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Exposé on Master's Thesis

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Title: Synergizing Real and Virtual World through Digital Twin Integration: A Case Study for Handling Products with Franka Robot in MyJoghurt
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1 Topic

A digital twin is a virtual representation of a physical object or process capable of collecting information from the real environment to represent, validate and simulate the physical twin's present and future behavior. Digital twin technology plays a crucial role in the ongoing digital transformation across various industries, aligning with the broader goals of Industry 4.0. Its development has been driven by advancements in sensor technology, IoT, big data, and AI, and it continues to expand into new domains, transforming how we design, operate, and maintain complex systems.[8]
The use of digital twins (DTs) and the corresponding technological development has become quite significant both in the research domain and in the evolution of Industry 4.0. A DT can contribute to multiple aspects in various disciplines, such as predictive maintenance, personnel simulator training, parameter tuning, and also as a visual and graphical representation tool. [10]
This case study explores the integration of digital twins in the context of a MyJoghurt production line. By leveraging a Franka robot and message data communication protocol, how digital twins can enhance efficiency, monitoring, and control in a manufacturing and logistics environment is demonstrated.

2 State of Science and Technology

2.1 Digital Twin Technology

Citation: [1, 4]
Reference: fig. 1
Figures:
Digital twin technology is at the forefront of the digital transformation revolution across various industries. It integrates several advanced technologies to create dynamic, high-fidelity virtual models that provide real-time insights into physical systems.
In order to examine the application of a digital twin system for a Franka robot in the MyJoghurt production line, it is essential to thoroughly research and understand the fundamentals of digital twin technology. This involves exploring its definition, evolution, current state of technology, and its integration into Industry 4.0 frameworks. Applying the DT technology highlights the benefits of real-time monitoring, operational efficiency, and predictive maintenance.
Microsoft Azure IoT Hub and Azure Digital Twins (ADTs) utilise a combination of technologies, tools,

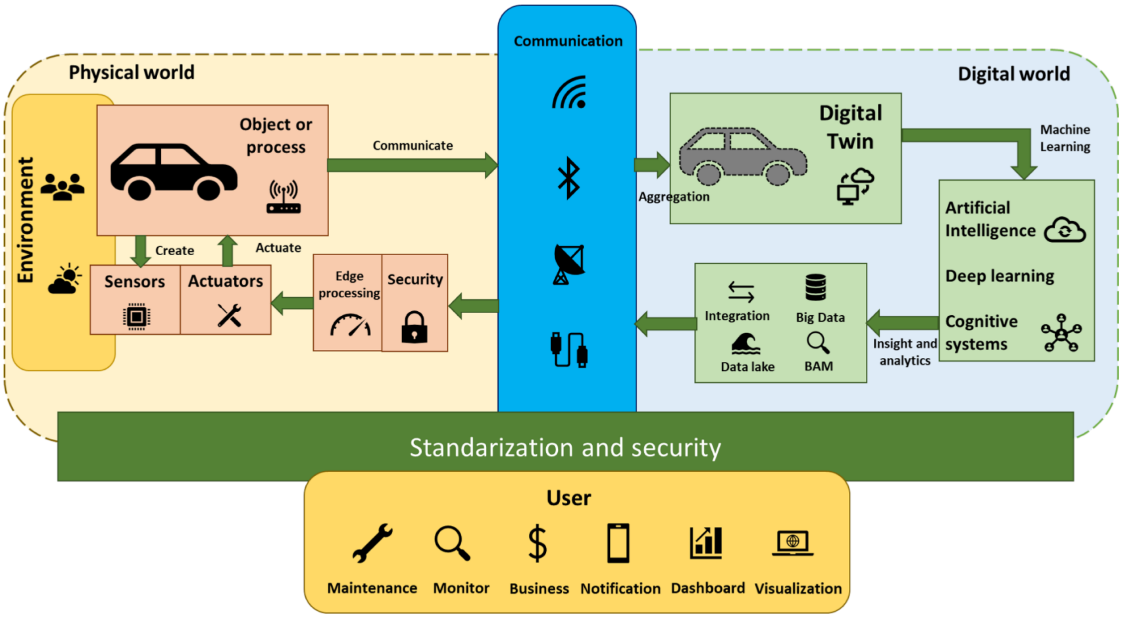

Figure 1: Digital Twin Technology Application

and algorithms to build and manage Digital Twins.[4]
The core concept of a digital twin involves three main components:

- Physical Entity: It involves the real-world object or system that is being mirrored. In this thesis, the Franka Robot Arm is used to transport the productions from the storage zone to the logistics system. The MyJoghurt system is treated as a part of the logistics supply chain, where understanding the intricate details of its entities is crucial for optimizing operations and integrating digital twin technology.

- Digital Model: It involves the virtual representation of the physical entity. The AAS shell needs to be created to represent the entities in the virtual world. ADT cloud services offer DTDL language that is based on JSON format and a comprehensive set of APIs and tools. DTDL allow defining the model from scratch or inheriting from another. A model is defined by name, ID, and other properties. A DT model can have relationships to other models to exchange data, attached components as other models, and commands request and response.

- Data Connection: It refers to the continuous flow of data between the physical entity and the digital model to ensure they remain synchronized. In the thesis, TCP Protocol and MQTT Protocol will be discussed and applied to transfer the data message from agents to the digital twins.

By treating the MyJoghurt system as an integral part of the logistics supply chain and analyzing its entities in detail, the whole product line could be simulated and messages for optimization and improvement could be sent through communication technology. From raw material suppliers to end customers, each components can benefit from the enhanced visibility and real-time insights offered by digital twins.

2.2 Asset Administration Shell

Citation: [2, 6, 11]
Reference: fig. 2

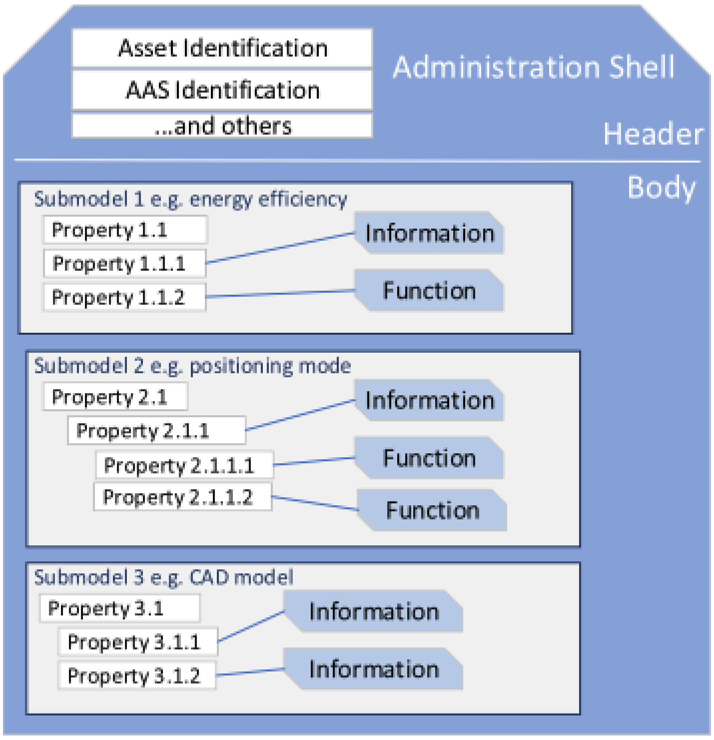

Figure 2: Asset Administration Shell Structure

Figures:

In the context of Industry 4.0, every asset is managed by an AAS containing all its relevant information; such information includes properties, operations, but also documentation, datasheets, CAD files or source code. This is what makes AAS so appealing for a production system life cycle management, since all this information is structured under just one entity, i.e. the AAS, and accessible by different domain-specific tools.
Because of the lack of consistent standards, currently there is a huge amount of devices and technologies labeled CPS, embedded systems (ES) and Internet of Things (IoT). The transition between the different categories is often seamless, thus the differentiation mostly depends on their purpose. However by applying the requirements of the Industrie 4.0 to the main assets in the production process, the AAS can be subdivided into five segments:

- External Interface
- Authentication and Security
- Data Management
- Functionality
- Administration
- Internal Interface

Thus, the Asset Administration Shell serves as the digital representation of a physical asset, collecting all relevant information and functionalities. It standardizes the way data about an asset is managed, accessed, and communicated, thus facilitating the integration into digital systems.

2.3 Communication Protocol

Citation: [5, 7]

Reference: fig. 3

Figures:

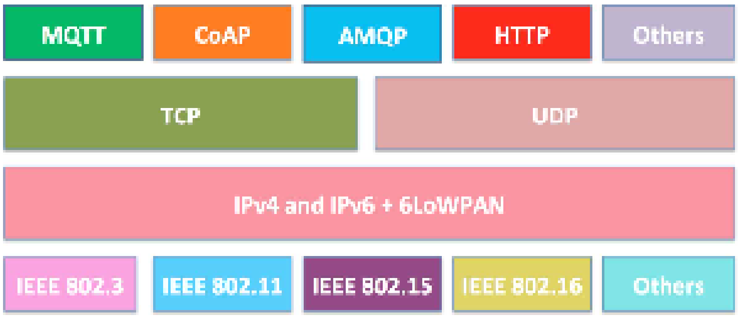

Figure 3: Protocol Stack for IoT Systems

The standard and real-time communication technology is an unalloyed inevitability for the development of Internet of Things (IoT) applications. However, the selection of a standard and effective messaging protocol is a challenging and daunting task for any organisation because it depends on the nature of the IoT system and its messaging requirements. Messaging protocol is an ongoing dilemma for the IoT industry; consequently, it is important to understand the pros and cons of the widely accepted and emerging messaging protocols for IoT systems to determine their best-fit scenarios.

- MQTT: MQTT client publishes messages to an MQTT broker, which are subscribed by other clients or may be retained for the future subscription. Every message is published to an address, known as a topic. Clients can subscribe to multiple topics and receives every message published to the each topic. MQTT is most suitable for large networks of small devices that need to be monitored or controlled from a back-end server on the Internet.

- CoAP: CoAP is a lightweight M2M protocol from the IETF CoRE (Constrained RESTful Environments) Working Group. CoAP supports both request/response and resource/observe (a variant of publish/subscribe) architecture. CoAP uses Universal Resource Identifier (URI) instead of topics. Publisher publishes data to the URI and subscriber subscribes to a particular resource indicated by the URI. Clients and servers communicate through connectionless datagrams with less reliability. However, it uses “confirmable” or “non-confirmable” messages to provide two different levels of QoS.

- AMQP: AMQP (Advanced Message Queuing Protocol) is a corporate messaging protocol designed for reliability, security, provisioning and interoperability. AMQP supports both request/response and publish/subscribe architecture. AMQP exchanges messages in various ways: directly, in fanout form, by topic, or based on headers. The communication between client and broker is a connection-oriented. Reliability is one of the core features of AMQP, and it offers two preliminary levels of Quality of Service (QoS) for delivery of messages: Unsettle Format (not reliable) and Settle Format (reliable).

- HTTP: HTTP supports request/response RESTful Web architecture. Analogous to CoAP, HTTP uses Universal Resource Identifier (URI) instead of topics. Server sends data through the URI and client receives data through particular URI. HTTP is a text-based protocol and it does not define the size of header and message payloads rather it depend on the web server or the programming technology. Communication between client and server is a connection-oriented. It does not explicitly define QoS and requires additional support for it.

2.4 Digital Twin Visualization

Citation: [3, 9, 12]

Reference: figs. 4 and 5

Figures:

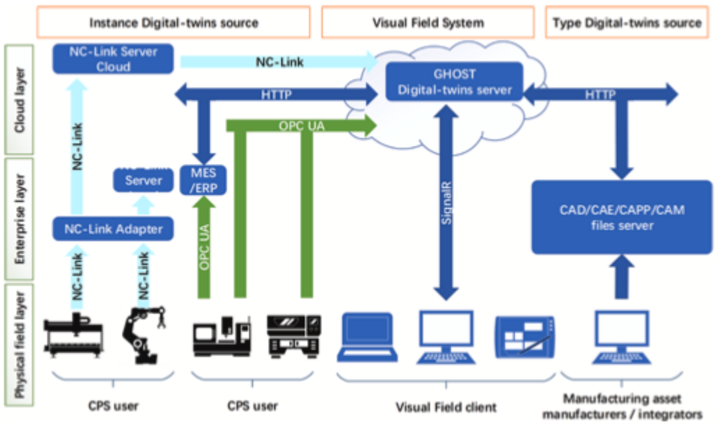

Figure 4: Deployment of digital-twin visualized architecture.

Digital-twin information visualization (3D virtual DMU) is an effective solution that accurately and intuitively presents multi-dimensional digital-twin information during the life cycle of FMS. The data is retrieved from different data repositories using web services, which implement the Digital Twin concept.

A proposed architecture was presented with the aim to manage the data from the digital twin, using web services, to distribute the data in other systems like an Augmented Reality System. The architecture using web services can enable users to easily access product, simulation and manufacturing data of a Digital Twin, via a web browser. It is independent of any device and enable the data to be visualized on portable computer and devices.

In an intelligent manufacturing system, massive digital-twin information described by different modeling methods is being collected and integrated. Digital Mock-up (DMU) can construct the "Physical-Cyber" mapped data of the digital-twin model into virtual 3D scenario motions and state changes. The efficiency and precision of "Cyber-Human" interaction can be improved through data visualization.

- Digital-twin modeling of FMS based on AML: AML is an open and neutral XML-based data exchange format that can be used for the descriptions of product, process and resources throughout the life cycle of a production system. Automation ML can be used to implement data exchange between multi-disciplinary tools, including factory plant design and planning, mechanical engineering, electrical design, control engineering, PLC programming and robot programming, etc.

- Digital-twin samples of FMS in GHOST: Multi-dimensional digital-twin data in FMS manufacturing processing is collected and backtracked by the universal bus protocols. Currently, the GHOST server supports NC-Link protocols and OPC UA protocols to get physical scene real-time data and history samples. Filtering rules for digital-twin data are configured by AML in GHOST. Real-time digital-twin information is cached by Redis SQL and then stored as historical samples in PostgreSQL.

- Digital-twin information in physical HCPS scenarios: Digital-twin information on the full life cycle of FMS can be classified into five categories: geometric information, historical samples, object attribute, snapshot collection and topological constraint. Geometry information, object

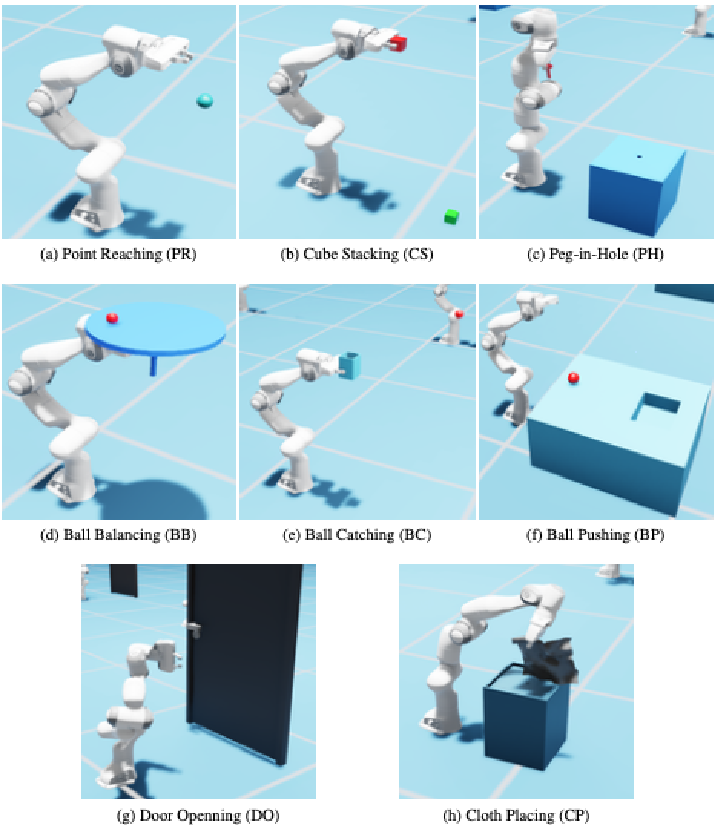

Figure 5: Case Study: Robotics manipulation tasks included in the proposed benchmark based on Isaac Sim.

attribute and topological constraint can be configured and managed using AML, while historical samples and snapshot collection are collected, transmitted and managed over universal bus protocols (e.g., NC-Link and OPC UA).

As shown in the figure, NVIDIA is an advanced physical simulator that offers seamless integration with NVIDIA hardware and software, providing robust support for high-speed, GPU-accelerated simulation and AI training. Isaac Sim is capable of providing highly realistic simulations that accurately model the system behaviors in the real world, making it an ideal simulator for the development of AI-enabled robotics applications.

3 Objective of the Thesis

The primary objective of this thesis is to explore and demonstrate the application of digital twin technology within the context of the MyJoghurt production line, specifically focusing on the integration of a Franka robot. This will involve several key goals:

- Installation of Franka Robot: The transport plant is lack of an automated mechanism to automate repetitive and labor-intensive tasks within the MyJoghurt production line, thereby increasing overall operational efficiency. The aim of the part contains increasing the flexibility and adaptability of the production line by incorporating a programmable and reconfigurable robot arm.
- Understanding Digital Twin Technology: The aim is to research and analyze the fundamental principles, knowledge of digital twin technology and to investigate the current state of digital

twin technology and its role within Industry 4.0 frameworks. How digital twin technology is applied in smart manufacturing processes to improve efficiency, predictive maintenance, and production planning will be discussed. Case studies and real-world examples will be used to illustrate successful implementations and identify best practices.

- Analyze the MyJoghurt Production Line: The aim is to conduct a detailed analysis of the MyJoghurt system as part of the logistics supply chain. The plant is controlled by a PLC (Programmable Logic Controller). It is essential to understand how this PLC operates and how it can communicate with a Digital Twin (DT) system.
- Data Management: The aim is to evaluate the processes for managing large volumes of data generated and used by digital twins. This includes data collection, storage, processing, and real-time analysis to support monitoring in manufacturing and logistics operations.
- Integrate Digital Twin Technology: The aim is to develop a digital twin model for the Franka robot and its interactions within the MyJoghurt production line and then to establish a continuous data connection between the physical world and its digital twin to ensure synchronization.

By achieving these objectives, the thesis aims to contribute to the body of knowledge on digital twin technology and its practical application in smart manufacturing and logistics systems-MyJoghurt Plant.

4 Work Plan and necessary Resources

4.1 Activity A

Search and read literature, understand the latest digital twin technology, find problems that have been solved, and become familiar with digital twin tools.

4.2 Activity B

Install the Franka robot and establish connections. Design and mount relevant parts of the robot. Program the robot for specific tasks. Conduct initial testing and validation.

4.3 Activity C

Analyze the MyJoghurt production line and the role of the PLC. Evaluate the current MyJoghurt production line for integration points. Understand the PLC communication protocols.

4.4 Activity D

Then we implement data processing and real-time analysis techniques to manage the data streams. Create a digital twin model of the Franka robot within the MyJoghurt production line. Establish continuous data synchronization between the physical and digital systems.

4.5 Activity E

At last we summarize the entire process, simulate a virtual plant in Isaac Sim to finish a visualization.

4.6 Activity F

Write the thesis and prepare for the presentation.

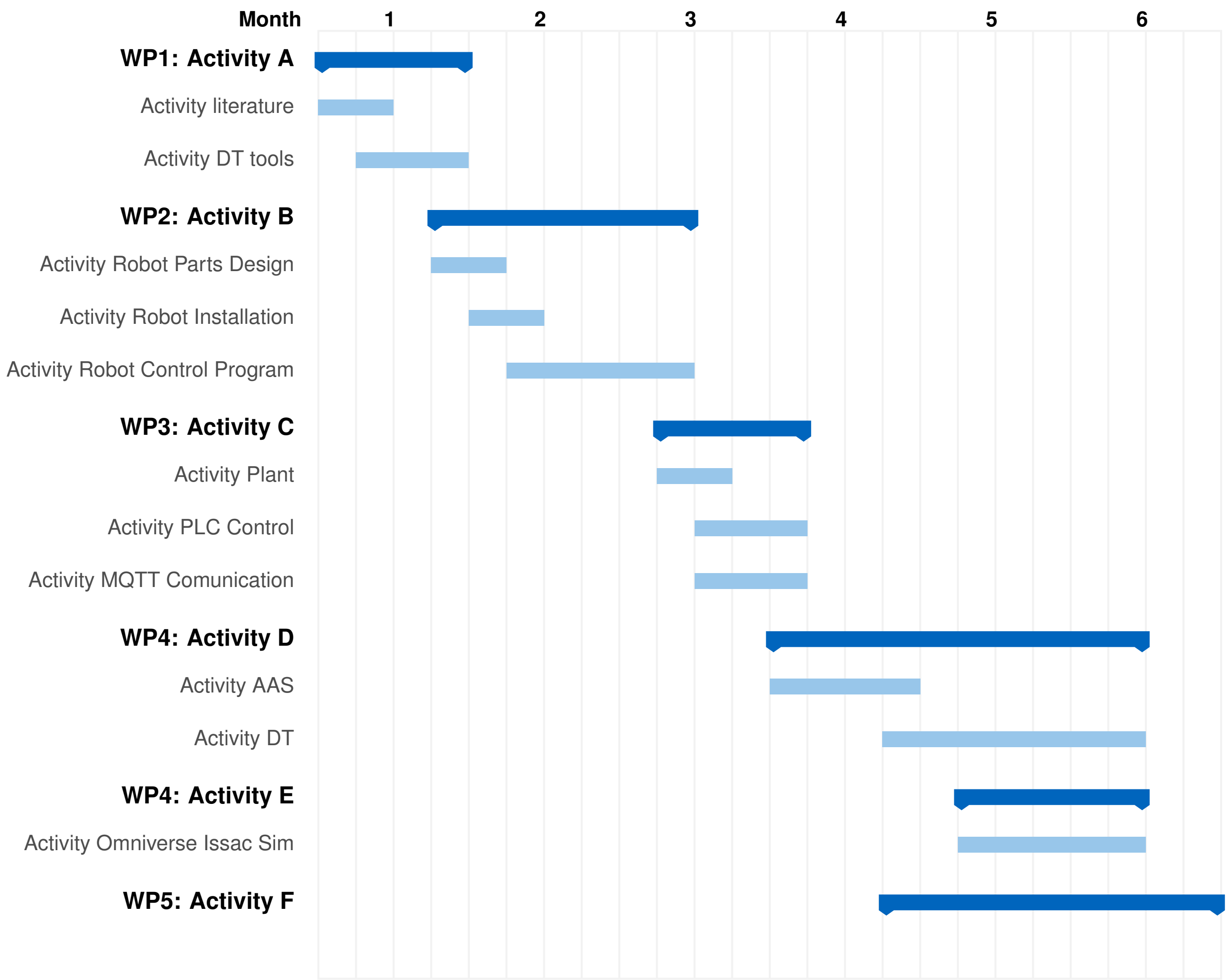

Figure 6: Time schedule.

5 Literature

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6 Structure of the Thesis

- Introduction
  - Motivation
- Background
  - State of Art
  - Industry 4.0 Framework
  - Digital Twin Technology
- Communication Protocols
  - Overview and Standards
  - TCP
  - MQTT
- Franka Robot Integration
  - Installation and Configuration
  - Robot Control Programming
  - Robot Data Management
  - Robot Ultrasonic Sensor
- Asset Administration Shell
  - Concept and Implementation
  - AAS Creator
  - AAS Results
- MyJoghurt Production Line
  - Overview and System Architecture
  - PLC Operations and Control
- Digital Twin Scope
  - Fundamentals and Applications
  - Case Studies and Implementations
- Visualization
- Conclusion
- Future works

Review

Content presentation created by:

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