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Application and Practical Analysis of Industrial Meta-Universes

Xiaofeng Gu[1, *]

[1]Automobile college, Tongji University, Shanghai, 201800, China

*Corresponding author's e-mail: gusfe170019@outlook.com

Abstract

Connecting the digital and real worlds, the Industrial Metaverse will enable the continuous interaction of information, data and decision-making, the Empowering industries to digitally solve extremely complex real-world problems and create huge social benefits. This paper describes the main technologies of industrial meta-universe; through the case of E* industrial meta-universe project, it disassembles and analyses the technical route of industrial meta-universe; in combination with the existing technologies, it puts forward the corresponding improvement suggestions and makes its own thinking.

Keywords

Industrial meta-universe; Digitalisation; Manufacturing.

1. Introduction

The metaverse is a virtual, extended, and integrated shared space containing multiple virtual worlds and entities, consisting of both physical and virtual reality. The industrial metaverse, as an important branch of the metaverse, focuses on mapping and extrapolating highly complex systems such as factories, machinery, and transport. It is able to provide participants with a real-time synchronised, interactive immersive real-world reproduction and simulation environment.

Using the Industrial Metaverse, factories will be able to perform real-time modelling, design iteration, production forecasting and process optimisation in twinned virtual environments before actual manufacturing takes place. Overall, Industrial Metaverse will open up a new digital industrial model.

1.1. Main technologies

Key technologies in the industrial meta-universe include digital twins, the Internet of Things, virtual reality, artificial intelligence and blockchain. Together, these technologies support the mapping, simulation and optimisation of complex industrial systems, enabling the visualisation, intelligence and remoteness of production processes[1]. Below we focus on analysing digital twins.

Digital twin technology is a new type of technology that combines the physical world with the virtual world based on digital technology. By using data such as physical models, sensor updates, and other data, the simulation process of integrating multi-disciplinary, multi-physical quantities, and multi-probability is completed by mapping in the virtual space, so as to create a virtual entity corresponding to the physical entity, i.e., the digital twin[2].

The digital twin has the following characteristics:

(1) Virtual-reality mapping: comprehensively reflecting the structure, material, operation status, environmental parameters and other information of physical entities;

(2) Real-time synchronisation: dynamically reflecting changes in the state of physical entities, ensuring synchronisation between the virtual and physical worlds;

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(3) Symbiotic evolution: Evolving with the life cycle process of the entity, covering the entire life cycle from design, production, operation to end-of-life[1];

(4) Closed-loop optimisation: the formation of optimisation instructions or strategies for the physical world based on the analysis and simulation of the intrinsic mechanisms of physical entities.

1.2. Direction of industrial meta-universe applications

1.2.1. Product design and development

Predicting product performance, reliability and potential problems through simulation in a virtual environment; rapid iteration and optimisation of product design solutions based on the simulation results of the digital twin.

1.2.2. Manufacturing

Real-time monitoring of the production line's operating status, timely detection of potential faults and predictive maintenance [3]; optimisation of the production process and improvement of overall production efficiency.

1.2.3. Operations management

Operations and maintenance personnel remotely monitor, diagnose and repair equipment in a virtual environment, reducing the time and cost of on-site operations.

1.2.4. Intelligent decision support

Integrate large amounts of real-time data and provide deep insights and decision support to the business through data analytics.

2. Case study of the E*Industrial Metaverse Project

2.1. Project background analysis

Currently, the automotive industry is shifting from a series of stand-alone virtual simulations to a meta-universe, and building meta-universe factories will become an important trend in the automotive industry after 2024.

The project aims to accelerate the construction of E*Automotive's whole-process innovation capability from product development to factory manufacturing operations, and to promote the digital transformation and upgrading of the automotive industry.

2.2. System architecture deconstruction

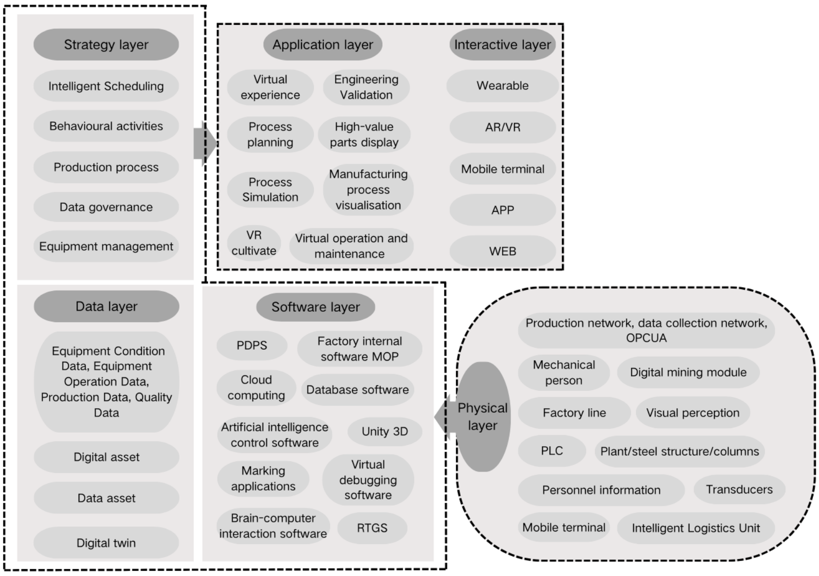

Figure 1. E* Metaverse Project System Architecture

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The system architecture of the Industrial Metaverse project, shown in Figure 2, is a highly integrated system where each layer is critical. The following is a detailed breakdown of the architecture:

2.2.1. Physical layer

Robot and PLC control system: Automation and intelligence of the production process is achieved through the collaborative work of the robot and the PLC control system.

Sensor and Data Acquisition Module: Real-time acquisition of various types of data in the production process, including equipment status, production progress, quality parameters, etc., to provide support for data analysis and decision-making.

Factory production lines and plant facilities: Provide the physical environment required for production, including production line layout, equipment configuration, plant structure, etc.

2.2.2. Software layer

Virtual debugging software: simulate and debug the process in a virtual environment to improve the stability and efficiency of the production line.

Real-time communication software: real-time transmission and synchronisation of data in the production process to ensure the timeliness and effectiveness of information.

Internal factory software: MES, MOM are used for factory production management and monitoring to improve the transparency and controllability of the production process.

2.2.3. Data layer

Artificial Intelligence Control Software: Through machine learning and deep learning algorithms, various parameters and conditions in the production process are adjusted and optimised in real time.

Database software: stores and manages all kinds of data in the production process, ensuring data integrity, security and traceability.

2.2.4. Strategy layer

Based on multi-dimensional information such as fixed assets, equipment number models, equipment status data, operation data, production data and quality data, it provides management with comprehensive decision support.

2.2.5. Application layer

Engineering validation and simulation: Ensure the sequential and logical nature of the production process; use simulation to model the process flow, validate and optimise various parameters and conditions in the production process.

Manufacturing process visualisation: Monitor and display various data and status of the manufacturing process in real time to ensure that the production schedule and quality meet the expected requirements.

Intelligent scheduling: optimising production planning using algorithms and data analytics.

Data Governance: Real-time tracking and management of production equipment information and usage, including equipment location, status, and maintenance records.

2.2.6. Interactive layer

User Interface: Provide users with multiple ways to access and operate the whole system through WEB, APP, mobile terminals and AR/VR devices.

The entire industrial meta-universe system achieves intelligence, efficiency and visualisation of the manufacturing process through the collaborative work of all layers.

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2.3. Analysis of technical routes

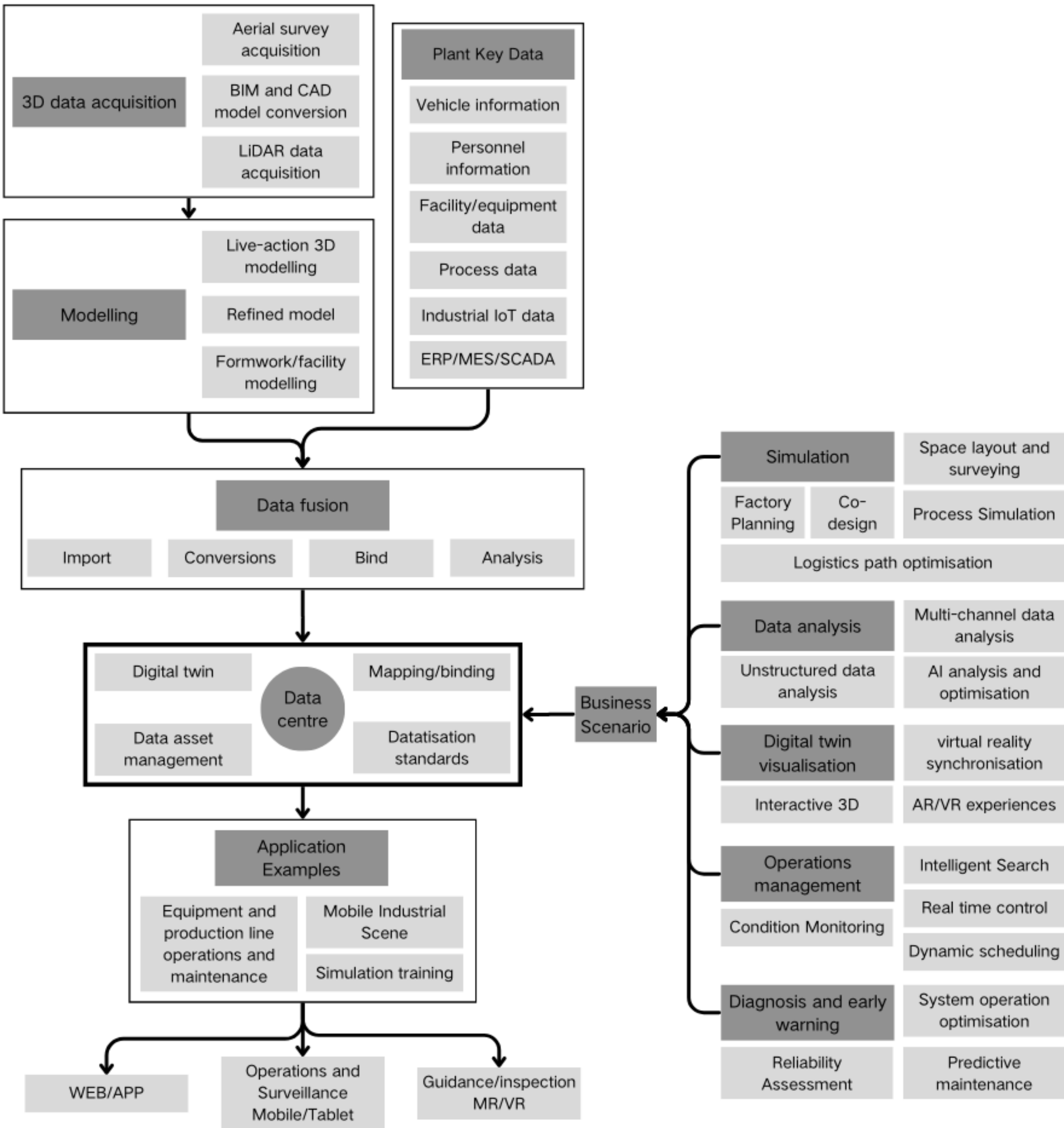

Figure 2. Technical route of the E* Metaverse project

After the technical analysis, the technical route of the project was mapped out as shown in Figure 3.

Firstly, aerial survey, tilt photography acquisition and LIDAR technology are used to obtain high-precision 3D data[4]. At the same time, the standard BIM and CAD models are converted into a unified format to provide a basis for subsequent model building.

In the model building stage, detailed models of industrial equipment and scenes are constructed by means of real-life 3D modelling techniques, combined with detailed models and facility models.

By fusing model data with key plant data, matching data can be integrated into a unified platform for data sharing and collaboration.

The data middle office serves as the core of data management and is responsible for data standardisation, mapping, creation of digital twins and management of data assets.

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At the application level, through WEB/APP, mobile phones and other terminals, users can access and operate industrial equipment and processes in real time. Meanwhile, the functions of operation and maintenance, monitoring, guidance and simulation training provide strong support for industrial production and staff training.

In terms of business scenarios, Industrial Metaverse covers all aspects from factory planning, collaborative design to process simulation, spatial layout and measurement. Through multi-channel data analysis, AI analysis and optimisation and other technical means, it achieves in-depth mining and utilisation of industrial data.

In terms of business management, Industrial Metaverse achieves full control of industrial equipment and processes through status monitoring, intelligent search, real-time control and other functions.

2.4. Key technologies

2.4.1. PLC program remote brush writing

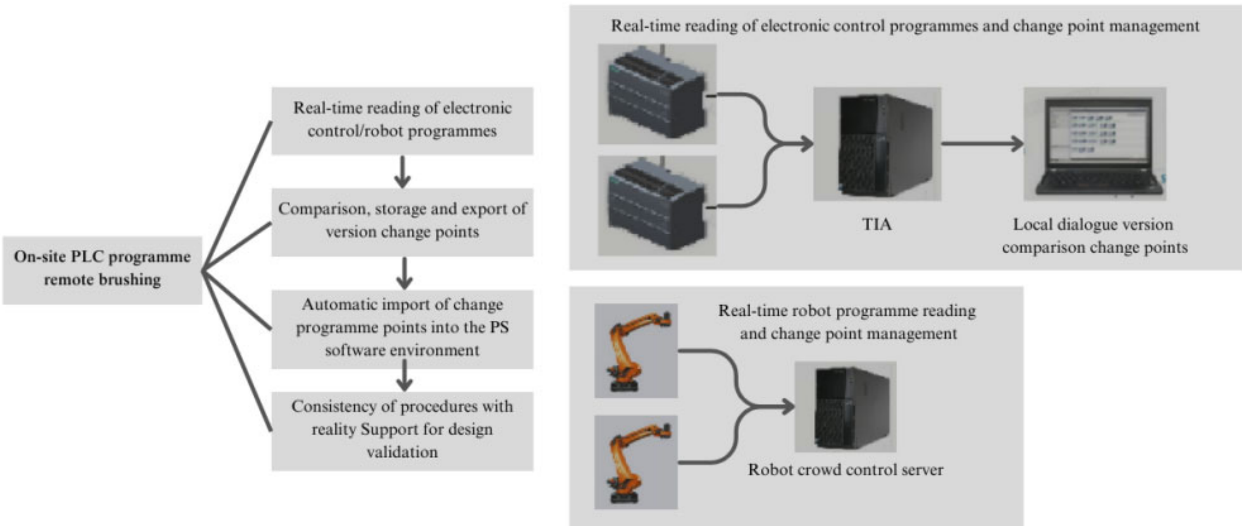

Figure 3. PLC programme remote brushing technology route

The above figure depicts the PLC technology implementation process in detail.

By comparing, storing and exporting version change points, it is ensured that differences between old and new versions are accurately recorded. These change points are then automatically imported into the PS environment, providing for further validation and testing. In the PS environment, design validation of the program's virtual-reality consistency was carried out to ensure that the program in the virtual environment was consistent with the program in the actual running environment, thus reducing the risk of errors in real-world applications. The electronic control programme was compared with the change points through the TIA project server and local session versions, which ensured an accurate grasp of the changes in the electronic control system [5].

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2.4.2. VC virtual debugging platform

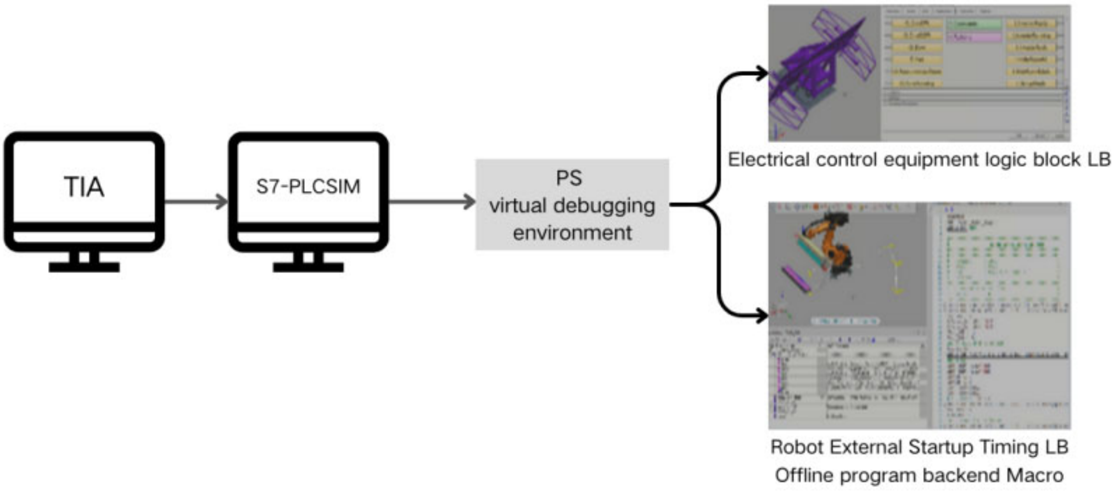

Figure 4. Virtual debugging technology route

The above figure depicts the technical route of PS-based virtual debugging, which can be roughly divided into six phases, initialisation phase, program loading and configuration phase, virtual debugging phase, result presentation and analysis phase, program optimisation and iteration phase and actual deployment phase.

Initialisation phase:

Before starting virtual debugging, first configure the hardware interface part to ensure correct connection and communication. At the same time, start the PS virtual debugging environment, load the PLC system, and prepare the necessary debugging resources such as the logic block LB of the electronic control device and the robot external startup timing LB.

Program loading and configuration:

Load the written PLC program into the PS virtual debugging environment. While loading the programme, configure the robot's external start-up timing LB and offline programme backend macro to ensure that the robot can start up according to the predefined timing and conditions[6].

Virtual debugging phase:

Once the program is loaded and configured, the virtual commissioning process is initiated.The PLC system starts to simulate the behaviour of a real PLC, interacting with the electronic control devices and the robot. The electronic control device logic block LB runs in the PS vi zrtual debugging environment for real-time monitoring and debugging[7]. At the same time, the robot's external startup timing and offline programme backend start running to ensure that the robot starts and runs under the correct timing and conditions.

Program optimisation and iteration:

Based on the analysis of the results of the virtual commissioning, the PLC program can be optimised and iterated to improve the control logic and performance of the electronic control equipment and the robot.

3. Reflections and Improvements

Before proposing an improvement plan, we list the improvement objectives: to enhance the capability and extend the existing system to maximise its effect; to fill in the gaps and add to the deficiencies in the overall application; and to expand the application to maximise the effect of the meta-universe.

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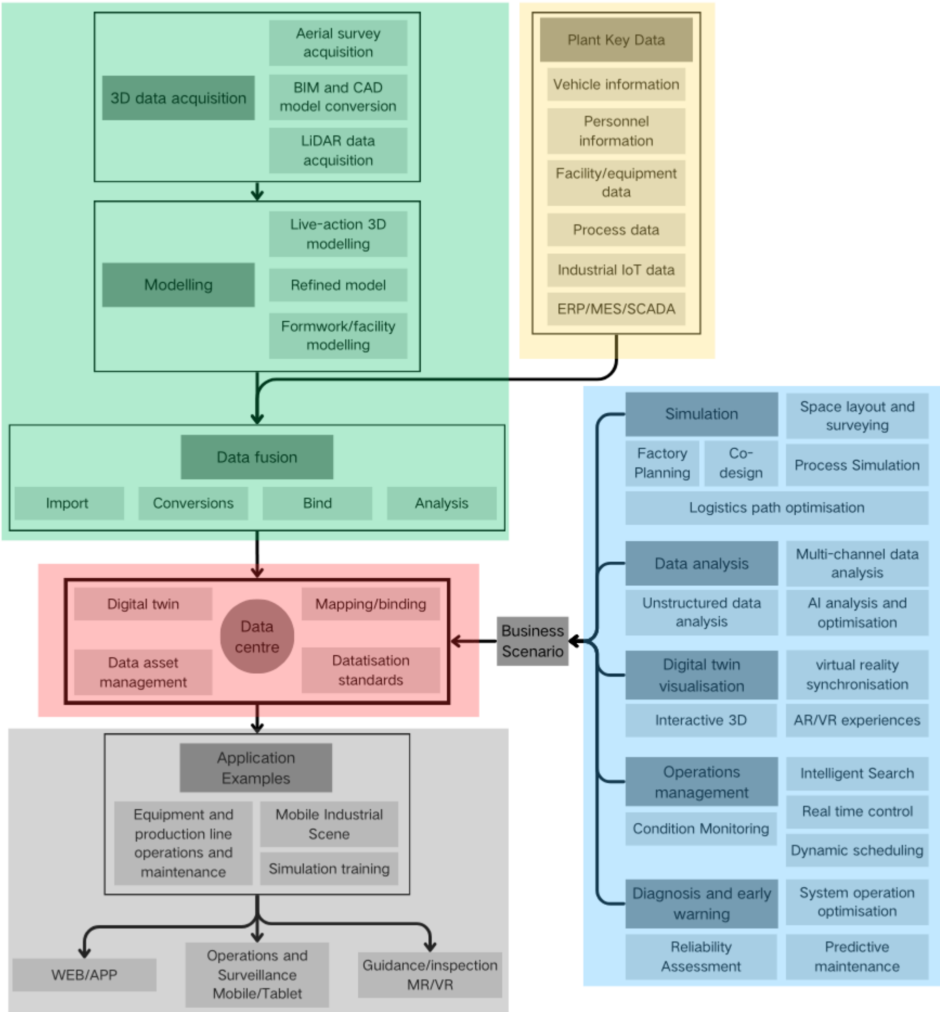

Figure 5. E** Metaverse Project Technology Route Module

As shown in Figure 6, the technical route is divided into the following modules based on the key technologies and main roles of each part: data base (green), data source (yellow), data middleware (red), engineering tower (blue), and data frontend (grey). The following is an analysis of the current status of each module and suggestions for improvement:

3.1. Data base

3.1.1. Status analysis

(1) Data integration standards are not uniform across vendors, resulting in inconvenient use of point cloud data;

(2) Some of the data in the modelling did not meet the requirements of the standard data format, and some structural data were not available for measurement;

(3) When data are processed and integrated, different data exist in different locations and use different formats, making integration applications difficult.

3.1.2. Solution

(1) Construction of an additional point cloud data browsing meta-universe platform to accompany the definition of relevant standards;

(2) Integration of BIM, equipment, and site layout 3D models into a unified digital asset management platform [8];

(3) Lack of device data for reverse modelling;

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(4) Converting data forms from Revit to JT using python for consistency processing[9], standard model archiving management.

3.2. Data sources

3.2.1. Status analysis

(1) Siplant's low data collection capacity does not allow for the integration of a wider variety of data;

(2) At this stage, the three different types of data transmission are in the same form (low-speed simulation test data, medium-speed production data, and high-speed reverse control data), and there is no transmission mode specificity, and the transmission efficiency is low [10].

3.2.2. Solution

(1) The use of MOP+ tools improves Siplant's data mining capabilities, enabling the integration of a wider variety of data and the formation of a MOP+ data lake [11];

(2) Most of the simulation test data are low-speed data in Json and Xml format, which can be transmitted through RestAPI [12]; medium-speed data such as alarm, yield, and beat in the production data can be transmitted through Mqtt; high-speed data that need reverse control can be communicated directly with the device through OPC UA; and the transmission of the Web screen is through HTTP format.

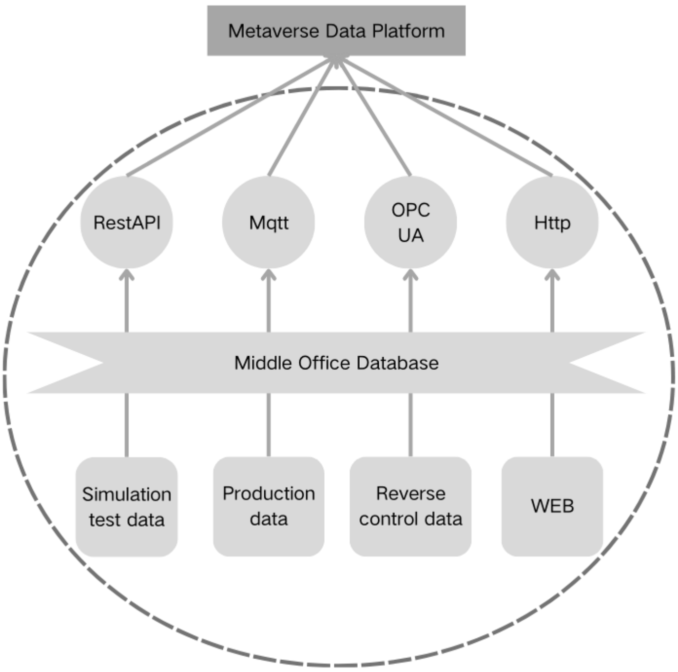

Figure 6. Data transmission architecture

3.3. Data centre

3.3.1. Status analysis

(1) The equipment on display was not managed effectively;

(2) The construction of control simulation system is incomplete: PLC program can only be used to verify the body process program, and it is impossible to efficiently verify the control logic of the machine transport line, the upper machine, BDC and other complex scenarios [13]; the construction and debugging relies on the on-site system, and there is a lack of a virtual environment for the control system of the physical factory to simulate the control system of the mirror image;

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(3) The lack of interaction interfaces between the data in the data centre, the engineering tower and the data frontend does not allow for efficient digital interaction [14].

3.3.2. Solution

(1) As shown in the figure below, use Line Designer to merge the vectors that demonstrate the presentation of multiple 3D data formats;

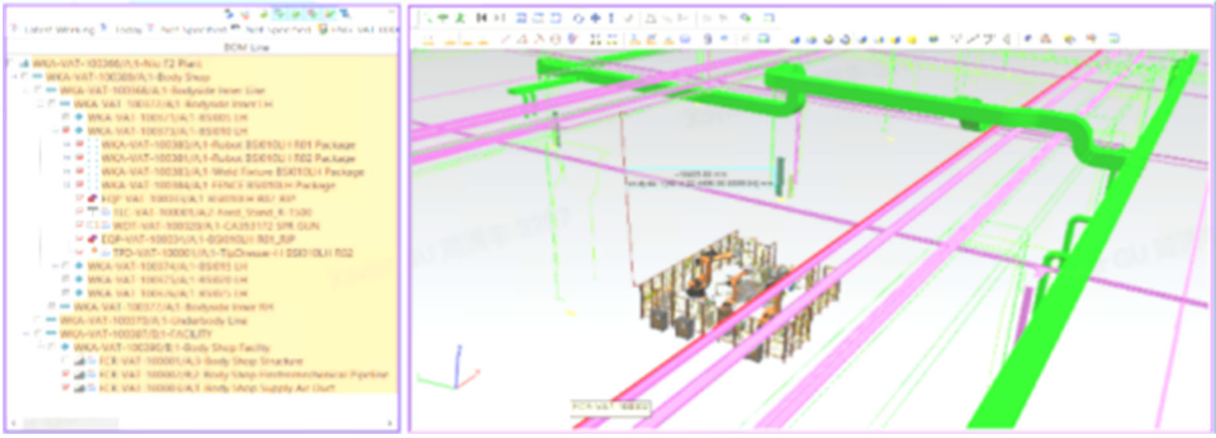

Figure 7. Data management system with Line Designer [15]

(2) Build a control system simulation system to mirror the control system of a physical plant;

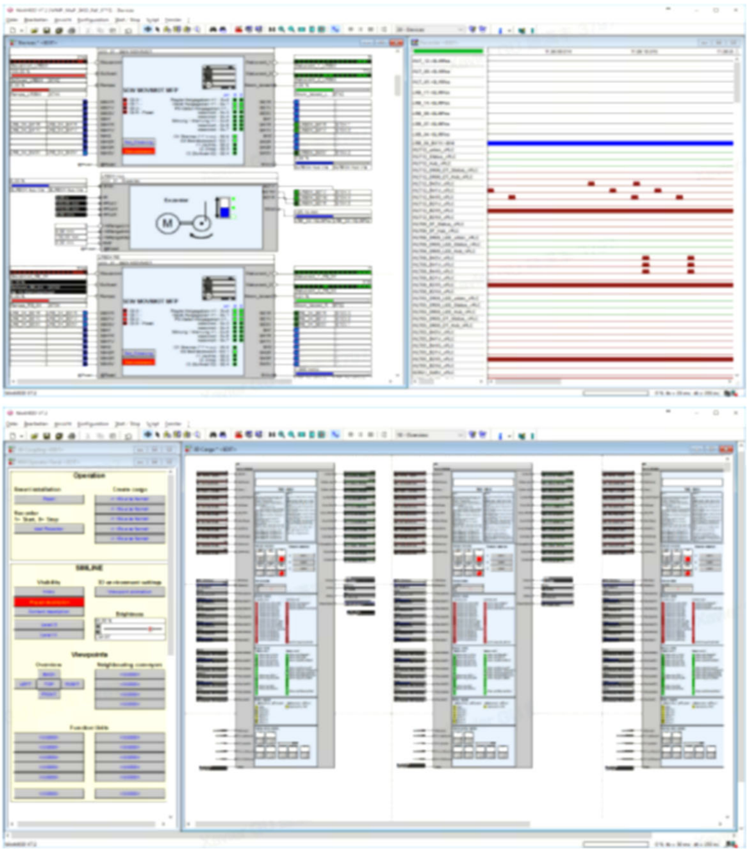

Figure 8. Schematic diagram of the control system simulation system

(3) Develop new interfaces for data interaction according to data interaction requirements to meet future business scenarios.

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3.4. Engineering towers

3.4.1. Status analysis

(1) Some applications have been verified by the PS environment to interfere with existing devices;

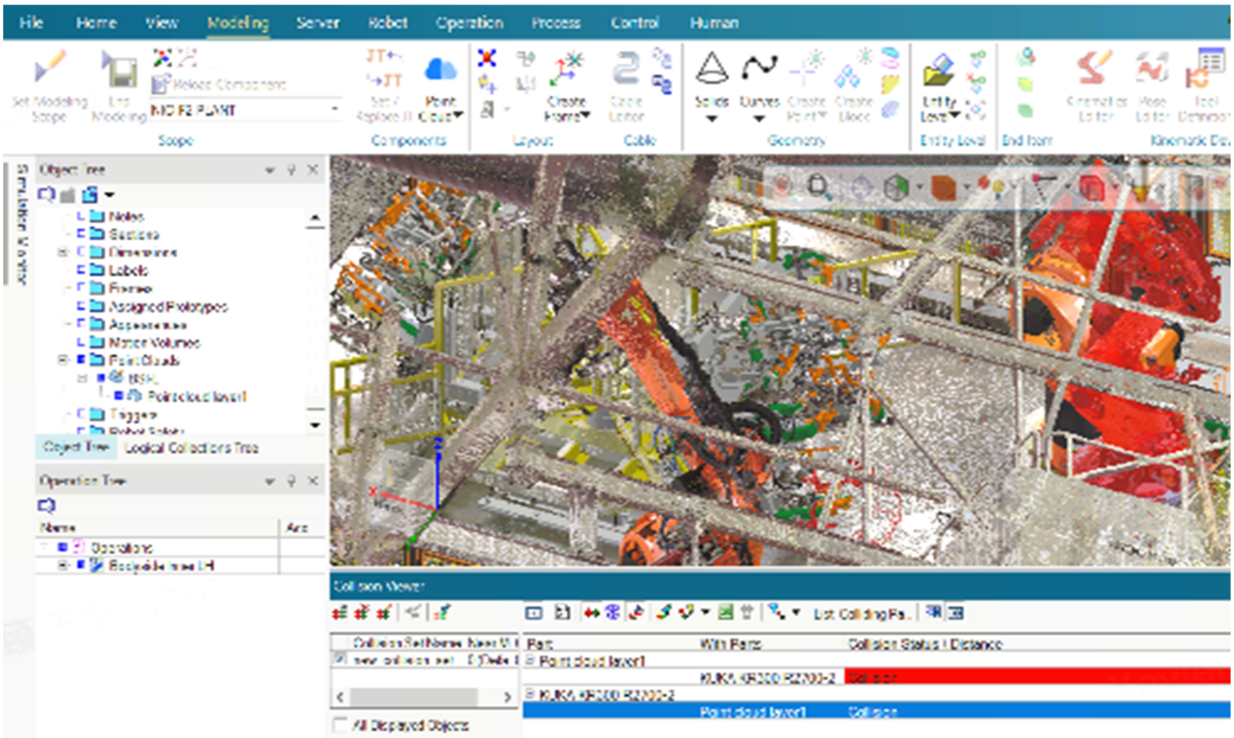

Figure 9. New device interferes with existing device

(2) Lack of meta-cosmic data AR/VR applications and operational guidance

3.4.2. Solution

(1) Simulation analysis and validation of the whole supply chain process to find out the existing process problems; algorithmic optimisation to form the optimal solution for order production, guiding and driving the physical entity space.

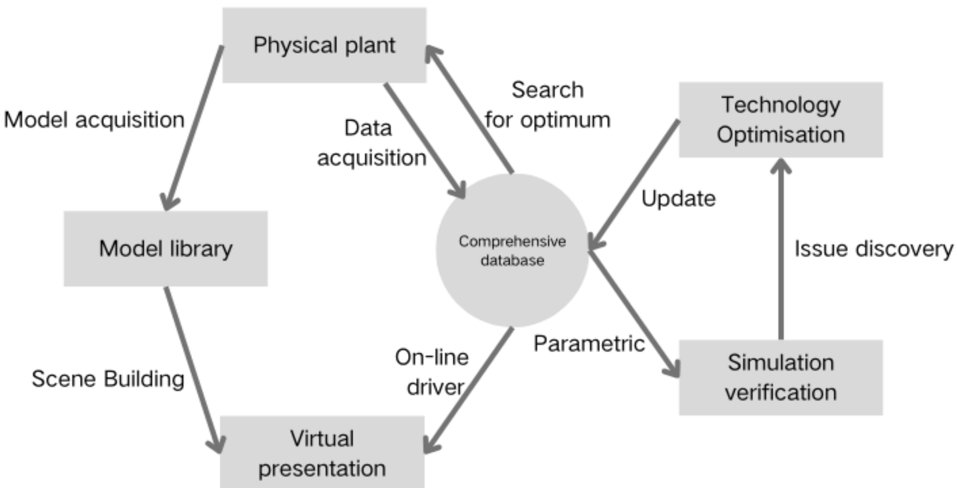

Figure 10. Data Optimisation Conceptual Route

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(2) Produce virtual training materials and set up a three-stage training method of learning, practice and assessment to make training and learning more efficient [16].

4. Conclusion

The application of industrial meta-universe is expected to bring revolutionary changes to the industrial manufacturing field. However, by analysing the actual application cases of enterprises, it can be concluded that at present, each individual technology is close to maturity, but how to connect each individual technology in series to form a set of mature and systematic meta-universe implementation scheme needs to be continuously tried and improved.

The current meta-industrial universe suffers from the following major problems:

(1) The lack of technical standards limits effective integration and collaboration between different systems and devices;

(2) The generation of large amounts of real-time data is accompanied by data security and privacy concerns;

(3) The high initial investment costs and the lack of short-term benefits undermine their widespread popularity.

Looking ahead, the Industrial Metaverse is expected to have an even more profound impact on the industrial manufacturing sector. We expect that with the joint efforts of all parties, the Industrial Metaverse will be able to overcome the existing problems and achieve a healthier and more sustainable development.

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