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 or **Digital Model** 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.

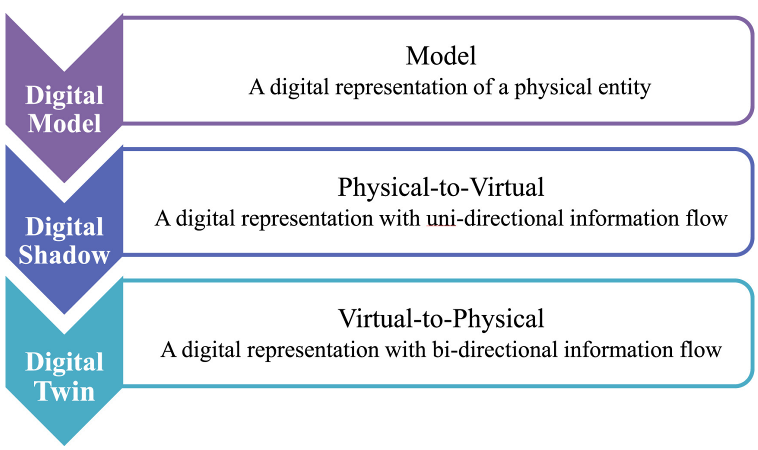

Figure 1: Levels of integration

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]

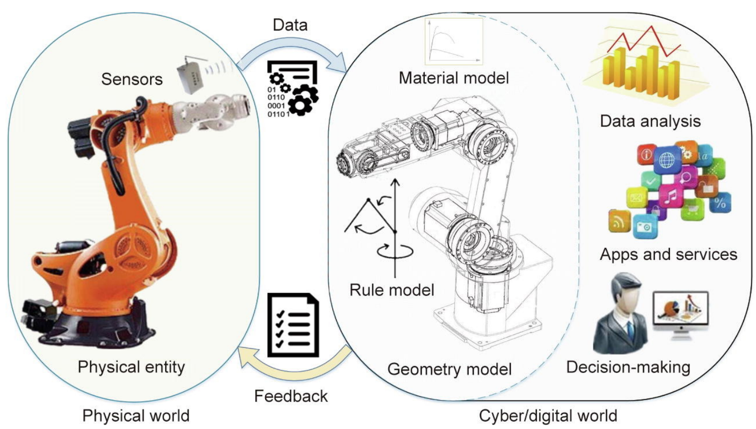

Figure 2: Integration of CPS and DTs

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]

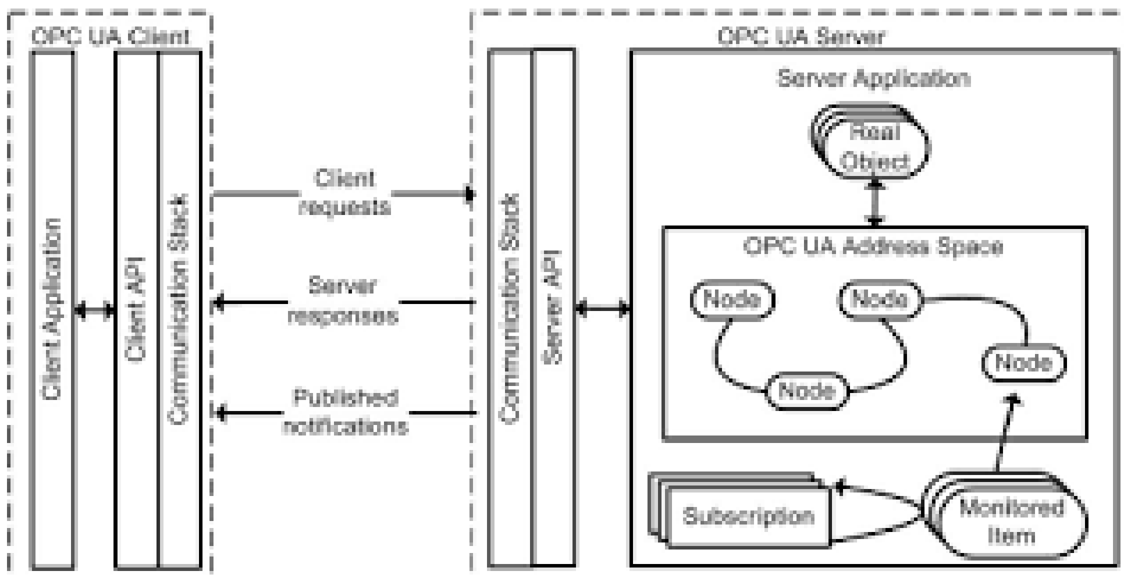

Figure 3: OPC Unified Architecture

3 Industrial robots

Industrial robots are automatically controlled, reprogrammable, general-purpose manipulating devices, programmable in three or more axes, which can be either fixed or mounted on a mobile platform for use in automation applications in an industrial environment. [6]
Robots can be used to weld, paint, assemble, disassemble,pick and place, pack and label, palletize. [7] They can be an aid to material handling. [7]
In this project, due to the limitation of not having all types of industrial robots, we are only using arm type robots such as the KuKa KR3 to develop the required use case. An arm robot, or better known as an **articulated robot**, is the most commonly used industrial robot. robot that resembles a human arm, hence the name robot arm or manipulating arm. manipulating arm. Articulated arms have multiple joints which allow them to which allow them to move in a variety of ways. [7]

Figure 4: KuKa KR3 Cell

4 Usecases for DT

4.1 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.

4.2 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. We will also have a look at some use cases in automatic small parts storage with industrial robots and Digital Twins.

4.2.1 ThuRoboticLab (TRL)

At THU, several KuKa KR3 R540 robots are utilized in the Robotics Lab, serving as laboratory equipment to aid students in their learning. The robots are primarily programmed offline, meaning that a program is written on a PC without testing, then copied to a USB stick, which is subsequently plugged into the robot cells for uploading. While this approach is straightforward, it lacks security. For instance, there is no mechanism to ensure that the code does not move the joints beyond the robot's main limits, potentially leading to defects over time. Additionally, the programming language used for these robots is KukaLanguage (KL), which is not ideal for generalizing robotics concepts. A more versatile language, such as Python or C++, would be more suitable, particularly within a ROS2 environment. Moreover, this offline programming method, or simply using the robot HMI for control, consumes a significant amount of time that could be better spent practicing more concepts. To address these issues, we propose creating a virtual environment to run a digital twin of the robots. This would allow students to use a more accessible programming language to test their exercises. This environment will be connected to the real robot via OPC UA, linking the digital and physical robots. Additionally, visualizations reflecting the real data of the robot will enable students to verify the outcomes of their runs effectively.

4.2.2 Optimized Order Picking and Packing

In an Automatic Small Parts Warehouse (AKL), the efficiency and accuracy of order picking and packing are crucial for operational success. The current method of programming industrial robots using KukaLanguage (KL) is not ideal for generalizing robotics concepts and is time-consuming. To address these limitations, we propose utilizing a digital twin (DT) of the warehouse robots. The digital twin will allow for the simulation and optimization of picking paths and packing strategies. By visualizing real-time data, operators can identify the most efficient routes and methods for order fulfillment. This not only reduces the time required for programming and testing but also enhances the accuracy of the picking and packing process. Furthermore, the digital twin will enable operators to verify the outcomes of their runs through detailed visualizations, ensuring that orders are picked and packed correctly. This approach will lead to more efficient order fulfillment, reduced shipping costs, and improved overall warehouse operations.

4.2.3 Real-time Inventory Management

In an Automatic Small Parts Warehouse (AKL), maintaining accurate inventory levels is essential for smooth operations. The current system's limitations in real-time data collection and processing can lead to discrepancies and inefficiencies. To overcome these challenges, we propose implementing a digital twin (DT) for real-time inventory management. The DT will continuously gather data from sensors and RFID tags on inventory items, updating the virtual model with current stock levels and locations. This real-time visualization will enable operators to monitor inventory accurately, identify low-stock items promptly, and optimize restocking processes. By simulating different restocking strategies, the DT will help in selecting the most efficient approach, ensuring that inventory levels are maintained without overstocking or stockouts. This integration will lead to improved inventory accuracy, efficient restocking, and overall enhanced warehouse management.

4.2.4 Energy Efficiency and Dynamic Reconfiguration

Energy consumption is a significant concern in warehouse operations, impacting both costs and environmental sustainability. The current system lacks the capability to dynamically adjust operations for optimal energy use. To address this, we propose using a digital twin (DT) to enhance energy efficiency and enable dynamic reconfiguration of warehouse processes. The DT will simulate various operational scenarios, identifying energy-saving opportunities and optimizing robot movements and tasks to minimize energy consumption. By continuously monitoring energy usage and adjusting operations in real-time, the DT will ensure that the warehouse operates at peak efficiency. Additionally, the DT will facilitate dynamic reconfiguration of workflows based on real-time data, adapting to changes in demand and operational conditions. This approach will result in significant energy savings, reduced operational costs, and a more sustainable warehouse environment.

4.2.5 Remote Monitoring and Control

In an Automatic Small Parts Warehouse (AKL), the ability to monitor and control operations remotely is crucial for maintaining efficiency and addressing issues promptly. The current system's reliance on on-site presence for monitoring and control limits flexibility and responsiveness. To enhance remote capabilities, we propose implementing a digital twin (DT) for remote monitoring and control. The DT will provide a real-time virtual representation of the warehouse, accessible from any location. Operators can monitor the status of robots, inventory levels, and overall warehouse operations through the DT, receiving alerts for any anomalies or issues. Additionally, the DT will enable remote control of robots and other systems, allowing operators to make adjustments and resolve problems without being physically present. This remote capability will improve operational flexibility, reduce downtime, and ensure that the warehouse can be managed efficiently from anywhere.

4.2.6 Predictive Maintenance

In an Automatic Small Parts Warehouse (AKL), equipment downtime can significantly impact operational efficiency and lead to increased costs. Traditional maintenance approaches, such as reactive or scheduled maintenance, often result in either unexpected failures or unnecessary maintenance activities. To address these challenges, we propose implementing a digital twin (DT) for predictive maintenance. The digital twin will continuously collect and analyze data from various sensors embedded in the warehouse equipment, such as robots, conveyors, and storage systems. By leveraging advanced analytics and machine learning algorithms, the DT will predict potential equipment failures before they occur. This predictive capability will enable operators to perform maintenance activities only when necessary, based on the actual condition of the equipment. Furthermore, the DT will provide detailed insights into the health and performance of the equipment, allowing operators to identify patterns and trends that may indicate underlying issues. This proactive approach to maintenance will minimize unplanned downtime, extend the lifespan of the equipment, and reduce maintenance costs. By integrating predictive maintenance into the warehouse operations, the digital twin will ensure that the equipment remains in optimal condition, leading to improved reliability, efficiency, and overall operational performance.

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