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Research on design of the smart factory for forging enterprise in the industry 4.0 environment

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1. Introduction

With the word-wide proposing of "Industry 4.0", China follows the trend of the times closely–put forward "Made in China 2025" plan in 2015. The implementation of the pilot of Intelligent Manufacturing in 2015 was issued by the National Development and Reform Commission on March 18, 2015 and meanwhile the pilot of smart manufacturing was officially launched.

With neural networks, expert systems and artificial intelligence techniques being widely used in the manufacturing system, manufacturing information and knowledge representation, transmission, storage and reasoning based on big industrial data become possible. On the other hand, a new type of intelligent manufacturing production mode emerges. Intelligent manufacturing lies in product life-cycle manufacturing activities, mainly including design, processing, robotics, control, process planning, scheduling, intelligent measurement and so on. Intelligent manufacturing technology is the combination of traditional manufacturing techniques and computer technology, network technology, automation technology and artificial intelligence technology. Intelligent manufacturing mainly includes digital design and co-simulation of production line, logistics systems and production information system.

The following reviews the three aspects on the present situation of research at home and abroad:

1. Digital design and co-simulation of production line. It uses the core equipment, robots, and other automated equipment to test and verify the production system before actual production: logistics, equipment layout and their impacts on productivity and cost, which can provide almost unlimited flexibility of the production and test the influence of different production strategies or new production plans. Stopwatch time study and simulation software were used to establish production line models by Skoogh A [1]. The results show that using simulation can improve production line balancing rate, capacity and average work rate of all processes [2]. Therefore, lots of co-simulation models were studied. A mathematical model for the continuous rolling production line was presented based on tlaminar cooling model as well as temperature prediction and control [3]. Another example is the Model View Controller (MVC) architecture which was adopted to design the simulation system in order to realize multi-view of production lines [4]. A multi-objective optimization model based on Stackelberg game theory is proposed to determine the specifications of new and re-manufactured products [5].

2. Intelligent workshop logistics system. It contains transportation, storage, purchasing, handling, packaging, distribution processing, marketing, logistics and information processing as well as labor, materials, equipment and resources required by the external environment to the system. The first step is to establish a logistics system model. Shih LH [6] recovered logistics study in reverse logistics system planning by using a mixed integer programming model to optimize the design of the infrastructure network and reverse flow. The proposed model tries to minimize the total cost, including transportation costs, operating costs, fixed costs of the new facilities and landfill costs [7]. And 2D layout and logistics model of production line can be designed through defining the hierarchical structure of production line and forming a resource information worksheet [8]. With this worksheet and product information as input, 3D production line simulation model can be established quickly to evaluate the logistics plan [9]. A reversible track supply chain logistics model based on Radio Frequency Identification (RFID) technology was proposed to demonstrate the functional structure of the enterprise logistics real-time tracking system [10]. Using a reversible system, sharing and database management of the products in the supply chain as well as real-time tracking were achieved.

Additionally, with the popularity of industrial robots, more logistics information and tasks can be handled by them. A model based on iterative learning control (MB-ILC) was proposed for industrial robot manipulators to avoid non-causal problems [11]. A novel approach of decentralized hash tables was proposed for mobile robot teams to solve intra-logistics tasks by D Sun [12]. Centralized solutions suffer from limited scalability and have a single point of failure. The task is to transport materials between stations keeping the communication network structure intact and most importantly, to facilitate a fair distribution of robots among loading stations. Wu W [13] introduced mobile robot program into the flexible logistics transportation control system. It achieved the recognition of the work in any position, resulting in efficiency improvements of the system. Programmable Logic Controller

(PLC) and mobile robots can be interconnected by Object Linking and Embedding for Process Control (OPC) and wireless communications.

3. Intelligent plant production information system. It includes Product Data Management (PDM), Computer Aided Process Planning (CAPP) and Enterprise Resource Planning (ERP) and so on. PDM as an integration link can ensure the right information be sent at the right time to the right people in the right form [14]. It makes work more effective with less errors, and also the organizations to reduce redundancy. According to the features of process data from CAPP, Zhang X proposed an improved pattern of the parent-child strategy to make a periodical full backup [15]. Shaul L [16] made a particular study of the life cycle stages of enterprise resource planning (ERP) to solve the redundancy on ERP. From orders to output, the Manufacturing Execution System (MES) makes responds to events in reporting, tracking and handling. Quick response to production status allows to optimize processes and furthermore improve the management efficiency.

The intelligent manufacturing mainly includes digital design and co-simulation of production line, logistics systems and production information system. Therefore, the key technologies used by intelligent manufacturing mainly include data acquisition technology based on RFID, data classification based on fuzzy clustering / Neural Networks, plant layout design based on SLP, scheduling based on intelligent algorithm. The above will be the focus of this paper.

This paper is based on emerging industry development project of Jiangsu province of China"350MN multi-directional forging intelligent continuous production line". The project arms to build a high-level digitization workshop, so that the intelligence level of the manufacturing process can be improved.

The procedure of precracking in details is described in.

2. Intelligent production architecture

Based on the above analysis of intelligent manufacturing and manufacturing industry, an intelligent production architecture of intelligent manufacturing for certain forging enterprise is proposed as shown in Fig. 1. The core of the presented study are data acquisition and data classification. Besides, the co-simulation of production line is the foundation and the scheduling is the goal. It is helpful to manage and share network resources with different functions through a unified standard interface.

1. The construction of production line is the first step of the proposed intelligent manufacturing to design the public facilities and intelligent automation equipment. Design of the facilities includes the forging workshops for 220MN/130MN production lines, workshops for finishing and molding, factories for finishing and testing, test centre of engineering and other facilities.

2. Since some information systems such as CAPP, ERP and MES have been applied in the enterprise, data acquisition and the switch between applications are the focus as the basis for data analysis and scheduling optimization.

3. After collecting the data, useful data need to be screened and furthermore classified as the research difficulty. Through data classification, the similarity of the between the samples and an accurate division after several iterations will be mined.

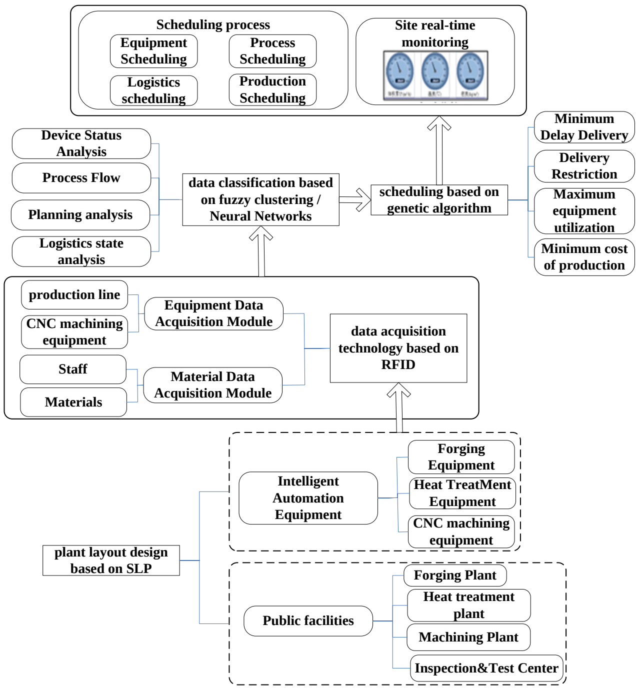

Fig. 1 Intelligent production architecture

4. The production analysis reports which are in the form of billboards, and special graphics will be presented by comprehensive intelligent manufacturing management systems. The automation equipment and systems can be integrated for optimal production lines scheduling with necessary data gathered in time to monitor production status and carry out fault diagnosis more effectively by using networking technology.

The user can obtain the required data at any time from a variety of historical information, which will serve as the basis for decision making. A simple description is illustrated in Fig. 2.

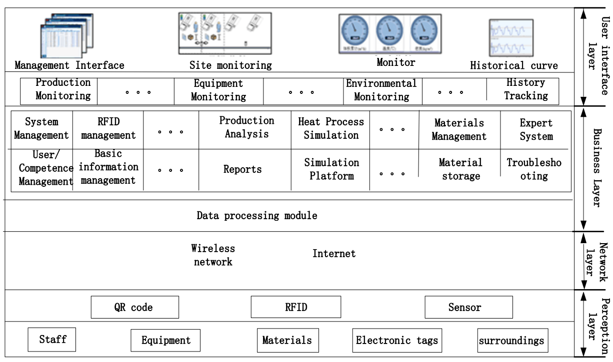

Fig. 2 The framework of the Real-time monitoring center

3. Design support for intelligent manufacturing

3.1. Intelligent plant facility layout based on System Layout Planning (SLP)

Since the 1950s, many experts in Western countries carried out systematic analysis and research on plant layout and logistics, and raised a lot of qualitative and quantitative methods for designing plant layout. Richard

Muther proposed system layout design [17], which is adopted to be covered in detail in chapter 4. A framework for intelligent plant facility layout based on SLP is shown in Fig. 3.

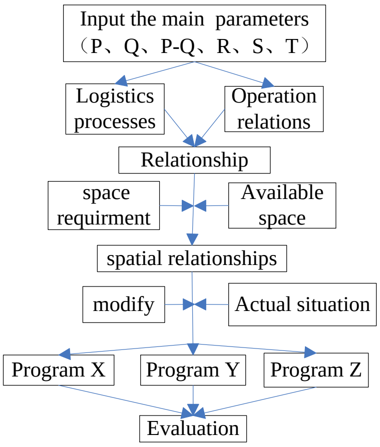

Fig. 3 he general procedure of systematic Layout Planning

3.2. Data/information acquisition for the intelligent system

RFID technology is widely used to provide a more convenient way for the intelligent manufacturing. he radio signal is transformed into a radio frequency electromagnetic field by using the RFID, and the tag with data will be converted to a signal which can be identified and tracked automatically[18]. Besides, label itself has power and can take the initiative to send out radio waves (tune into radio frequency electromagnetic fields). Information contained in the tag is stored electronically, which can be identified within a few meters. And then a variety of automation equipment and application systems can be integrated by the network technology. The real-time data acquisition, condition monitoring and fault diagnosis for the product line can be implemented. The framework for information tracking and collection based on RFID is shown in Fig. 4.

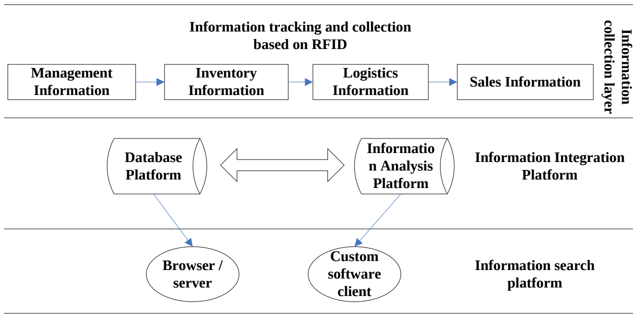

Fig. 4 he information tracking based on RFID

Radio frequency technology will be the focus of future research on intelligent plant.

3.3. Information analysis and processing of intelligent manufacturing systems

For analysis and processing of mass data, fuzzy clustering/neural network technology has been considered. In this study, Fuzzy *C* Mean (FCM) is the main method adopted. FCM gives a data set, and sets the number of cluster centers [19]. The final is to confirm the clustering objective function. And the fuzzy inference system can be generated through the cluster information: best data with minimum rules and divide the data by fuzzy links automatically.

The data centers and membership matrix are requested in the data set for FCM. The membership degrees of data clusters and data points are described by membership matrix, while defining each membership function implicitly. "Good" models and isolated spots will be found if the membership function is well-defined. Let $d_s(x_k, v_i)$ represents the distance between the point x_k and v_i. v_i is the center of cluster No. *i*. $(u_{ik})_{n*C}$ is the membership matrix. Actually the process of fuzzy clustering is to minimize the objective function:

$$j_m(u,v) = \sum_{k=1}^{n} \sum_{i=1}^{C} (u_{ik})^m d_s(x_k, v_i),\ u_{ik} \neq 0,\ \sum_{i=1}^{C} u_{ik} = 1. \tag{1}$$

The objective function is necessary to set 2 key parameters *C* (2≤ *C* <*n*) and *m* (1≤ *m*< +∞). *C* is a preset number of clusters. Usually only by trying more than one *C* values can select the best clustering.

$$m \leq \frac{G}{(G-2)}, \tag{2}$$

The *m* is a blur of clustering, and generally take it as 2.Getting the partial derivative of *u* and *v* is the process of solving.

$$v_i = \frac{\sum_{j=1}^{n} u_{ij}{}^m x_j}{\sum_{j=1}^{n} u_{ij}{}^m},\ u_{ij} = \frac{1}{\sum_{k=1}^{C} \left[\frac{d_{ij}}{d_{kj}}\right]^{2/(m-1)}}. \tag{3}$$

Only when the algorithm converges, all kinds of clustering centers and each sample value for membership can be obtained. And then the fuzzy set division is completed.

For the reason that the FCM needs too much time to get a result, this study will improve the algorithm by utilizing some advanced technology. For example: Grid technology[20]. It meshes before defining the membership functions, which can reduce the processing time.

Neural network technology is another main method for data processing.

3.4. Intelligent manufacturing systems scheduling and solution with field data

Genetic algorithm (GA) for systems scheduling has better global search capability [21]. Probabilistic methods are the main method for the optimization. GA provided a common framework for solving complex system problems which only needs the objective functions and the fitness function, as shown in Fig. 5:

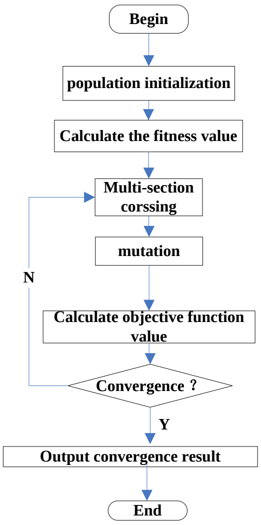

Fig. 5 The operation flowchart of genetic algorithm

Intelligent manufacturing service is the subject of this study based on QoS (Quality of Service). The fitness/ objective function can be considered as QoS combination (time, cost, flexibility, security, trust, etc.). The process of developing integrated resource planning platform relies on the GA. After GA operations, the service scheduling of intelligent manufacturing service can be obtained. A resource planning platform depend on DVR enterprise(certain application enterprises)is proposed in Fig. 6.

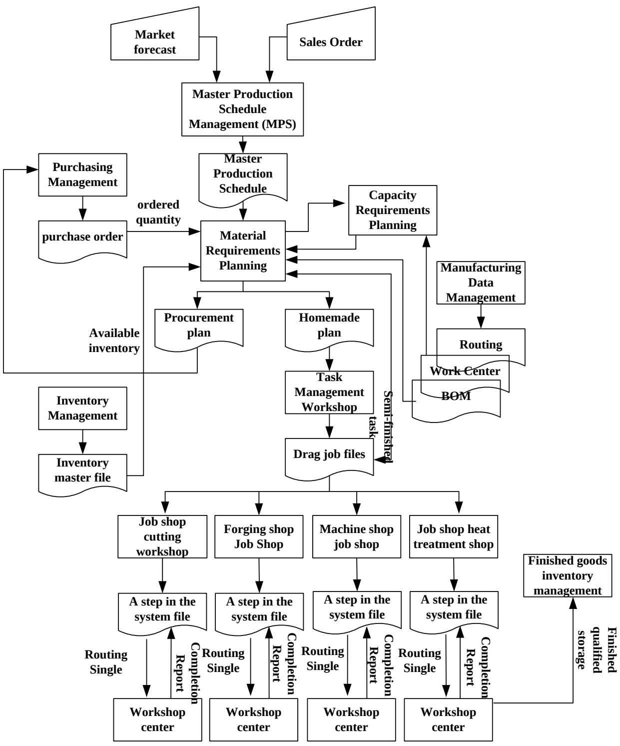

Fig. 6 Resource planning platform

This paper takes functional requirements into consideration in the division of the subsystem. Data acquisition, processing, analysis should be in shortest manner.

Based on the overall structure of the DVR digitization workshop resource planning platform, the system function frame is build. Systems are integrated into logistics management, manufacturing management, financial management, quality management, information centers, human resource management and systems management, and other major sub-modules.

The focus of future research will be the applications for enterprise information systems, such as CAPP, ERP, MES and so on. Which are distributed heterogeneous platform. In this architecture, data between applications can be integrated and exchanged.

4. Intelligent plant facility layout based on SLP

When carrying out systematic layout planning, the original information must be given first. These elements mainly refer to the product P (Product), yield Q (Quantity), production process route R (Route), auxiliary production sector S (Service), and the timing T (Time), as described below. And there is also a need for the analysis on the division of operation units by analyzing and consolidating. The routing is shown in Fig. 7.

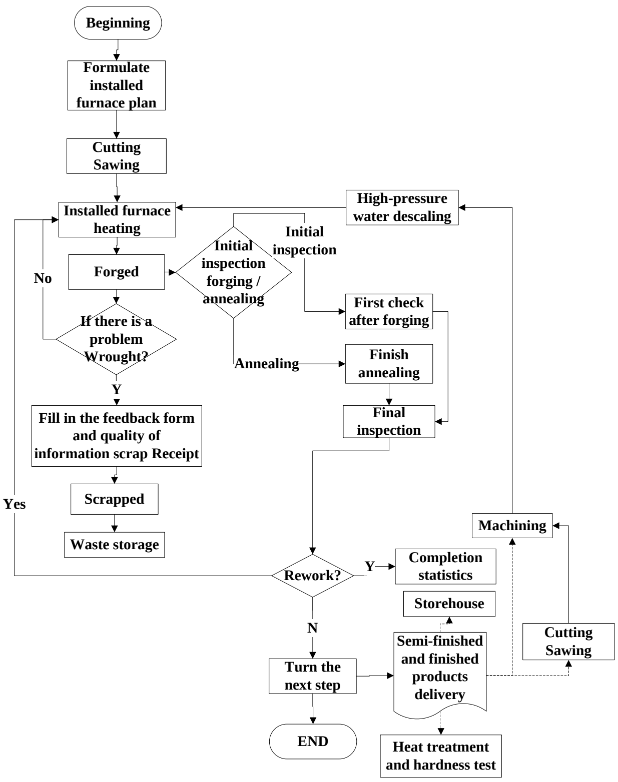

Fig. 7 The technology route of DVR production

4.1. The division of operating units

For machinery factory, production equipment and production line have a lot of flexibility and scalability to adapt to a variety of products. Machinery products are solid. They use the transportation of lifting, handling and vehicles. The continuous production need rely on inventory. Machinery factory is more complex. So the types of production workshop are generally classified by the basis of process characteristics and work nature.

4.2. Logistics analysis between operation units

According to the capacity and production technology, the amount of raw materials, shipping volume of the primary and secondary finished products will be determined. The analysis of logistics (1-13), combined with the strength of non-logistics in operation units is presented and show in the Table 2

Table 1

The division of forging shop operating units

No.	Operation units	No.	Operation units
1	Planning department	8	Heat treatment and hardness test station
2	Cutting sawing station	9	Semi-finished products in the processing section
3	High-pressure water descaling section	10	Final inspection station
4	Installed furnace heating station	11	Scrap storage section
5	Forged section	12	Semi-finished products into the treasury section
6	Initial inspection station	13	Product storage section
7	Annealing station	14	Statistics department

Table 2

The calculation table for relationship of each operation uni

No.	Opera-tionunits	Relationship					Comprehensive Relation-ship	
		Logistics Relationship (0.8)			Non-logistics relationship (0.2)			
		Logistics-strength	Strength rating	Scores	Rating	Scores	Scores	Rating
1	1-2	2.5	A	4	A	4	4	A
2	2-4	0.817	E	3	A	4	3.2	A
3	2-11	0.016	O	1	O	1	1	I
4	3-4	0	U	0	A	4	0.8	O
5	4-5	0.116	I	2	A	4	2.4	E
6	4-11	0.0012	O	1	O	1	1	I
7	5-6	3.23	A	4	A	4	4	A
8	6-10	1.6	A	4	I	2	3.6	A
9	7-10	1.6	A	4	E	1	3.4	A
10	8-13	0.76	E	3	I	2	2.8	E
11	9-10	0.485	I	2	A	4	2.4	E
12	9-11	0.025	O	1	E	3	1.4	I
13	9-12	0.01	O	1	E	3	1.4	I
14	10-12	0.77	E	3	E	3	3	A
15	10-13	0.017	O	1	E	3	1.4	I

Logistics strength is defined as the load capacity in a unit time via a fixed length. When the load is above 1, the logistics strength is defined as the A-class and the value is 4; when the load value is 0.5, the logistics strength is defined as the level E and the value is 3; when the load value of 0.1-0.5, logistics strength is defined as class I and the value is 2; when the load value of 0.1-0.5, the logistics strength is defined as the O-level and the value is 1; when the load value is 0, the logistics strength is defined as the U level and the value is 0. Non-logistics strength is classified according to the process flows. Select weight value (0.8: 0.2) to quantify the relationship of logistics and non-logistics.

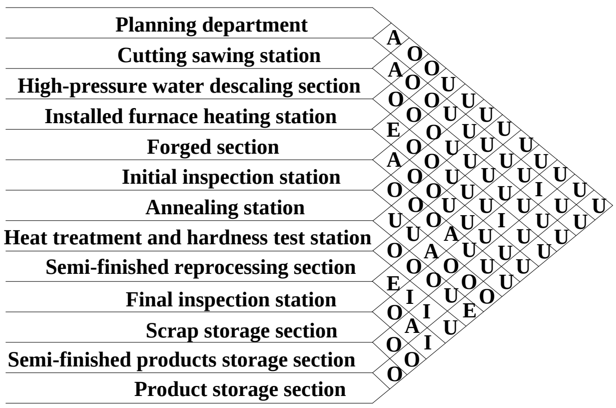

Fig. 8 Comprehensive relationship of each operation units

4.3. Workshop layout scheme

From the data in Table 2, this study summarizes the comprehensive relationship of each operation units:

The operation units can be arranged optimally by calculating the proximity of the operation units. The relevant location of operation units is placed in accordance with the order of arrangement of the various operation units, and the relevant location map of operation units is shown in Fig. 9.

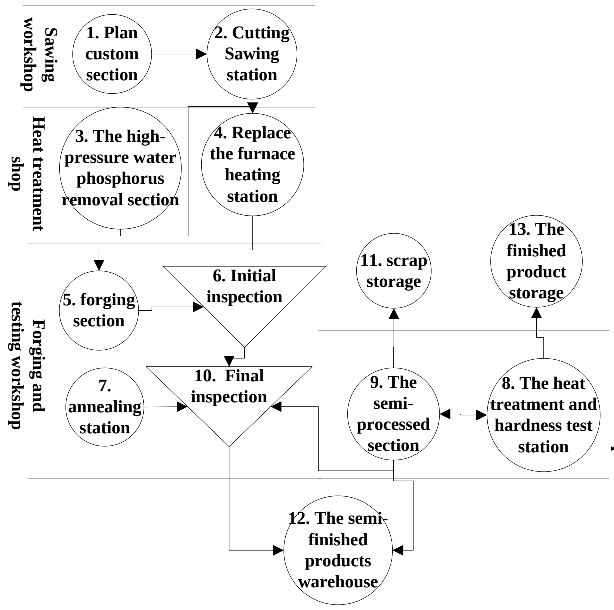

Fig. 9 Workshop layout diagram

5. Conclusions

The "Industry 4.0" and the "Made in China 2025" have been proposed for a period. Industrialization and information technology integration faces new opportunities. Intelligent manufacturing is the trend. In the process of constructing the smart plant, the notable feature is that all the participants and resources in manufacturing can be highly interactive which enable employees to control. This research studies the design of intelligent manufacturing for certain forging enterprise. Beside the intelligent plant facility layout, the data acquisition technology, data classification, scheduling are also the focus. The key technologies, such as RFID, fuzzy clustering/Neural Networks, genetic algorithm, are discussed and will be the future research directions. This presentation seeks to provide a template for the future development of smart factory, which can provide theory and case for intelligent manufacturing.

However, current research on Intelligent manufacturing for “Made in China 2025” still stays on the level of theory and framework. Therefore, the above work is just a preliminary attempt. Before it can be wildly used in practice, there still exits a great deal of works to be done in the future. The followings will be research priorities:

1. Information Collection. Spatial modeling, searching, display and interaction of industrial Internet will be carried out by positioning technology of three-dimensional based on RFID. How to make Large-scale use of RFID in the smart factory will be the points in the future study. And the research will pay more attention on the function of reading and writing of the RFID chips. The finally goals is that the RFID technology can be industrial portable and handheld.

2. Data classification based on AI. Knowledge engineering, situational awareness technology, pattern recognition technology will be developed which make the AI system have the ability of self-decision-making, self-executing and self-visualization.

3. Application of industrial robots. Grinding, polishing, drilling, milling and other processes in the intelligent factory can be robotized. Flexible control, collision detection and human-machine collaboration of industrial robots will be widely used and will be the future efforts.

Acknowledgments

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RESEARCH ON DESIGN OF THE SMART FACTORY FOR FORGOING ENTERPRISE IN THE INDUSTRY 4.0 ENVIRONMENT

S u m m a r y

A new generation of the industrial revolution whose codes are intelligent manufacturing has a huge demand for intelligent production. Based on the information of the Industry 4.0 and Made in China 2025, an intelligent plant design and planning have been proposed and presented in detail. Data acquisition based on RFID, data classification based on fuzzy clustering/Neural Networks, scheduling based on genetic algorithm are also discussed. For the future study, these key technologies will raise a wile-range research and twill make an important role in the construction of intelligent manufacturing. In addition, this study presents an optimization of fuzzy clustering by joining the grid algorithm which can shorten the processing time of the fuzzy clustering by meshing the data before fuzzy clustering. In general, this paper for the data acquisition, data classification, plant layout design, scheduling has a great significance to build the intelligent manufacturing systems.

Keywords: Smart factory, RFID, Fuzzy clustering(FCM), System Layout Planning.

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