A Flexible Manufacturing System based on Virtual Simulation Technology for Building Flexible Platforms

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***Abstract*—Flexible manufacturing systems have become relatively mature in the industrial field, representing the most advanced research achievements in the development of the manufacturing industry. But currently, there are few resources and high costs in universities to create a system that is more practical, and it cannot meet the practical teaching requirements of students in multiple majors. In response to the above issues, this study first designed a flexible manufacturing system from the overall architecture, then introduced and integrated virtual simulation technology, and utilized multi-objective genetic algorithm for cargo location optimization to improve the work efficiency of the flexible system. The research results indicate that after 213 iterations of the proposed algorithm, the iteration curve of the total objective function value tends to be stable, and the effect of cargo location optimization is relatively ideal. At this time, the total objective function value is 142.5. In addition, as the scale expands, the corresponding number of iterations for multi-objective genetic algorithm at its maximum scale is 411.2. The application effect of virtual flexible manufacturing system in practical teaching in universities is good, and visual learning methods can better attract students' attention.**

***Keywords*—Flexible platform; virtual simulation technology; manufacturing control system; multi-objective genetic algorithm; slotting optimization**

I. Introduction

With the advent of the Fourth Industrial Revolution and the rapid development of the social economy, people have put forward higher requirements for the richness of the industrial industry. This has led to a shortened lifespan of industrial products, and currently traditional single production and manufacturing technologies are no longer able to meet industrial production needs [1-2]. Therefore, to improve industrial production efficiency and meet the flexible requirements of production manufacturing systems, Flexible Manufacturing Systems (FMS) have emerged and received widespread support in related fields. FMS is a set of CNC machine tools and other automated process equipment, which is an organic combination of computer information control system and automatic material storage and transportation system. It has the advantages of high equipment utilization rate, high product quality, flexible operation, stable production capacity, and large product response capacity [3-4]. However, universities lack relevant technology and funding to learn flexible manufacturing technology, resulting in a lack of theoretical knowledge and practical application for students in related majors [5-6]. And the cost of the flexible manufacturing system close to the actual production is very expensive, which cannot meet a large number of teaching tasks, which hinders the path of cultivating mechanical automation talents in Colleges and universities, and does not meet the needs of social development. To reduce damage to flexible manufacturing equipment caused by improper operation by students and avoid personal injury, this study introduces Virtual Simulation Technology (VST) to construct a Virtual Flexible Manufacturing (VFM) system, to meet the combination of physical control system of virtual equipment and practical teaching. This paper aims to address the limitations of flexible physical systems in practical training and teaching in universities, create FMS that is more in line with practical production, and cultivate the professional and practical abilities of comprehensive talents. There are two main innovative points in the study. The first point is to propose a VFM system that integrates VST, which can interact with physical control systems, receive control commands, and feedback virtual sensor signals. The second point is to use multi-objective genetic algorithm (MOG) for cargo location optimization to improve the efficiency of flexible systems. The structure of the study mainly consists of four parts. The first part is a review of relevant research results. The second is about the design of VFM that integrates VST, as well as the optimization of cargo space in the VFM system based on MOG. The third is to verify the effectiveness and applicability of the proposed method; the final part is a summary of the entire content.

II. Related Work

With the acceleration of informatization and industrialization, the performance of industrial products is becoming increasingly complex, and traditional physical manufacturing systems are unable to meet the current production needs of industrial products. FMS has emerged as the times require. It enhances the competitiveness of enterprises, which also puts higher requirements on the application abilities of relevant practitioners and professional students. Numerous scholars have conducted in-depth research and exploration on this topic. H. Wang et al. found that there are many factors unrelated to processing in flexible manufacturing systems, resulting in significant differences in the formulation and implementation of production plans. Therefore, a study proposed an improved genetic algorithm with local search to optimize scheduling data based on discrete manufacturing enterprises. The experimental results show that compared with the current scheduling strategy of the enterprise, the scheduling strategy proposed by this algorithm has an average improvement of 29.61% in minimizing completion time, 44.8% in minimizing transportation time, and 44.64% in machine load balancing [7]. C. Zhu et al. proposed an integrated optimization method to plan and schedule a hybrid flexible manufacturing system for producing nylon components, in order to minimize energy consumption and completion time. The effectiveness and feasibility of the proposed method were verified through practical cases [8]. Setiawan A proposes an FMS based on a stacker crane model to establish a learning production system. The maximum error of this model in the x-axis and y-axis directions is 2mm [9]. Daniyan I et al. proposed an FMS including assembly, Lean manufacturing, logistics and quality assurance to adapt to the dynamic of manufacturing operations. The system can properly perform the sequence of assembly and quality assurance operations with minimal interruption and manual intervention during the manufacturing of rail car components [10].

VST is the mapping activity of a virtual simulation environment on a computer. By constructing actual device models in virtual environments and utilizing the excellent data processing capabilities of computers, VST can achieve the same results as real application scenarios, making it a new technology in various fields. M. Wei et al. innovatively introduced a virtual simulation platform to teach the power system analysis course in order to improve students' understanding of knowledge, hands-on ability, and research skills. After conducting the reform teaching, students were very satisfied with the new teaching method and believed that it could effectively stimulate students' enthusiasm for learning [11]. J. Wood et al. found that the confidence and stress levels of providers are related to the survival outcomes of patients. Therefore, they innovatively utilized virtual simulation technology to create training opportunities to enhance providers' confidence and reduce stress. The research results showed that this method can effectively enhance trust in resuscitation training and reduce stress [12]. Wang Y and others proposed a multi Kinect fusion algorithm to achieve robust full body tracking in virtual reality assisted assembly simulation, and applied distributed computing to improve computational efficiency in the algorithm. Compared with other similar algorithms, this algorithm has better fusion performance [13]. To improve the performance of online art Design education system, Yang C built an online art Design education system based on 3D VST. The constructed model can meet the current needs of online art education, and the functional modules can also be continuously optimized in the future [14].

In summary, there are many research results on FMS and VST, but currently there is relatively little research on VST for FMS in universities. To shorten the design cycle of flexible production lines and improve their design accuracy, this study introduced VST to construct a VFM system.

III. Design of VFM Integrating VST

At present, China's research and application on FMS is rapidly advancing. But there is no flexible manufacturing platform in various universities in China that meets the actual production line for teaching, resulting in the inability of students to apply their professional knowledge in practice. Therefore, the research first designs the overall scheme of VFM system, then uses VST technology to build the system, and finally proposes a MOG algorithm for VFM system to optimize the storage location.

A. Design of FMS Integrated with VST Technology

In order to design the VFM system for teaching and training links and scientific research projects, the research requires that it cannot only carry out single electrical course training, but also have the ability to integrate multiple courses. Based on the teaching tasks of college students, the following requirements are proposed for the VFM system. Firstly, it needs to not only have flexibility in processing and manufacturing, but also consider flexibility in teaching practice. Secondly, in the teaching curriculum, the theoretical content includes various mechanical and software control methods, so it is necessary to achieve teaching and practical training for different purposes in the design of VFM systems. Finally, flexible manufacturing technology is also constantly developing, and the speed of system updates and iterations is also accelerating. This requires the design of the VFM system to meet the requirements of photography technology updates to achieve the upgrade of the system. In university teaching, the physical manufacturing teaching system may have drawbacks, such as high teaching costs, resource shortages, slow security and system upgrade iterations in student practice [15-16]. To address the above issues, the study introduces VST in the design of VFM, enabling students to conduct virtual simulations of VFM through virtual simulation software. In addition, the research selected the current mainstream computer 3D display technology and placed virtual devices with the same functions and attributes as flexible devices in a virtual environment to build a VFM system. At the same time, by adding virtual devices to upgrade and optimize the system, each computer can be seen as a set of flexible systems, which effectively solves the problems of high cost and limited resources in traditional flexible systems. According to its functions, it can be divided into three parts: logistics warehousing, production manufacturing, and control systems. The logistics warehousing system in the VFM system is its advantage, with high intelligence and freedom, which can distinguish various types of workpieces for mixed transportation. This link can use the information processing of computers and controllers, and perform intelligent control of multiple devices at the same time; The system can also transport processed parts in different functional areas, and the three-dimensional warehouse can improve its storage space utilization and workpiece processing efficiency through an intelligent automatic warehouse information relationship system. The production and manufacturing system includes flexible production lines, six axis CNC machining centers, robots, and inspection devices. The control system is the command core of VFM. Design VFM by analyzing its impact on the functionality and work efficiency of the system, and study the optimization of warehouse locations in the system to improve the efficiency of flexible system work by improving the efficiency of goods in and out. From this, the VFM design process in Fig. 1 can be obtained.

The virtual development platform used in this study is a specialized simulation software for electromechanical systems. It is based on the latest virtual debugging and simulation technology and provides users with a fully open virtual device development platform. The 3D model is based on the development of mainstream 3D modeling software, and uses the latest 3D rendering technology and Physics engine to show the most realistic simulation effect. Compared with other simulation software, electromechanical integration simulation software and physical controllers have better information exchange capabilities, which can simplify the implementation of external controllers' motion control of virtual devices in virtual software. The hardware equipment in the designed VFM system uses computers and HTC VIVE. Computers provide a running environment for simulation software; HTC VIVE is the implementation of Virtual Reality (VR) functionality in simulation systems. From this, the overall framework of the virtual simulation system can be obtained, as shown in Fig. 2, which is composed of a model layer, a data layer, and a human-machine interaction layer.

B. *Construction of FMS Integrating VST*

The proposed VFM system has novelty. Virtual flexible devices not only have the same mechanical structure and motion mode as actual devices, but also interact with physical control systems for signals. It also has the function of receiving control commands and feedback virtual sensor signals. In the 3D modeling process of the VFM system, the modeling results generate a large amount of redundancy, and exporting them can also generate a large amount of data. After being imported into simulation software, it will occupy a large amount of computer memory, causing problems such as crying and incomplete animation display when the virtual simulation system runs. Therefore, this study will achieve lightweight processing by converting 3D models into 3DXML format. Therefore, the research realizes the lightweight processing by converting the 3D model into 3DXML format, which only contains the entity information of the 3D model and the assembly features of the mechanical structure, and its storage space is reduced by 90% compared with the traditional CAD and manifest formats. There are many 3D shapes in 3D modeling, which are not necessary for the simulator and can greatly reduce the display effect. Therefore, the most commonly used method for simplifying 3D models is the edge folding algorithm. Its principle is as follows: let a plane Q be (1) [17].

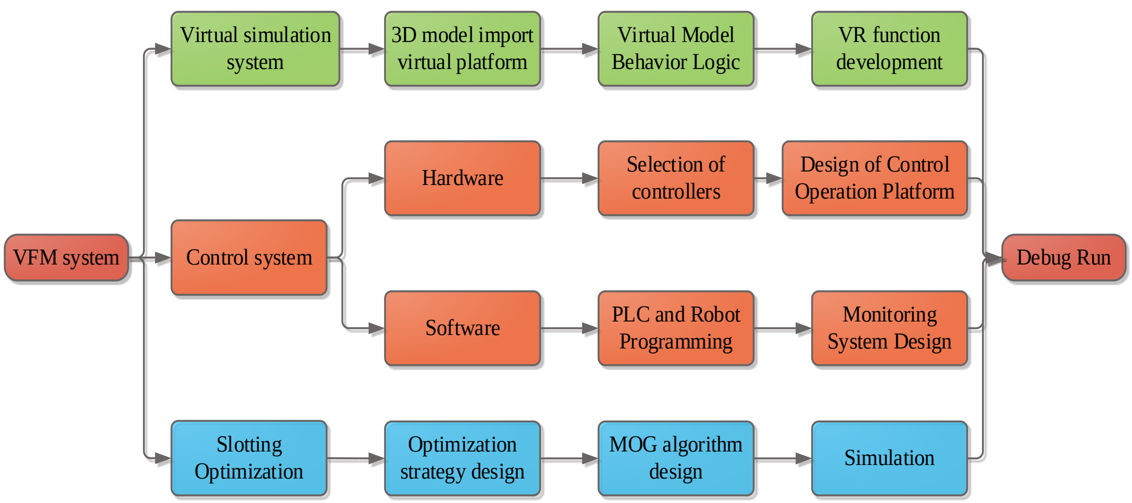


Fig. 1. VFM system design process.

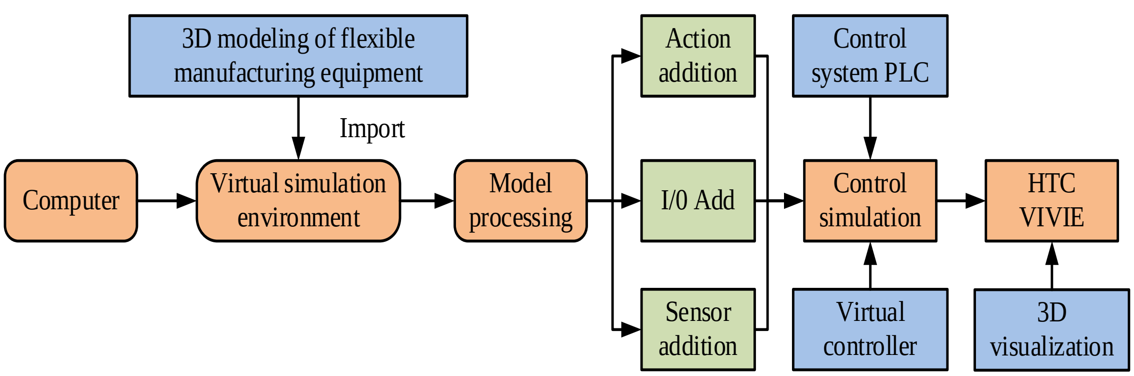


Fig. 2. The overall framework of virtual simulation systems.

$$\begin{cases} ax+by+cz+d=0 \\ a^2+b^2+c^2=1 \end{cases} \tag{1}$$

In (1), d represents a constant. By setting the coordinate of point p as (x,y,z), the distance from it to Q can be obtained, as (2).

$$d(p)=|ax+by+cz+d| \tag{2}$$

By (2), $Q=[abcd]^T$ can be gaibed. If the other vertex is $\bar{g}=[xyz1]^T$, the square of the distance from $\bar{g}$ to Q is obtained as (3).

$$d_Q^2(\vec{g})=\vec{g}^T D_Q \vec{g} \tag{3}$$

In (3), D_Q is a Symmetric matrix of 4×4, as (4).

$$D_Q=\begin{bmatrix} a^2 & \text{ab} & \text{ac} & \text{ad} \\ ab & \text{b}^2 & \text{bc} & \text{bd} \\ ac & \text{bc} & \text{c}^2 & \text{cd} \\ ad & \text{bd} & \text{cd} & \text{d}^2 \end{bmatrix} \tag{4}$$

When folding edge (g_1,g_2) to $\bar{g}$, the quadratic error matrix of $\bar{g}$ is obtained. Then simplify the operation and take matrix $L(g_1)+L(g_2)$ as the quadratic error matrix between the new vertex and (g_1,g_2) to obtain the folding cost of (g_1,g_2), as (5).

$$\Delta(\bar{g})=\bar{g}^T\left(L(g_1+Lg_2)\right)\bar{g} \tag{5}$$

To perform edge folding operation, a position must be selected for $\bar{g}$. Since the Error function is a Quadratic function, the minimum value of $\Delta(\bar{g})$ can be calculated from its partial derivative, as (6).

$$\partial\frac{\Delta(\bar{g})}{\partial x}=\partial\frac{\Delta(\bar{g})}{\partial y}=\partial\frac{\Delta(\bar{g})}{\partial z}=0 \tag{6}$$

Assuming matrix h is (7).

$$h=\begin{bmatrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{12} & h_{22} & h_{23} & h_{24} \\ h_{13} & h_{23} & h_{33} & h_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{7}$$

If h is an invertible matrix, the new vertex $\bar{g}'$ can be obtained as (8).

$$h=\begin{bmatrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{12} & h_{22} & h_{23} & h_{24} \\ h_{13} & h_{23} & h_{33} & h_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix}^{-1}\begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} \tag{8}$$

If h is an irreversible matrix, select two breakpoints or key points of (g_1,g_2) as new vertices. The 3D models of different flexible devices are processed and rendered in a lightweight manner to obtain a virtual model, as Fig. 3.

Fig. 3 includes a three-dimensional warehouse, CNC machining center, conveyor belt, conveyor robot, and visual gripper robot. The development of VR functions in virtual simulation systems requires the application of HTC VIVE virtual reality devices for assistance. Compared with the traditional VR equipment, students can freely carry out mechanical equipment through the Head-mounted display and can observe the mechanical structure closely. The data collection and transmission structure of HTC VIVE is Fig. 4. The connection between HTC VIVE hardware and computer ports is the foundation for VR interaction.

C. Optimization of Cargo Location for VFM

To further explore methods to improve the efficiency of VFM work, this study focuses on the problem of low efficiency in managing goods in flexible systems. The VFM system is used as the research object and the MOG algorithm is used for cargo location optimization. After running the VFM system for a period of time, due to the use of automatic mode, manual mode, and cargo in and out functions during the teaching process, the flexible system may experience scattered storage of goods and unreasonable distribution of cargo locations. Therefore, the study introduces MOG to optimize the allocation of warehouse locations in the VFM system, thereby improving the warehousing efficiency of the warehouse and ultimately achieving the goal of improving the efficiency of VFM work. The research will optimize the efficiency of goods in and out of storage, as well as the stability of cargo locations. The former increases the frequency of goods entering and leaving the warehouse in the warehousing system, and allocates them to a location closer to the warehouse entrance and exit, in order to shorten the time for goods entering and leaving the warehouse. In the optimization of cargo space stability, in order to better align with practical applications, it is necessary to study adding physical attributes such as mass and friction to the virtual cargo model. Therefore, the study also needs to consider the stability of warehouse shelves in different cargo weights. In response to the above, lighter goods will be prioritized in the upper part of the shelf, while heavier goods will be allocated in the lower part of the shelf. This placement method not only improves the stability of the shelf, but also reduces the power consumption of the warehouse during inbound and outbound operations. Genetic algorithm (GA) currently performs well in global search and can effectively reduce the probability of getting stuck in local search for the optimal solution. Compared with other algorithms, this algorithm is more suitable for solving complex combinatorial problems and can search for the optimal solution more quickly. Due to the multi-objective nature of the cargo location optimization problem in VFM, the research chose the MOG algorithm based on GA for solution [18-20]. Fig. 5 shows the structural flow of a standard GA.

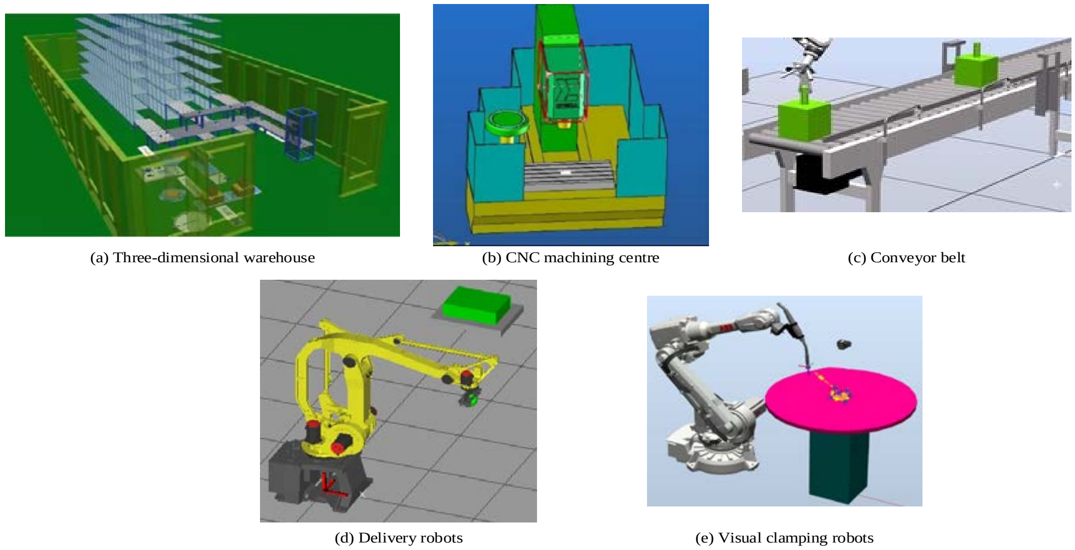


Fig. 3. Schematic diagram of virtual lean meat equipment.

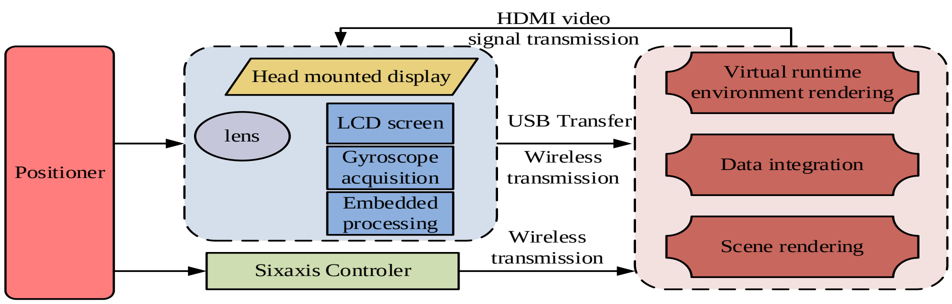


Fig. 4. Data Collection and transmission structure of HTC VIVE.

Before optimizing the storage space, it is first necessary to determine the optimization object and its key information attributes. According to the three-dimensional warehouse of the VFM system, the objects of cargo location optimization are the stacker, the goods processed by the system, and the cargo spaces included in the shelves. Key information includes the X-axis and Y-axis speeds of the stacker, as well as the origin position. The goods include weight, model, and delivery rate; The storage location contains a number. The study designed three types of processed goods in VFM and added physical properties to them, so that the goods had different qualities and met optimization requirements, as Fig. 6.

The objective of cargo location optimization is to optimize the efficiency of goods in and out of storage and the stability of cargo locations. The multi-objective mathematical model established is (9).

$$\begin{cases} f = \omega_1 f_1 + \omega_2 f_2 \\ f_1 = \sum_{x=1}^{a}\sum_{y=1}^{b}\sum_{z=1}^{c} R_{xyz} t_{xyz} \\ f_2 = \sum_{x=1}^{a}\sum_{y=1}^{b}\sum_{z=1}^{c} \left(m_{xyz} \times n_{xyz} \times z\right) \\ \omega_1 + \omega_2 = 1 \end{cases} \tag{9}$$

In (9), f_1 and f_2 are the objective function values for optimizing the efficiency of goods entering and exiting the warehouse and optimizing the stability of the storage space, respectively. ω_1 and ω_2 are the corresponding weights for optimizing the efficiency of goods in and out of storage and optimizing the stability of storage locations. R_{xyz} represents the shipment rate of the goods at location (x, y, z). t_{xyz} represents the time it takes for the goods to move from the storage location to the warehouse. m_{xyz} and n_{xyz} correspond to the weight and quantity of the goods. The steps to optimize using the MOG algorithm are as follows: first, use integers for encoding, so that the integers composed of (x, y, z) correspond to the rows, columns, and layers of the shelves. Secondly, the fitness function is determined. According to the multi-objective mathematical model, the objective function is positive and the minimum demand solution is obtained. The calculation is (10).

$$\begin{cases} Fit(x, y, z) = \sum_{i=1}^{n} \omega_i \times \frac{1}{f_i - f_{\min} + 1} \\ \begin{cases} 1 \le x \le a \\ 1 \le y \le b \\ 1 \le z \le c \end{cases} \end{cases} \tag{10}$$

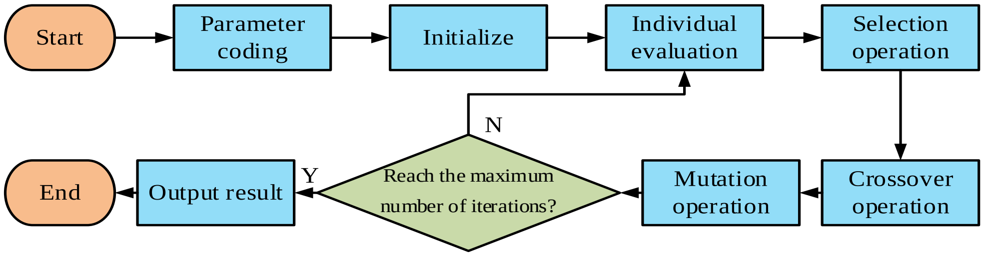


Fig. 5. The process of standard GA algorithm.

(a) Square objects (b) Cylindrical object A (c) Cylindrical object B

Fig. 6. Three virtual cargo schematic diagrams for VFM system design.

Finally, the selection operator and other related parameters are determined, and the selection operator uses the roulette wheel selection method.

IV. Result Analysis of VFM Fused with VST

To verify the performance of the VFM system and its effectiveness in practical teaching applications, this chapter first analyzes the performance of the system based on the MOG algorithm and its effectiveness in cargo location optimization, and then analyzes the application of VFM in practical teaching.

A. Analysis of Cargo Location Optimization Results based on MOG Algorithm

Firstly, to verify the performance of cargo location optimization based on MOG, MATLAB software is used for simulation experiments. The research will evaluate the optimization results based on the objective function value and cargo distribution. In addition, in order to verify the performance of the algorithm more scientifically, Multi objective optimization algorithm (MOO) commonly used at present is selected for comparative experiments, such as Multi objective Particle Swarm (MOPS), Multi objective Evolutionary algorithm (MOE) and Parallel Single Ended Inheritance (PSEI). Table I shows the cargo attributes and parameter settings of MOG.

From Fig. 7, it can be observed that after 213 iterations of the proposed MOG algorithm, the iteration curve of the total objective function value tends to stabilize, and the effect of cargo location optimization is relatively ideal. At this time, the corresponding total objective function value is 142.5. MOPS needs to iterate 307 times before the change curve starts to stabilize, with a stable function value of 148.3; MOE stabilized after 256 cycles, with a value of 152.7; PSEI requires 286 iterations to reach a stable state, with a stable value of 150.2. The above results show that the MOG algorithm can obtain lower total objective function values in smaller iterations.

The paper uses MATLAB software for cargo location optimization operations using different multi-objective optimization algorithms.

To further explore the optimization effects of different MOOs in different scale problems, four optimization problems with different scales were set up, as displayed in Table II. From it, the MOG algorithm has the best optimization performance at different scales, followed by MOE and MOPE. And as the target scale problem expands, the optimization performance of each algorithm also shows varying degrees of decline. This is because as the scale expands, the objective function value of the original plan shows an exponential increase, so the decrease in optimization effect is within a reasonable range. From the perspective of convergence, when the scale is small, the iteration times of the four algorithms are not significantly different, because the solution to the optimal solution is relatively simple at small scales. However, the expansion of scale has demonstrated the advantage of MOG in iteration speed. At the maximum scale, the corresponding number of iterations is 411.2, which improves the efficiency of MOPS, MOE, and PSEI by 17.3%, 36.7%, and 40.9%. In summary, the MOG algorithm can effectively improve the probability of local optimization and accelerate convergence, with good cargo location optimization performance.

TABLE I. RELEVANT PARAMETER SETTINGS AND CARGO ATTRIBUTE INFORMATION OF MOG ALGORITHM

	Parameter	**Set value**	**Parameter**	**Set value**
Setting of relevant parameters for MOG algorithm	Number of shelf rows	3	Population size	300
	Number of shelf columns	8	Maximum Number Of Iterations	500
	Number of shelves	6	Crossover probability	0.8
	Location length/m	0.5	Mutation probability	0.08
	Stacker X-axis direction speed/(m/s)	0.6	Shelf spacing/m	0.9
	Stacker Y-axis direction speed/(m/s)	0.5	ω_1	0.5
	Stacker Z-axis direction speed/(m/s)	0.3	ω_2	0.5
Property information of goods	Type of goods	Cargo mass/kg		Delivery rate of goods
	Column cargo E	0.8		0.5
	Column cargo H	0.6		0.3
	Column cargo I	0.4		0.1

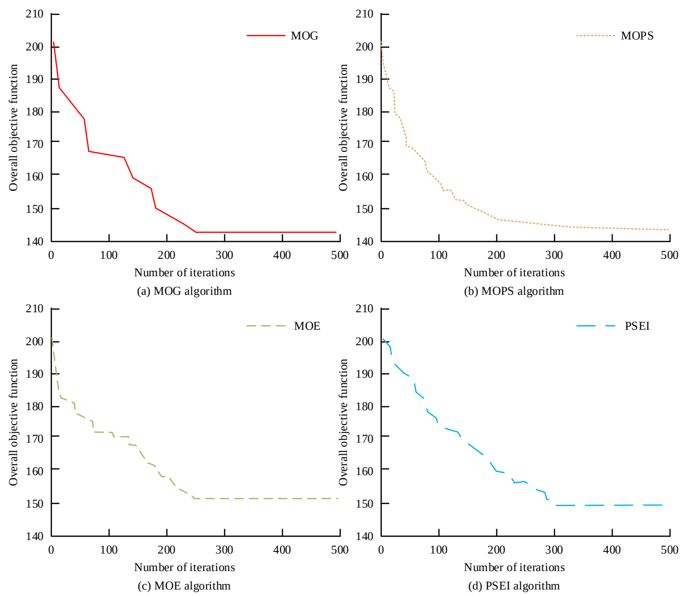
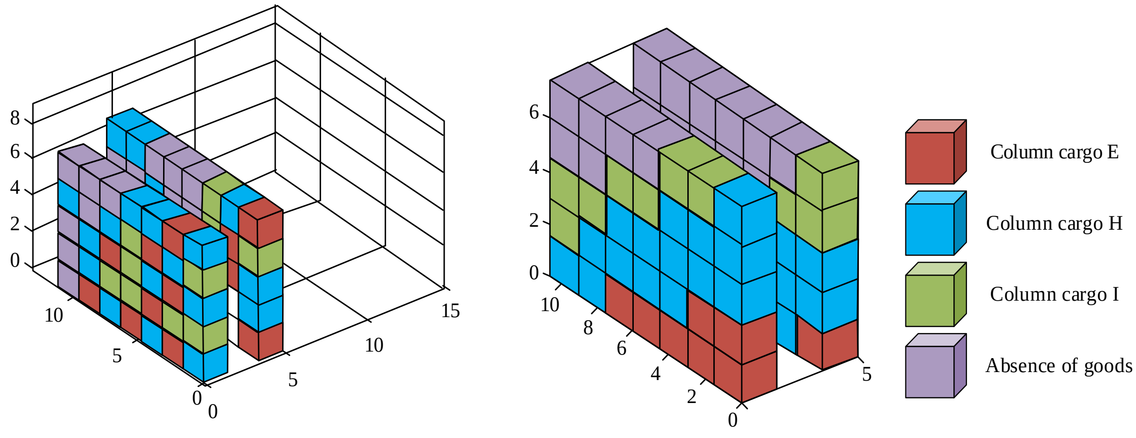


Fig. 7. The variation curve of the total objective function value for cargo location optimization using different MOO.

TABLE II. OPTIMIZATION RESULTS OF VARIOUS MOO IN PROBLEMS OF DIFFERENT SCALES

Number of goods/number of goods		25/120	50/203	75/547	100/810
MOG	f_1	99.50	91.34	108.98	132.49
	f_2	189.2	193.7	185.3	178.5
	Iterations	194.2	2993.5	336.6	411.2
MOPS	f_1	99.59	93.43	112.42	147.43
	f_2	189.3	199.0	187.3	234.2
	Iterations	218.8	323.5	419.6	482.3
MOE	f_1	102.3	93.6	124.7	139.2
	f_2	152.4	198.2	252.8	290.5
	Iterations	276.1	421.5	488.2	562.2
PSEI	f_1	112.33	85.43	120.32	141.08
	f_2	264.1	223.4	267.8	287.9
	Iterations	284.5	348.3	385.8	579.2



(a) Before optimization (b) After optimization

Fig. 8. Effect diagram of the distribution of warehouse locations before and after optimization based on MOG.

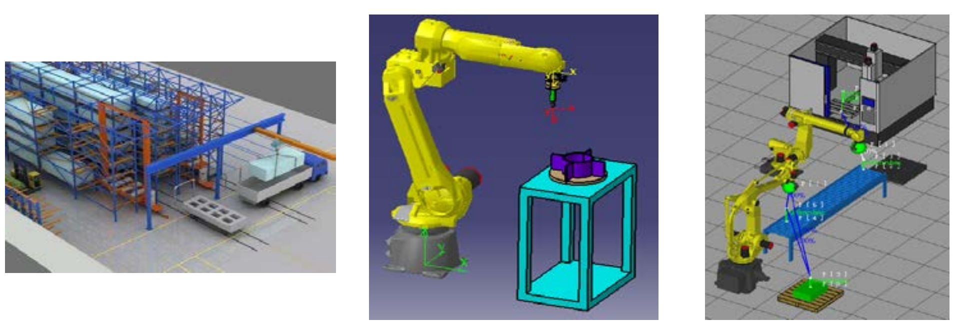
To verify the effectiveness of MOG in optimizing warehouse locations, Fig. 8 was developed. Fig. 8(a) and 8(b) represent the distribution of goods before and after the optimization of the cargo location. In Fig. 8(a), the goods were placed in a chaotic and disorderly manner in the warehouse of the VFM system, and there were no goods placed at the bottom of the shelves. This method of placing goods results in poor storage stability and has a negative impact on the efficiency of Tiger House's inbound and outbound operations. In Fig. 8(b), after MOG optimization, some goods are placed in a regular and uniform manner in the warehouse, with heavy items placed at the bottom of the storage space and light items placed at the top of the storage space. The results show that MOG based cargo location optimization can ensure both the efficiency of goods in and out of storage and the stability of shelves.

B. *Application Analysis of VFM*

To explore the application of VFM in practical training teaching, the study first prepares three hardware devices: computer, HTC VIVE, and control console. The hardware connection of this system includes the communication connection between the console and the computer, the use of TCP/IP protocol and network cables to complete the communication connection between the computer and PLC, and the connection between the computer and HTC VIVE. Connect the VR helmet to the computer graphics card and transfer data through HDMI and USB cables. After completing the hardware connection, communication connections between different software on the platform can be made. Simply add PLC geology to complete the communication connection.

During the operation of the VFM system, a schematic diagram of the main virtual flexible equipment can be obtained, as Fig. 9. The main flexible equipment working process includes the three-dimensional warehouse outbound, the gripping operation of the conveying robot, and the machining process of the CNC machine tool. After the construction of HTC VIVE is completed, the VFM system can be visualized in 3D.

To analyze the application of VFM in various universities, a corresponding usability and satisfaction evaluation table was set up, and a survey was conducted on 5000 students using the system in universities across the country. The results are listed in Fig. 10. Most students have a good evaluation of the use of VFM, with scores exceeding 18 for different evaluation questions, and a total score of 93.34 ± 3.09. This indicates that the user experience of the system is excellent. Students believe that the use of this system can enhance their learning confidence, and most students are willing to continue using the system for learning. The results show that the VFM system is well applied in universities and is widely loved by students.



(a) Square objects (b) Grasping operation of the conveying robot (c) Machining process of CNC machine tools

Fig. 9. Schematic diagram of virtual flexible equipment operation.

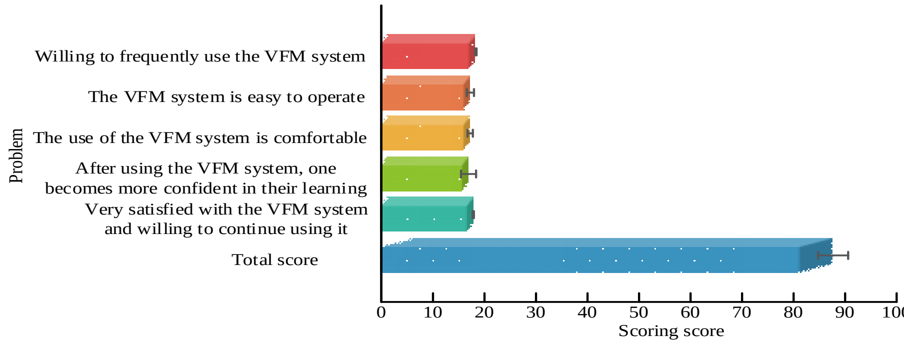


Fig. 10. Availability and satisfaction analysis of VFM system.

V. Conclusion

Many universities in China lack the application of FMS that is compatible with actual production lines in practical training and teaching, and due to issues such as resource shortages and high documentation costs, actual FMS cannot meet teaching tasks. To address the issue of the inability of university students to translate their knowledge into practical applications, the study first completed the overall design of the VFM system, followed by the design of the VST-VFM system, and finally optimized the efficiency of cargo allocation. Experimental results show that compared with other mainstream algorithms, the proposed MOG algorithm has the least number of iterations of 213. At this time, the iterative change curve of the total objective function value tends to be stable, and the effect of cargo location optimization is ideal. The average value of the corresponding total objective function is 142.5, which shows that the proposed method can not only improve the efficiency of goods in and out of the warehouse, but also enhance the stability of the shelf. With the expansion of the scale, the number of iterations of the proposed MOG algorithm is 411.2 at the maximum scale, which is 17.3%, 36.7% and 40.9% higher than that of mops algorithm, MOE algorithm and PSEI algorithm. The placement of goods in the warehouse optimized by MOG algorithm is regular and uniform, which means that the proposed method can effectively improve the probability of local optimization, accelerate convergence, and have better performance of cargo location optimization. In the evaluation results of the availability and satisfaction of VFM system applied in Colleges and universities, the total score is 93.34 ± 3.09, which indicates that students are very satisfied with the experience of the system and believe that it can effectively improve their learning confidence. In summary, the VFM system proposed in the study has excellent performance and has good application effects in practical training and teaching in universities. However, there are still shortcomings in the research. The constructed VFM only has basic functions for actual processing and production. In future research, VST can be used to introduce other equipment or models for improvement.

References

[1] G. Zang, P. Sun, A. Elgowainy, and M. Wang, "Technoeconomic and Life Cycle Analysis of Synthetic Methanol Production from Hydrogen and Industrial Byproduct CO_2," Environmental Science and Technology, vol. 55, no. 8, pp. 5248-5257, 2021.

[2] S. Ruidas, M. R. Seikh, and P. K. Nayak, "A production inventory model for high-tech products involving two production runs and a product variation," Journal of Industrial and Management Optimization, vol. 19, no. 3, pp. 2178-2205.

[3] M. N. A. Khalid, and U. K. Yusof, "An Improved Immune Algorithms for Solving Flexible Manufacturing System Distributed Production Scheduling Problem Subjects to Machine Maintenance," International Journal of Mathematical Models and Methods in Applied Sciences, vol. 15, pp. 17-25, 2021.

[4] P. Dubey, P. Chauhan, P. Shekhar, P. Agarwal, and P. Sharma, "Quantisation of driving enablers enabling transition from traditional to flexible manufacturing system," International Journal of Manufacturing Technology and Management, vol. 35, no. 2, pp. 89-108, 2021.

[5] Z. P. Yin, Y. A. Huang, H. Yang, J. Chen, Y. Duan, and W. Chen, "Flexible electronics manufacturing technology and equipment," Science China Technological Sciences, vol. 65, no. 9, pp. 1940-1956, 2022.

[6] X. Y. Wang, Q. Zhao, B. G. Hyun, L. Yu, L. Ma, H. Liu, J. Wang, and C. B. Park, "Flexible Poly(ether-block-amide)/Carbon Nanotube Composites for Electromagnetic Interference Shielding," ACS Applied Nano Materials, vol. 5, no. 5, pp. 7598-7608, 2022.

[7] H. Wang, Y. Wang, X. Lv, C. Yu, and H. Jin, "Genetic Algorithm with Local Search for the Multi-Target Scheduling in Flexible Manufacturing System," Journal of circuits, systems and computers, vol. 31, no. 16, pp. 123-149, 2022.

[8] C. Zhu, G. Sun, and K. Yang, "(12 8213 PROOFREAD (NG))A COMPREHENSIVE STUDY ON INTEGRATED OPTIMIZATION OF FLEXIBLE MANUFACTURING SYSTEM LAYOUT AND SCHEDULING FOR NYLON COMPONENTS PRODUCTION," International Journal of Industrial Engineering, vol. 29, no. 6, pp. 979-1001, 2022.

[9] A. Setiawan, "Perancangan Model Stacker Crane Flexible Manufacturing System untuk Pembelajaran di Institusi Pendidikan," Jurnal Rekayasa Sistem Industri, vol. 10, no. 1, pp. 45-54, 2021.

[10] I. Daniyan, K. Mpofu, B. Ramatsetse, E. Zeferino, and E. Sekano, "Design and simulation of a flexible manufacturing system for manufacturing operations of railcar subassemblies," Procedia Manufacturing, vol. 54, no. 2, pp. 112-117, 2021.

[11] M. Wei, H. Zhang, and T. Fang, "Enhancing the course teaching of power system analysis with virtual simulation platform:," International Journal of Electrical Engineering & Education, vol. 60, no. 3, pp. 289-312, 2023.

[12] J. Wood, L. Ebert, J. Duff, "Implementation Methods of Virtual Reality Simulation and the Impact on Confidence and Stress When Learning Patient Resuscitation: An Integrative Review" Clinical Simulation in Nursing, vol. 66, pp. 5-17, 2022.

[13] Y. Wang, F. Chang, Y. Wu, Z. Hu, L. Li, P. Li, P. Lang, and S. Yao, "Multi-Kinects fusion for full-body tracking in virtual reality-aided assembly simulation," International Journal of Distributed Sensor Networks, vol. 18, no. 5, pp. 625-636, 2022.

[14] C. Yang, "Online Art Design Education System Based On 3D Virtual Simulation Technology," Journal of Internet Technology, vol. 22, no. 6, pp. 1419-1428, 2021.

[15] B. Arthaya and V. Ivan, "Preliminary Design of 3D Printing Prosthetic Hand," Journal of Advanced Manufacturing Systems, vol. 22, no. 1, pp. 67-84, 2023.

[16] M. A. Nanfeng, X. F. Yao, and K. S. Wang, "Current status and prospect of future internet-oriented wisdom manufacturing," SCIENTIA SINICA Technologica, vol. 52, no. 1, pp. 55-75, 2022.

[17] S. Gogos, A. Touzell, and L. B. Lerner, "What we know about intra-operative radiation exposure and hazards to operating theatre staff: A systematic review," ANZ Journal of Surgery, vol. 92, no. 1-2, pp. 51-56, 2022.

[18] S. Nimrah and S. Saifullah, "Context-Free Word Importance Scores for Attacking Neural Networks," Journal of Computational and Cognitive Engineering, vol. 1, no. 4, pp. 187-192, 2022.

[19] J. Zan, "Research on robot path perception and optimization technology based on whale optimization algorithm," Journal of Computational and Cognitive Engineering, vol. 1, no. 4, pp. 201-208, 2022.

[20] M. Barma and U. M. Modibbo, "Multiobjective mathematical optimization model for municipal solid waste management with economic analysis of reuse/recycling recovered waste materials," Journal of Computational and Cognitive Engineering, vol. 1, no. 3, pp. 122-137, 2022.