of Digital Twin concepts , i.e. mirroring, shadowing and threading, is linked to or integrated with Industry 4.0 concepts such as the Internet of Things (IoT), cyber-physical systems (CPS), artificial intelligence (AI) and others. Today, any new implementation of digital twins should include one or more Industry 4.0 concepts. [2]

2.1 DT and CPS

Cyber-physical systems integrate cyberworld and dynamic physical worlds in a multi-dimensional and complex manner. CPS provide real-time sensing, information feedback, dynamic control and other services through the integration and collaboration of computing, communication and control, known as the "3Cs". [3]
Another concept associated with cyber-physical integration is the Digital Twin. A DT simulates real-world behaviour and provides feedback by creating high-fidelity virtual models of physical objects in virtual space. A DT reflects a bidirectional dynamic mapping process, breaking product lifecycle boundaries and providing a complete digital footprint of products. [3] This allows companies to predict physical problems earlier and with greater accuracy, to optimise the manufacturing process and to produce better products. [3]

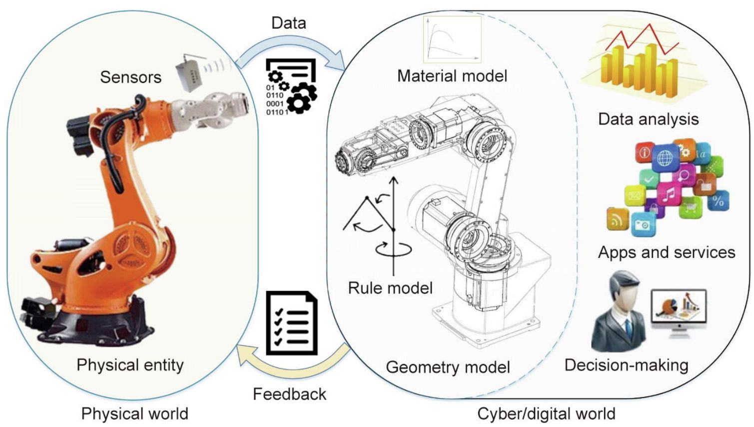

Figure 2: Integration of CPS and DTs

2.2 DT and IoT

Nowadays, we can connect physical objects remotely, accessing sensor data remotely, controlling the physical world remotely. The Internet of Things (IoT) is a concept which aims to combine data collected with data obtained from from other sources. [4]
The Internet of Things is an essential part of Industry 4.0. It is a means of communication between people, machines and products. One approach to the establishment of communication is **OPC UA**. [4]
OPCUA makes it easier to connect the digital twin to the physical twin with a third application. This could be to control and monitor the system. [5] It also allows the system to be centralised to create a main server to which more digital twins and physical twins can be connected. [5]

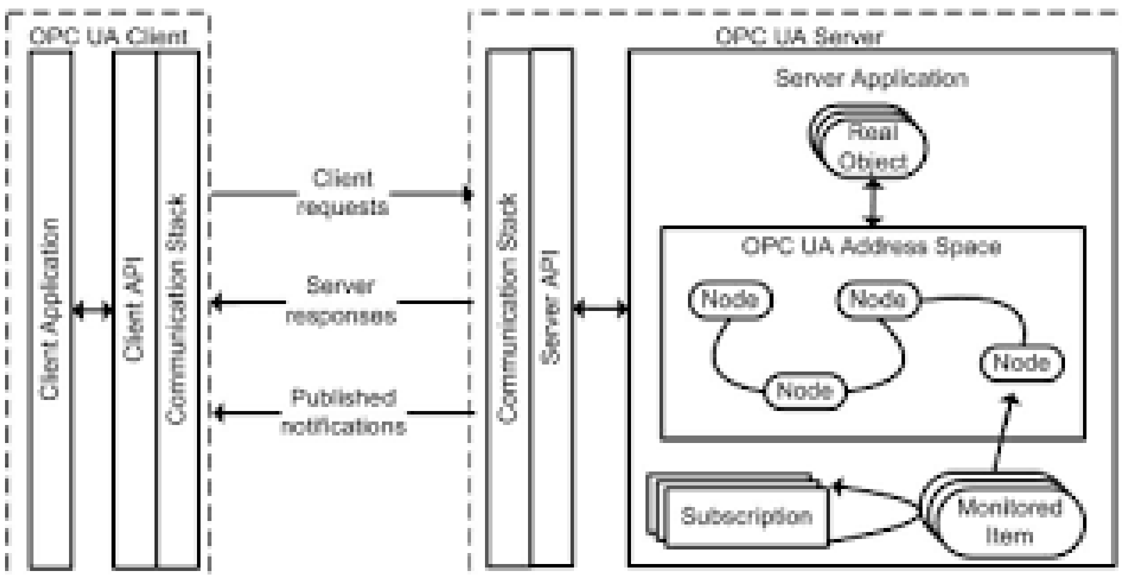

Figure 3: OPC Unified Architecture

3 Usecases for DT

3.1 System specifications

The existing system consists of a KuKa robot "KR3-R540" with a KC4 controller as a physical twin, with the team from last semester creating a digital mirror of the system using ROS2 and Gazebo. The next step in this project is to develop a digital shadow of the system. This will involve connecting the physical twin to the digital model in a unidirectional way. After that we should be able to go to the next step by implementing a full digital twin or bi-directional communication between the digital model and the physical twin, reading and monitoring data from the sensors in real time and sending commands to the physical twin via the digital model.

3.2 Usecases

We can take a step towards potential use cases that we can implement by thinking about Industry 4.0 concepts such as CPS and IoT.

3.2.1 DashKuKa

The objective is to integrate the digital twin and the physical twin into a unified dashboard for control and monitoring. This dashboard can be implemented as a desktop application, mobile app, web page, or VR application. Through this interface, users can send commands to the OPCUA server, which will subsequently synchronize the actions of both the physical and digital twins simultaneously, ensuring better synchronization between them. Additionally, the interface can display the values of the sensors, providing real-time data and insights. The use of OPCUA in this context enhances the efficiency of the synchronization between the physical and digital twins.

3.2.2 SmartKuKa

An AI system can be integrated to read and analyze the data for enhanced operational efficiency. Specifically, a machine learning (ML) model can be utilized to better calculate the movement of robotic joints and optimize the trajectory path. This ML model can be integrated into the system layers where sensor data is processed. By analyzing real-time data and historical patterns, the AI can provide precise control and improved efficiency for physical operations, ensuring optimal performance and predictive maintenance.

- **Simulation and Testing**: The digital twin provides a virtual replica of the physical system, allowing the AI to run simulations and test various trajectory paths without affecting the physical twin.
- **Data Generation**: The digital twin generates additional data that the AI can use to refine its models and improve predictions. This includes historical data, real-time sensor inputs, and environmental conditions.

- **Feedback Loop**: The AI uses the digital twin to create a feedback loop where predictions and optimizations are continuously tested and validated virtually before being applied to the physical twin.
- **Predictive Maintenance**: By analyzing data from both the digital and physical twins, the AI can predict when maintenance is needed and optimize schedules to minimize downtime.

3.2.3 RemoteKuKa

The idea is to access the robot remotely and monitor it through the Digital Twin. The digital twin provides a real-time virtual representation of the robot, allowing operators to monitor its status, movements, and sensor readings remotely. Commands can be sent to the digital twin, which are then synchronized with the physical robot, ensuring precise control and coordination even from a distance. The digital twin can display sensor values and operational data on a user-friendly dashboard, providing insights and enabling informed decision-making. By continuously comparing the digital twin's model with the physical robot's performance, any deviations or anomalies can be detected early, allowing for prompt corrective actions. Additionally, the digital twin helps predict maintenance needs by analyzing sensor data and operational trends, optimizing maintenance schedules to minimize downtime.

3.2.4 MultiKuKa

The concept is to use digital twins to coordinate and monitor the actions of multiple robots within an industrial or automation setting. Each robot has its own digital twin that mirrors its physical state and actions. The unified dashboard provides a centralized interface for overseeing and managing the collective operations of all robots.

References

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