Research on Digital Manufacturing of Lithium Battery Pilot Production Line Based on Virtual Reality

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Abstract: In order to systematically study and verify the digital manufacturing architecture and its key technologies, to solve the problems that enterprises currently face in the process of transformation and upgrading of digital and network manufacturing, a lithium battery pilot production line was selected as the research object, using the virtual reality technology as the underlying foundation, integratedly tested and verified the technology contents of the production line including the virtual simulation technology, manufacturing execution construction, information acquisition, and equipment automated transformation required for the construction of a digital factory, tested and verified the inter-drive and mutual control of the pilot line digital twin with its physical entity. The results show that virtual reality technology can provide a virtual testing platform for digital manufacturing which improves the efficiency of automation transformation, digital production and network operation of the actual production lines. This can provide a useful reference for enterprises to achieve a higher degree of digital manufacturing and maintenance in the future.

Keywords: virtual reality; digital manufacturing; digital factory; digital twin; production line transformation

1. Introduction
The global manufacturing is undergoing profound changes, and manufacturing has once again become the focus of competition among all the countries. Intelligent manufacturing is the deep integration of new-generation information technology and advanced manufacturing technology which runs through all links in the entire lifecycle of production and service. It is a main driver of innovation and development in various countries and also it is a main path for the transformation and upgrading of China's manufacturing. The enterprises are the main body which implementing intelligent manufacturing, the improvement of quality and efficiency of production is the goal of each enterprises when implementing intelligent manufacturing [1, 2].

With the continuous development and evolution of manufacturing technology and information technology, intelligent manufacturing presents the basic three paradigms of digital manufacturing, digital network manufacturing, and digital network and intelligent manufacturing. The foundation and characteristics of these three paradigms are digital manufacturing [3]. Digital manufacturing uses digital description and analysis of product information, process information and resource information to efficiently provide the products and services that meet customer needs. Virtual reality technology is one of the core technologies of the digital manufacturing system. It can provide a virtual integrated environment for digital manufacturing, and can efficiently and flexibly simulate, verify and optimize all aspects of the actual product manufacturing lifecycle. It is one of the breakthroughs in the research of digital manufacturing [4,5].

At present, there are many researches on digital manufacturing in the world. Professor Grieves [6] proposes to promote the application of digital manufacturing technology from the perspective of lean manufacturing based on product lifecycle. Tuegel [7] proposes the use of digital twins in the united
states air force laboratory to solve the problems of aircraft manufacturing and maintenance within complex service environments. Joachim [8] proposes the need to understand the current development trend of digital manufacturing from the perspective of embedded innovation in the future. Guo [9] realizes the digital system and digital management of construction equipment enterprises based on material and capital flows. It can be found that the scholars have many different research focuses, but the research on digital manufacturing using virtual reality technology as the underlying infrastructure is relatively rare.

This paper takes a lithium battery pilot production line as the research object, the production line has a low degree of automation, almost no data transmission between stations, and no manufacturing execution system (MES) for production management. Therefore, we take virtual reality technology as the entry point, and carry out research on production line automation digitalization and network upgrade. Based on immersive virtual reality technology, digital twins at each station of the production line have been established, and a miniature digital factory has been systematically constructed including production line equipment simulation, data sensing network, equipment automation transformation and manufacturing execution management. The purpose is to accumulate and get the basic technologies of digital network manufacturing for our company with our own study, and then apply it to the actual products manufacturing and service upgrade process.

2. The System Structure

2.1. Research Link Selection
The research object of this paper is a lithium battery pilot production line which includes dozens of processes involving material chemical and electromechanics, such as material mixing, coating, stacking, welding, liquid injection and charge and discharge. It is a typical production line with the features of both process manufacturing and discrete manufacturing. In order to focus on the research and construction of a miniature digital factory based on discrete manufacturing, four key links were selected including lithium battery pole piece size detection, sorting and stacking, pole piece transportation, feeding and lamination, as shown in Figure 1.

![Figure 1. The research object](image)

2.2. Framework of the Scheme
The overall goal of the research is to use virtual reality technology as an implementation means to establish component models, equipment models, processing models and management models in a virtual environment, to establish a miniature digital factory that contains component quality inspection, component sorting and stacking, parts transportation and product assembly etc. which has functions of data uploading, data analysis and data management. And then it can be used to guide the implementation of the physical production line project. The overall design framework of this miniature digital factory is a typical discrete digital factory containing five levels such as the field layer, the control layer, the operation layer, the management layer and the enterprise layer. And need to complete the corresponding work content in each layer of this miniature digital factory. At the same time, this miniature digital factory also contains three types of digital Twins such as the product digital twins, the manufacturing digital twins and the management digital twins, as shown in Figure 2. The purpose of such a comprehensive design is to be able to lay the
foundation for the automation, digitalization and network upgrade of a larger range of production lines that the company will face in the future.

Figure 2. Overall design framework.

The field layer of this miniature digital factory is composed of three units: a logistics unit containing pole piece silos, a conveyor belt and an AGV, a sorting unit containing a visual inspection machine and a robot, and an assembly unit containing automatic stacking of pole pieces. The equipment and sensors at the field layer are connected to the control system at the control layer through the field bus and wireless sensor network to form an IoT (internet of things) system on the shop floor. At the operation layer, the data monitoring and acquisition system manages the hardware devices at the field layer through the control systems. At the management layer, the cloud-based MES system completes production management and operation management. At the enterprise layer, orders are placed on Pad mobile terminals to simulate real-world ERP systems for distributing production tasks.

This miniature digital factory built on the basis of virtual reality technology contains the product's digital twin, which is a virtual lithium battery pole piece, that specifically includes product information such as the size structure and number of pole pieces, which can be completed through using the visual inspection and digital counter devices; It contains the manufacturing digital twins which is the virtual pole piece stacking, that specifically includes production information such as production equipment, process planning, and processing and transportation of the production line, and it can be achieved through using the industrial robots, connection devices and AGV; It also contains the management digital twins, which is the digital operation and maintenance management of the production line, that specifically includes management information such as pole piece stacking management, equipment operation management and the line maintenance management, and it can be achieved through a self-developed MES system which built on the public cloud.

3. Application and Verification
The digital factory framework based on virtual reality technology which contains three types of digital twins was applied to the digital transformation of the actual line of lithium battery. It includes four major subsystems such as the line automation transformation, the data acquisition network construction, the cloud-based MES system deployment and the VR-based virtual-real mutual controlling.

3.1. Automation Transformation
The goal of automatic transformation is to improve four links of the production line such as improving the accuracy of pole piece detection, improving the efficiency of pole piece sorting and increasing the functions of automatic transportation of pole pieces and automatic feeding which is connected into a miniature assembly line. This miniature assembly line belongs to the implementation level of the field layer in the digital factory which includes the detection equipment digital twins, the sorting equipment
digital twins, the transport equipment digital twins and the lamination equipment digital twins. The design index requirements of each device of the line are shown in Table 1.

**Table 1. Functions and parameters of the automation equipments**

| Object          | Name                          | Function                                      | Main Parameter                                                   |
|-----------------|-------------------------------|-----------------------------------------------|-----------------------------------------------------------------|
| system          | assembly line of pole piece   | quality inspection, sorting and stacking, material transportation and lamination | power source 220V, 50Hz; air source 0.6-0.8MPa; emergency stop device |
| sub system      | quality Inspection            | robot vision inspects the size of each pole piece and data storage | 6 million pixels; target surface size 1 / 1.8”                  |
|                 | sorting and stacking          | The robot recognizes, sorts and stacks the products, then recording the data | rotation range 280 °; maximum carrying capacity 3kg; standard cycle time 0.4s |
|                 | material transportation       | AGV automatically picks up and transports material to the lamination area | speed 10-30m / min; maximum load 50kg; stop accuracy ± 3mm      |
|                 | feeding and lamination        | pushes the material frame into the lamination machine or pulls it out | maximum working radius 1441.5mm; wrist load 6kg; repeat positioning accuracy ± 0.02mm |

Based on the virtual reality technology, a three-dimensional model of the visual inspection equipment was established as shown in Figure 3, the installation position, the structure, the size and the installation position of the visual inspection camera were determined according to the virtual model, and the pass frequency of each pole piece could also be calibrated.

![Figure 3. The visual inspection equipment](image1)

A virtual 3D model of the four-axis sorting robot and docking station is established, as shown in Figure 4 which can simulate and determine whether the planned robot can meet the design requirements in terms of the sorting function, the operating frequency and the equipment size. The structure and size of the docking station were clarified, the number of docking stations and the compatibility with the sorting robot were also clarified, which provided a simulation basis for the subsequent selection of AGV.

![Figure 4. The sorting robot and the docking stations](image2)
A virtual three-dimensional model of AGV was established, as shown in Figure 5, the selection of AGV was confirmed, and the function of automatic transportation of pole piece material frame and the transportation efficiency were verified and experienced. At the same time, the magnetic track laying scheme on the workshop site and the safe working area of the staff were also confirmed which provides a designing reference for larger actual production line transformation.

Figure 5. The AGV

A virtual three-dimensional model of the six-axis feeding robot was established, as shown in Figure 6, which confirmed the feasibility of the robot's active feeding function, and verified the corresponding feeding program code; At the same time, it provided simulation planning basis for the design of lamination tooling and the arrangement of safety fences according to the simulation of the feeding route.

Figure 6. The six-axis feeding robot

3.2. Data Acquisition and Communication
The purpose of establishing a data collection and communication network is to collect and upload environmental data such as production equipment status datas, product status datas, and temperature datas and humidity datas to the cloud-based MES system for integrated management, monitoring and optimizing for the actual manufacturing process, and lay the foundation for subsequent digital network manufacturing researches and projects. The common bus and wireless sensors were used to form the network structure of the production line. Due to the small space of this lithium battery pilot line, wireless sensor network are used in difficult wiring locations, so the entire data acquisition communication network is a wired and wireless hybrid sensor network system. The construction of the communication network system includes the implementation content of the control layer and operation layer of the miniature digital factory, including the digital twins of equipment operation management and digital twins of production line operation and maintenance controlling. However, it was not necessary to use the virtual reality simulation to assist in the designing and implementation of the actual network construction.

3.3. Cloud-based MES System
Different from the general MES system, this MES system is based on the IoT architecture which is established here with two goals: on the one hand, it is necessary to enable the production line to achieve efficient manufacturing execution based on data integration management and to realize the digital manufacturing and management of this miniature digital factory; On the other hand, it is to explore and develop a public cloud-based MES system to lay the foundation for the subsequent large-scale network
manufacturing. The logic diagram of the process flow and data flow of this MES is shown in Figure 7. At the same time, the cloud-based MES system itself is also a typical management digital twin. Based on virtual reality technology, a virtual MES operation interface is established in the virtual environment, as shown in Figure 8, the functions and operations required for the design are logically programmed, and after repeated debugging to realize the management and controlling of the virtual line by the virtual MES system. The content of this controlling mainly includes the management of the operating status of each device such as the completed output, the production cycle, the number of qualified products, the alarm information and the energy consumption and so on. It can provide a good simulation basis for the development and functional verification for the construction of the actual cloud-based MES system.

![Figure 7. Process flow and data flow](image)

![Figure 8. The virtual MES system](image)

3. 4. Interaction between Virtual and Reality

Based on VR technology, a digital twin of the entire lithium battery line including products, equipments and production management was established. In order to achieve data communication and function control between the digital twin and its actual line, the power switch was chosen as a research object, start-stop was tested to verify the information interconnection between virtual and real switches. The implemented technical method is to transmit the running state and operation parameters of the actual production line power switch to the developed interface program through the PLC. Then the interface program transmits the datas to the virtual switch program in the virtual environment through the UDP, then to drive the virtual power switch for synchronous start or stop actions, as shown in Figure 9.
Realizing the mutual drive and mutual control of the start-stop of the virtual and real power switch based on virtual reality technology which plays a very important demonstration role in the subsequent realization of the mutual control of the virtual and real drive in each key link of the entire production line, it also provides a good implementation path for deeper research on digital and network manufacturing.

4. Conclusion
In this paper, four key links such as the pole piece measurement, sorting, transportation, and stacking of a traditional lithium battery pilot production line were selected for research. Based on virtual reality technology, this production line has been upgraded and transformed into a miniature digital factory. This miniature digital factory is a typical discrete manufacturing one that includes the enterprise layer, the management layer, the operation layer, the control layer and the field layer. It also contains the digital twins of product, digital twins of manufacturing and digital Twins of management. Throughout the upgrade process, virtual reality technology has played a fundamental and decisive role that it provides a virtual simulation test platform environment which can be immersed and experienced before the reconstruction project would be implemented, and can easily plan, test or optimize the entire digital plant design. At the same time, the digital twins generated based on virtual reality technology can be well applied in other subsequent specially digital manufacturing related research such as product designing, manufacturing process optimization or management system upgrade, etc., and to lay a foundation for deeper digital manufacturing of the entire product lifecycle. Although this paper has done a wide range of demonstration research and case verification on digital manufacturing systems, it still stays at a low-level that only in some transformation of several stations of the production line, and has not carried out more in-depth simulation testing and verification, for example the start-stop control of the power switch. So, further exploration in data analysis, virtual debugging and man-machine collaboration is needed to study in the near future. At the same time, it is also necessary to combine industrial interconnection technologies such as 5G and IoT to take a better study about the synergy between digital manufacturing and network manufacturing and prepare for the true realization of intelligent manufacturing.

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