"5G+TSN+DT" Solutions for Digital Factory Key Issues of Networking, Precision, Automation and Digitalization

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Abstract. With advanced technologies of the Internet of Things (IoT) and Artificial Intelligence (AI) developing, key issues and challenges of networking, precision, automation and digitalization are arising for digital factory (DF) top designing and establishing. Advanced technologies of 5G, Time Sensitive Network (TSN) and Digital Twin (DT) provide new solutions for DT planning and operating. This study explores “5G+TSN +DT” practical solutions for DF designing and building, especially in the aspects of networking, precision, automation and digitalization, which is of great significance to understand the opportunities and challenges of DF industry development.

1. Introduction

With the development of the Internet of Things (IOT), cloud computing and artificial intelligence, factories are enhanced to be more and more intelligent. There is a great opportunity to this industry for more resource-saving and profit-making. Digital factory (DF) is an inevitable result for intelligent industry enhancements. However, issues and challenges of networking, precision, automation and digitalization are emerging since there is still a number of practical problems, which are not be considered during the processes of DF designing and planning.

Advanced technologies of 5G, Time Sensitive Network (TSN) and Digital Twin (DT) are expected to be the new opportunities and novel avenues for intelligent industry developments. (1) 5G is regarded as one of the most potential techniques for DF effective visual managements [1]. With wide spectrum of frequencies, a bigger-sized dataset is able to be transformed to the Manufacturing Execution System (MES) [2]. However, data safety protection and attack preventing is still the major challenges for this technique’s applications [3]. (2) TSN is a novel technology for industry networks, which is with great advantages by ensuring traffic flows with low delay, fluctuation and jitter, as well as the high stability and scalability [4,5]. Time-consuming of network configuration is still the vital issue for DL performing, especially during processes of model designing, data transforming, data analysis and simulation [6]. (3) Digital Twin (DT) is a special cornerstone for managers of intelligence factory to monitoring the manufacturing in the real-time and make a statistic-supportive decision [7]. This technology plays a novel role in the resource configuration, device motion, system control, and model optimization [8]. Challenges are explored by Wu in 2021, which includes of high requirements of the data interaction and fusion, high-precision and real-time data extraction, transformation and loading (ETL), scalability and
flexibility of the applied functional models, and resource-saving of machine learning (ML) and deep learning (DL) implements [9].

| Technologies | Advantages and applications | Challenges | References |
|--------------|----------------------------|------------|------------|
| 5G           | (1) Wide spectrum of frequencies, a bigger-sized dataset. | Data safety protection and attack preventing | (Agiwal, Kwon, Park, & Jin, 2021; Liu, Wu, Li, & Chen, 2021; Rodriguez et al., 2021) |
|              | (2) Helping with DF effective visual managements and MES. | | |
| TSN          | (1) Ensuring traffic flows with low delay, fluctuation and jitter, as well as the high stability and scalability. | Time-consuming of network configuration during processes of model designing, data transforming, data analysis and simulation. | (Houtan et al., 2021; Prados-Garzon, Chinchilla-Romero, Ameigeiras, Muñoz, & Lopez-Soler, 2021; Sudhakaran, Montgomery, Kashef, Cavalcanti, & Candell, 2021) |
|              | (2) Helping for industry network enhancements. | | |
| DT           | (1) Intelligent monitoring in the real-time and helping to make a statistic-supportive decision. | High requirements of the data interaction and fusion, high-precision and real-time data extraction, transformation and loading (ETL), scalability and flexibility of the applied functional models, and resource-saving of machine learning (ML) and deep learning (DL) implements | (He & Bai, 2021; Q. Liu et al., 2021; Wen-hao, Guo-bing, & Zi-chun, 2021) |
|              | (2) Helping for resource configuration, device motion, system control, and model optimization | | |
2. Solutions for Security Issues of DF Networks

An information security management system (ISMS) with ISO27001 ISMS certification is an effect method for DF network security protection. As the figure 1 shown, the real-time implementation of relevant enterprise policy management methods plays an important role in personnel network information constraints. In addition, for the network security protection, data security protection, security monitoring and emergency drill, 5G and TSN network technologies of internal network layout designing play a significant role for DF effective network establish, based on which, time-delay and accident risk reducing and real-time communication are promoted. The advantages of low latency, large bandwidth and ultra-high number of connections of 5G+TSN is able to have a great impact on the existing network, especially for the WIFI network, mobile terminal applications. 5G network is a key solution for insufficient bandwidth and high concurrency of data extraction, transformation and loading (ETL)[10]. Wide applications of this technology in on-site video and video conference system provides a guarantee for enterprise decision-making and security real-time monitoring. Besides, building logical security isolated network slices is another significant approach to support different application scenarios.

Figure 1. DF Internet security strategies.

3. Solutions for DL Precise Issues

The establishment of product life management (PLM) platform, intelligent product production, transportation, detection process, parallel linkage process simulation platform and virtual factory play a key role in the construction of DF precision.

Combining one flow of uncoiling shear, underground charge material conveying line and stamping automatic die changing system plays a significant role for workflow automatic numerical control and precision production. The robot is used to pick up parts in the production workshop, and the unmanned production in the injection molding machine area is realized through the centralized production mode. Through the central feeding system to achieve centralized supply of raw materials, reduce the workshop
logistics and reduce the workshop temperature. The key equipment achieves the real-time data acquisition of production action signal through the workshop Internet of things.

In the process of product transportation, it should be pay special attention to the precision construction of logistics in the factory area. AGV precision transportation system of the material flow line side warehouse is comprehensively considered during the planning layout, logistics route, distribution mode, etc. Promoting the comprehensive application of lean production, intelligent and standardized measures are adopted for vehicles entering and leaving the factory area to make overall planning for accurate vehicle guidance and unloading / delivery scheduling scheme. In order to make full use of the unloading shop, storage location, forklifting and other logistics resources, shorten the transportation time of materials from the supplier to the first-line warehouse. Based on RFID technology, the enterprise has established an intelligent logistics information management integrated system, which is combined with MES system, access control management system and JIT system to comprehensively control and monitor the vehicle in and out of the factory, supplier distribution and vehicle loading and unloading, and complete the manual intervention and intelligent rule setting for the unloading / delivery point and vehicle parking point in the factory, so as to realize the control of the busy and dangerous vehicles in the factory. It is effective to control and intervene the situation of vehicles in the whole factory and the situation of unloading occupancy.

In the process of product precision testing, it is suggested to adopt a highly integrated and intelligent testing system based on the application in the same industry, which integrates security testing, password burning and operation testing. Through the application of RFID system, the unmanned vacuum filling and automatic docking test are realized. At the same time, the application of robots and simple automation equipment has greatly released the need of human resources for heavy physical and simple repetitive jobs.

The process simulation platform established realizes the process simulation data linkage system of "design + process + manufacturing". Based on the product information, the process design scheme is generated, and the manufacturing platform completes the product manufacturing process based on the scheme. At the same time, each process module involves parallel manufacturing and cross validation at the same time, building the data linkage of product design platform, process simulation platform and product manufacturing platform.

The task of model establishment is completed based on the digital virtual factory driven by field equipment data. The overall content includes self-developed special intelligent equipment, industrial complete set, industrial production / handling robot, assembly line, intelligent logistics, digital storage equipment, intelligent workshop RFID intelligent sensor and control equipment. The digital model and virtual monitoring are driven by the status data of the actual workshop, and the accurate data analysis realizes the movement synchronization between the virtual factory and the actual workshop, and has the virtual roaming function of the whole production line, including the whole workshop roaming, single line display, single equipment view, etc. The operation mechanism of virtual factory based on DF is shown as the figure below.
4. Solutions for Security Issues of DF Networks

Smart cloud factory is the main trend of digital factory automation at present. It is suggested that adopting the network mode of TSN and 5G integration, and combines with ecology to connect TSN + 5G network to all aspects of the factory, realizing industrial high-definition image processing, industrial AR / VR, industrial network management, real-time control, cloud-based AGV and robot, etc. In this process, TSN and 5G technologies show the following advantages. (1) TSN can be used in all aspects of intelligent factory, and can be seamlessly connected with deterministic extranet technology. (2) 5G technology significantly improves the deterministic wireless communication ability of intelligent factory intranet. (3) The integration of 5G and TSN provides full coverage deterministic low delay communication guarantee for the intelligent factory intranet. (4) 5G network system is independent of TSN system. This network system can carry and use TSN network, bridge with multiple TSN domains, and almost meet all the characteristics of TSN. But at the same time, the integration of the two also faces many challenges, such as. the adaptation of time synchronization protocol and 5G and TSN network joint configuration issues.

In addition, based on DT advanced technology, data-driven decision support and real-time monitoring are realized [11]. In recent years, production line point stop information control system of DF industries uploads PLC point stop control data to the server through the serial port to WiFi, simulates the production status in real time through the 2D dynamic panel, and optimizes the process beat of the corresponding machine by analyzing the point stop times and the point stop time, which achieves the standardization of management and paperless process. It is effective to adopts equipment networking for overall equipment effectiveness (OEE). SMT assembly line is built in, SMT equipment efficiency monitoring is imported, and equipment status and product production cycle data are collected. Building the monitoring platform management page, effectively helping with the enhancement of visual operation management of the whole life cycle of cloud factory product production, production efficiency, real-time monitor the operation status of factory equipment, and the early warning of abnormal operation.
Big Data Comprehensive Solution for Digital Issues

Intelligent after-sales service application is designed and implemented for multiple industries. Through the real-time data pipeline, the data connection and closed-loop flow among the service sales application is implemented with fully utilizing the value of data assets [12]. The design framework of the enterprise’s efficient big data integrated solution is shown as the figure below.

![Figure 3. Digital cloud workshop.](image)

Figure 3. Digital cloud workshop.

5. Big Data Comprehensive Solution for Digital Issues

The digital architecture is requested to be established for DF building, such as the industrial app layer design, industrial PAAS layer design, edge design, network protocol and equipment layer, which plays a key role for the digital intelligence of all equipment [13].

The advanced and interactive mode of network rapid iteration is the vital approach for the factories’ digitalization, which includes the software package of monitoring, informatization and automation functions. Based on the intelligent data center, tasks of data descriptive analyzing, exploring and predicting are implemented, which finally the intelligent applied to practical scenario based on the operation and maintenance needs [13,14].

![Figure 4. Framework of the efficient big data comprehensive solution.](image)

Figure 4. Framework of the efficient big data comprehensive solution.
There are three phases for industrial data ETL. (1) As for data acquisition and processing, in order to collect and classify the dynamic data and static data, the method based on Kafka and DBUS unified pipeline, are practical way for the real-time analysis platform, where the structured data, logs, indicators, relational data and other data are stored in hive, elastic search and HDFS respectively. (2) It is significant to considering the data Distributed collaboration process. The realization of cloud collaborative production is reflected in R & D design collaboration and collaborative R & D process simulation. Collaborative supply is reflected in the end-to-end collaboration between upstream customers and downstream suppliers, and the supply chain collaboration of data exchange between product models and raw materials. Manufacturing collaboration, national base, headquarters release plan, through intelligent layout visualization APS, intelligent scheduling system to achieve release base production semi-finished product plan, headquarters docking assembly plan. Through data processing in data center, data sharing is realized. (3) Cloud edge collaboration is the most practical strategy for DL establishment. The cloud configuration and performance requirements will continue to increase with the increase of the amount of data processed by the canter. The data transmission from industrial field equipment is increasing with the passage of time and the intelligent development of the factory. The emergence of edge computing nodes realizes the calculation, storage and backup of specific small-scale data, reduces the amount of data collected to the central cloud, shares the pressure of the central cloud nodes, prevents data loss, ensures data security, and makes contributions to the mining and sharing of big data for cloud computing. At the same time, based on the training and optimization algorithm model of cloud big data, real-time small-scale data is used at the edge to realize self-learning closed loop.

6. Conclusion
DF is the foundation of intelligent factory, which is responsible for efficiency improvement, personnel reduction, production stability and quality promotion. However, there are several challenges of DF top-level design practically, especially for its network, precision, automation and digitalization. 5G, TSN and DT are emerging advanced technological achievements. 5G + TSN + DT model has great advantages in information security, accurate decision-making, and intelligent cloud factory construction. Besides, with the design and application of high efficiency big data comprehensive solution, enterprise data sets of all related departments are able to be collected synchronously, contributing significant value of data assets. For the future research direction, the following suggestions are proposed. (1) Based on artificial intelligence technology, future studies could consider utilizing methods of big data analysis and AI prediction model for intelligent digital factory management and decision supporting. (2) Based on the DT virtual factory model, the future research could research on the virtual instructions and prediction results, which is a great reference for physical factory decision making processes. (3) A more detailed and practical solution exploring from perspectives of network, precision, automation and digitalization are also suggested for the future research.

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