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Research Article

Complex Problem-oriented Mechanical Engineering Practice Platform Construction and Project Implementation

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Abstract

First-class practical teaching is the cornerstone of first-class underground education. Teaching engineering practice, which aims to solve complex engineering problems, is an essential requirement and fundamental positioning of undergraduate engineering education. This paper proposes the concept and objectives of building a platform for mechanical engineering practice with a focus on complex engineering problems. Establishes the CDIO Mechanical Engineering Practice Platform, the high-end equipment digital design Platform, and the virtual simulation practice teaching Platform, among others. The platform guides content reform in practice teaching. This involves strengthening the depth and breadth of practice projects by setting up a group of innovative design experiments and independent practice projects in the field of mechanical engineering, highlighting students' willingness for active learning and independent practice, and cultivating engineering thinking awareness and abilities. In addition, the operational model and mechanism of the mechanical engineering practice platform are discussed under the guidance of complex engineering problems, and the implementation process of practice projects guided by complex engineering problems is illustrated through examples. The construction of the platform and the implementation of projects play a significant role in cultivating students' abilities to solve complex engineering problems and improving their engineering literacy.

Keywords: Complex engineering problems; Engineering literacy; Construction of practice platform; Project implementation

Introduction

The cultivation of students' knowledge and ability comes from a close combination of theory and practical teaching. For engineering students, practice is the process of creative application and theoretical development, and it is the process of forming comprehensive abilities [1,2]. At the same time, practice, especially engineering practice, is an extremely important way to form engineering thinking and acquire engineering experience [3]. Students can gain knowledge from theoretical teaching, apply the knowledge in practice, at the same time they will challenge, explore, and pursue innovation. Only based on practice can we achieve the goal of innovation. Student minds are not a vessel for loading knowledge, but a torch that needs to be fired. The complex engineering problems oriented mechanical engineering practice platform architecture and its practice projects implementation are proposed in this paper to become an important spark of the torch.

Only through practice can innovation be achieved. For universities, especially engineering universities, it is particularly important to cultivate students' innovative abilities. Innovation ability is achieved mainly through practical activities, building on a solid theoretical foundation. Through practical experiences, students are guided to discover, propose, analyze, and solve problems, thus exploring, questioning, and improving through inquiry and clarification [4].

At present, engineering teaching lacks project-based or problem-based practical solutions under the context of real engineering, which make it difficult to cultivate students' team spirit and ability to solve engineering problems, and the phenomenon of 'doing fake questions in true work' generally exists [4-6]. The specific manifestation of the phenomenon includes lacking the subjective initiative of the experiment subject; concentrate on the experimental teaching of unit knowledge but the engineering system concept and overall control ability cultivation are insufficient; lack the cultivation of innovative thinking in engineering and ability to solve problems; lack the bases of cultivating the ability to solve complex engineering problems. Teaching today revolves around Well-defined Engineering Problems and Broadly defined Engineering Problems to practice. While solving complex engineering problems, students need to master and apply engineering thinking methods, be good at applying the knowledge they learned comprehensively and creatively, analyze, and solve the problems, and its core is 'knowledge fusion, learning for application'.

In June 2016, China formally acceded to the Washington Accord, which is regarded as a historical breakthrough of landmark significance in Chinese higher education. The Accord advocated three major educational concepts, Student-centered (SC), Outcome Based Education (QBE), and Continue Quality Improvement (CQI). The basic goal of underground engineering education in higher education is to cultivate the ability of students to solve complex engineering problems.

Solving complex engineering problems often requires the involvement of various technical and engineering methods. The essence lies in the application of extensive professional knowledge and engineering thinking skills, as well as the utilization of research approaches such as "model-algorithm-engineering implementation." This article focuses on "culturing the ability to solve complex problems" and explores and analyzes the construction of practical teaching platforms for mechanical engineering disciplines and the implementation of practical projects based on them [7].

Complex Engineering Problems Oriented Construction of Mechanical Engineering Practice Platform and Concept of Project Implementation

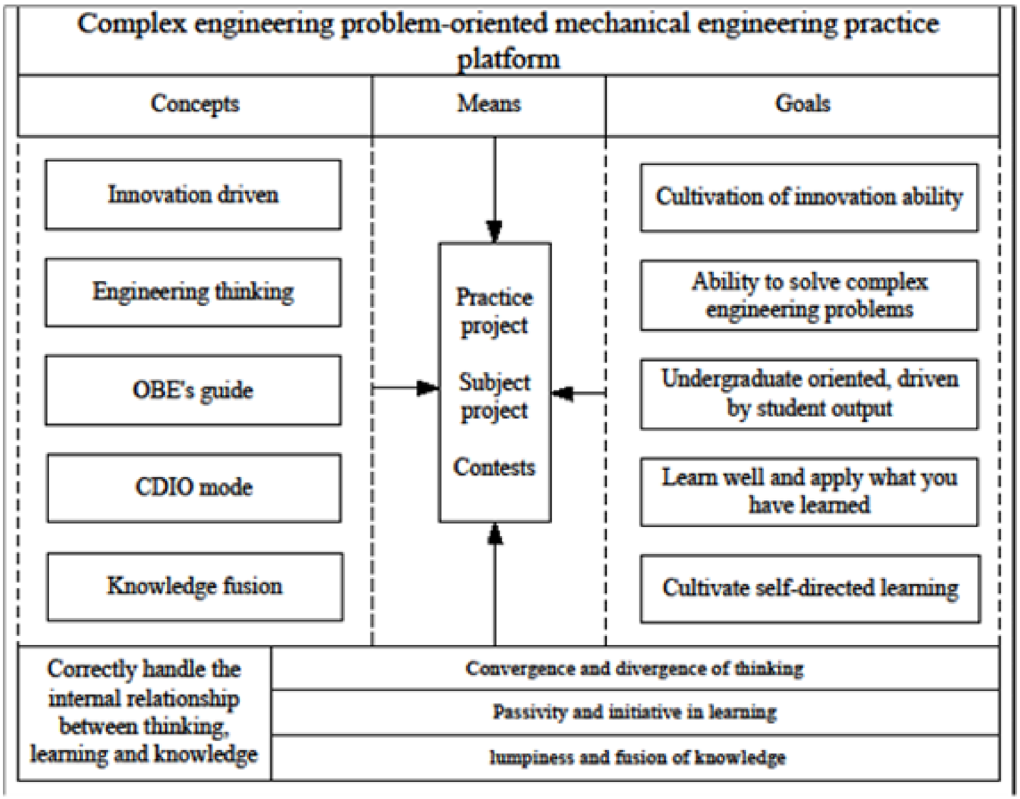

Figure 1: Complex engineering problem-oriented mechanical engineering practice platform concepts, means, and goals.

As important parts of practical teaching content and system, aiming at driving innovative ability and solving complex engineering problems, mechanical engineering practice platform construction and program implementation provide good hardware, software, and institutional environment for students to improve innovative and practical ability. This platform can stimulate students' engineering thinking and innovation ability, integrate the imparting of knowledge, ability cultivating and improvement of quality, raise the ability of humanistic quality and team cooperation for students of engineering, achieve the ability to solve Complex Engineering Problems. On the premise of consolidating the foundation, taking ability cultivating as the core, taking practical programs as the carrier, taking virtual simulation and mutual integration of teaching and research as the supplement, taking sharing, and opening as the starting point, a good job can be done in sharing practical teaching resources. By a variety of practices and trains of practical programs, the fragmented knowledge that students gain is connected by notes to achieve the ability to solve Complex Engineering Problems [8,9]. It can be solved mainly through two dimensions of students' experimental processes, vertical and horizontal dimensions; and vertical dimension uses the Conceive-Design-Implement-Operate (CDIO mode), horizontal dimension relying on the innovative design experimental project groups of professional core courses. The design concept of practical programs highlights innovation driving, engineering thinking, OBE orientation, CDIO model, knowledge fusion and association, etc., which is shown in Figure 1 [10].

Complex Engineering Problems Oriented Mechanical Engineering Practice Platform

Mechanical Engineering CDIO Practice Platform

The mechanical engineering CDIO practice platform, based on existing mechanical manufacturing equipment (conventional machine tools and CNC machines, etc.), control units (servo motors, multi-axis control cards, CNC platforms, etc.), and debugging platforms, procures a batch of innovative experimental equipment such as "Explorers" and "Smart Fish," and establishes an engineering innovation practice platform that combines "creativity + digital design + innovative practice + competitions." With the goal of cultivating students' innovation abilities and engineering development thinking, following the project practice model, students are guided through various stages of innovation and engineering practice, including idea generation, innovative design, digital design, prototype machining, physical construction, report writing, and defense, to develop their innovation and engineering practice capabilities.

The CDIO mechanical engineering practice platform emphasizes the principles of autonomy, openness, and personalization in practical teaching, providing conditions for cultivating high-quality innovative engineering talents. The platform should provide necessary workspace, machining platforms, raw materials, and standard components to ensure personalized project-based teaching for students. The practice projects are centered around students as teams, with the curriculum teaching team responsible for guiding the practice teaching, providing technical consultation and guidance, overseeing the process, and evaluating the results during the project implementation stage.

Digital Design Platform for High-end Equipment

The digital design experimental platform is aimed at the high-end equipment manufacturing industry, realizing the entire process of CA-IDEM engineering [10], including computer-aided innovation (CAI), computer-aided design (CAD), computer-aided engineering (CAE), and computer-aided manufacturing (CAM). The experimental platform targets high-end equipment design and, based on existing platforms such as TRIZ software, SOLID EDGE software, ANSYS software, 3D scanning, and printing, procures a batch of software and hardware systems for design, auxiliary engineering, and auxiliary manufacturing. This establishes a high-end equipment digital design experimental platform, as shown in Figure 2.

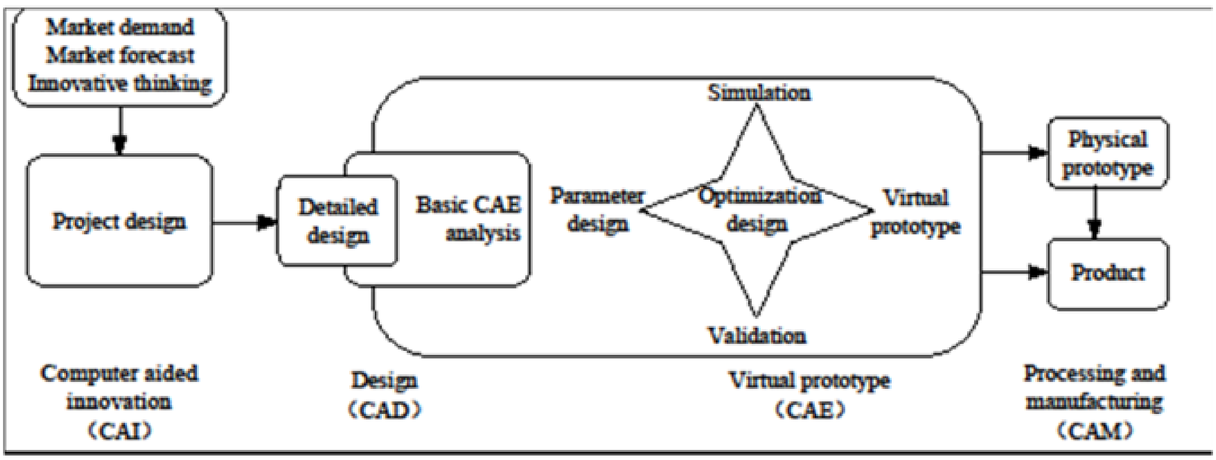

Figure 2: Digital design platform of high-end equipment.

Through learning of the high-end equipment digital design platform, students can follow closely the latest advancement of technology in mechanical industry. It can also capture students' attention to the hotspot of high-end equipment and generate interest in mechanical manufacturing industry, and then students would like to keep close watch on the forefront of the field of machinery and make their mind to join the determination of mechanical industry.

Virtual Simulation Practice Teaching Platform

A real laboratory is unable to fully demonstrate the structure and operation of complex mechanical products and mechanical integrated systems for students, and it is also impossible to make students to participate comprehensively in the whole process of mechanical products and systems design, manufacture, production, and organization in a real laboratory. Therefore, virtual simulation experiments must be carried out to make up for the deficiency of the real experimental environment, building the experimental teaching system of virtual reality cooperation together.

It could promote the transformation of students' innovative activities from the simple model of "divergent thinking + simple fabrication" to the advanced mode of "divergent thinking + mathematical modeling + scientific calculation + engineering design + parameter optimization" if the virtual simulation practical teaching platform was introduced into students' innovative activities, and also it can verify the correctness of innovative ideas with "virtual simulation". Through engineering design and parameter optimization, the academic, theoretical, and professional ability of students in engineering design with simulation software are improved. The virtual simulation experimental project is the necessary supplement and perfection of the real experiment project.

College-enterprise Cooperation Practice Base

It is one of the outstanding characteristics of future education that the College-enterprise cooperation can bring into play the respective advantages of the school and the enterprise and jointly cultivate the talents that are needed by the society and the market. Through the college-enterprise cooperation, work-study combination, students can obtain work experience in accordance with the actual production and service requirements of the enterprise to participate in work practice, so that they can get the necessary work experience that is required by enterprise and other employers while they are in the school period. During the production practice, students participate in the work practice which is conducive to cultivating students love and dedication to work, hard-working spirit, and make sure they can accept the influence of corporate culture earlier. At the same time, theoretical knowledge can be integrated with practical ability, so that the quality of teaching in schools can be truly improved. More importantly, the practical ability of the students, the ability to complete the work independently, and the ability to adapt to these professional posts have been very good training and exercise. Through college-enterprise cooperation, students can effectively improve vocational ability of students, so that graduates can quickly realize the role change from students to social people.

Complex Engineering Problems Oriented Connotation of Practical Teaching

Practical teaching oriented to complex engineering problems highlights the two characteristics that are the combination of teaching and research, and the active practice of the students, it can provide enough space for independent thinking and individual development, which is beneficial to cultivate students with good basic engineering quality, the ability to conceptualize, design, manufacture, and implement, and the ability to collaborate with team. Mostly, it includes the setting of typical experimental project groups and independent practice projects of mechanical innovation design.

Typical Experimental Project Group of Innovative Design of machinery

Typical experimental groups of mechanical innovative design, facing mechanical engineering specialties, connect with core courses for the machinery of engineering graphics, material mechanics, mechanical principle, mechanical design, microcomputer principle and application, advanced manufacturing technology, automatic control theory, numerical control technology, mechanical electrical system and production process automation, product shape modeling and innovative design, rapid prototyping and application, robot technology, etc. And it opens innovative design experimental projects such as mechanism innovative scheme design, complex products innovative design, reverse design and 3D printing, robot body design and multi-axis motion control, product-faced production line design and simulation, three-dimensional warehouse and its transportation system modeling and simulation, super large shovel hydraulic excavator working device design and virtual simulation, and virtual simulation of elevator group integrated control, etc. A typical experimental project group of core courses and innovative machinery design is shown in Figure 3.

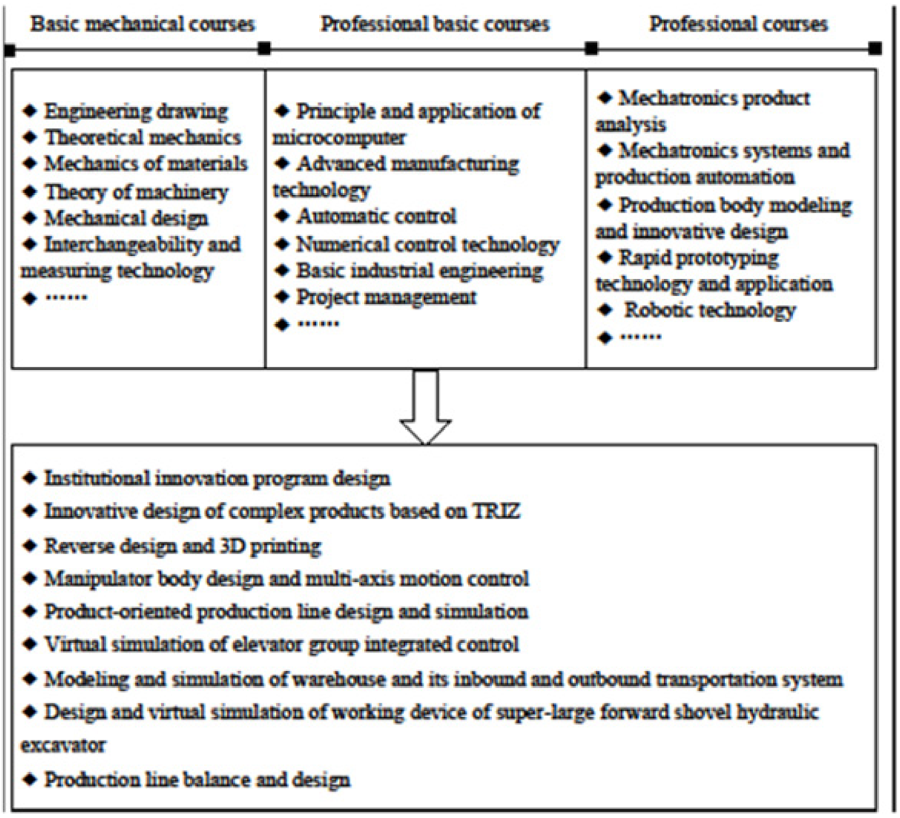

Figure 3: Mechanical core courses and innovative design typical experimental project group.

Typical experimental innovative design

Independent practice projects mainly include students' curriculum design, graduation design, and various competitive projects of machinery and innovative practice projects. This kind of project and the characteristics of the local industry and the regional economic development have a great coupling. In the process of implementation, project management knowledge needs to be actively introduced and the process and the monitoring of cost and quality need to be captured. The main characteristics are as follows: the main participants in the project are students majoring in machinery; the theme of the project is to achieve new product design and manufacturing of some specific functions; the project timeline is short (generally within one year), and the cost of the project is relatively small. When comparing the characteristics of innovative practice projects, the implementation steps are as follows.

1) Determine the topic of practice projects and identify the technical indicators that the project should meet.

2) Establish a project team and determine the main project leaders.

3) Working breakdown structure the project, identify the scope of the project, and determine each responsible for each subproject.

4) Schedule the progress of the practical project by using Grant Chart, key path method, and plan review technique.

5) Carry out the necessary cost control under the assumption of satisfying the predetermined technical parameters of the project.

6) Complete the predetermined goal of the project in quality and quantity under prescribed time and cost budget.

7) Evaluate the project, mainly through on-site PPT oral defense, product physical display, and experts' on-site questions and other links.

Complex Engineering Problems Oriented Operation Mode of Mechanical Engineering Practice Platform

The operation and daily management of the mechanical engineering practice platform are student-centered and have strong students' independent practice with various practical projects opened on the platform, which leads to uncontrollable experiment time and non-unique experimental results. This requires that its corresponding experimental teaching methods and experimental operating mechanism must be changed, highlight students individualized and autonomous development needs, and explore and improve new forms and new methods of practical teaching continuously. Establish an open and flexible operating mechanism and mode of practice platform (7×12 hours) and build a student's innovative ability training system and operating mechanism in all aspects.

Explore the open system of "student autonomy as the mainstay and teacher inspection as a supplement" and strengthen laboratory safety management. Establish innovation credits (optional) to provide institutional guarantees for students' innovative practice and establish innovation funds to provide funding guarantees for students to carry out thematic practical projects. At the same time, improve the open and shared operation mechanism to provide students with venue guarantees, and provide software and hardware support for the smooth development of students' practical activities. Improve and optimize the construction of a practical teaching-oriented network platform to provide convenience for students to choose practical projects independently. If conditions permit, open to domestic colleges and even all colleges and universities to improve equipment utilization and demonstration and establish a student-centered open and shared teaching model.

Project Implementation

Taking the experimental project of 'physical simulation elevator and elevator group optimization control' as an example, the experimental teaching content and methods are explained to solve the complex engineering problem of elevator group control.

Experimental Tasks and Requirements

The experimental project of "simulation physical elevator and elevator group optimization control", and its experimental tasks and complex engineering problems are shown in Figure 4.

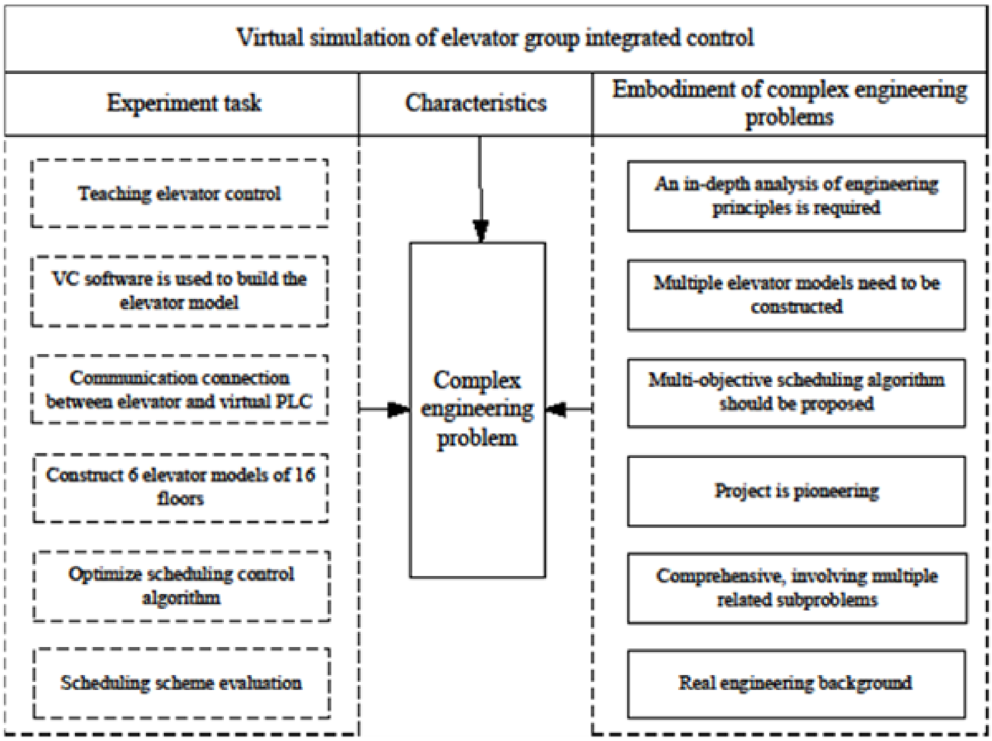

Figure 4: Experimental tasks and complex engineering problems.

Specific requirements of the experimental project: (1) Master the control methods and procedures of the physical teaching elevator (four floors), as shown in Figure 5. Master the functions of automatic leveling, automatic door closing, forward response to call signals inside and outside the car, direct driving, protection of elevator safe operation, emergency stop, slow up, slow down, lighting, fan, and other functions. (2) According to the simulated physical elevator, build the elevator model in VC software and run it in simulation. (3) Expand based on the existing four-story physical elevator model, build a 16th floor elevator model in the VC software, and communicate with the virtual PLC in the software, and use the written PLC program for simulation debugging and operation. (4) Establish Six elevators with 16 floors models in VC software, and associate them to form elevator groups, then propose optimal dispatch control algorithms. (5) According to the control algorithm, compile the elevator group control program and simulate the operation, and observe the operation of the elevator group during the immediate call. (6) Evaluate the operating plan.

(a) (b)

Figure 5: Four floors simulation physical elevator.

The experiment Content

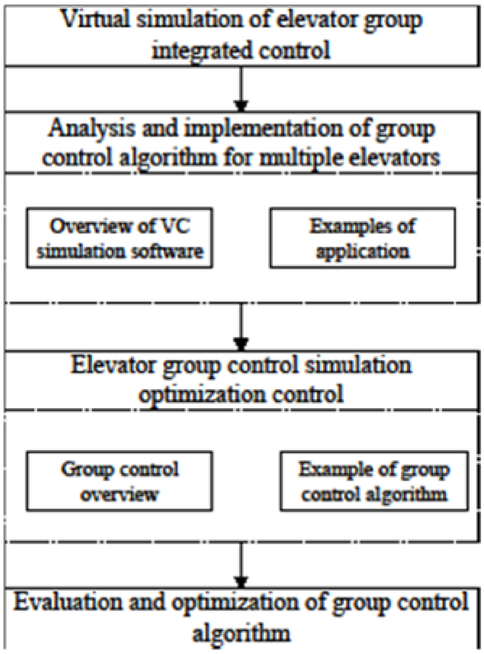

Figure 6: The experiment content.

The elevator control system determines the various experience indicators of riding the elevator, so students need to improve the elevator control strategy and the intelligence of the elevator system so that the overall performance of the elevator group is always at a higher level and then the best dispatch plan can be concluded. The experiment includes the use and control of multi-layer simulated physical elevators, VC (visual components) simulation software and virtual and real control of simulated physical elevators, and elevator group control simulation optimization control, as shown in Figure 6. Following the principle of the experiment content combine the virtual and real, break through the restriction of existing hardware resources, enable students to master elevator model construction, PLC (programmable logic controller) programming, elevator optimization scheduling methods, etc.

VC simulation software is a simulation software developed by the Finnish Visual Components limited liability company. The company is an industry-leading professional software development and implementation company for 3D manufacturing simulation and visualization. It provides simple, fast, and efficient simulation and visualization methods for automation equipment manufacturers, system integrators, and manufacturing companies, such as building overall visualization of the manufacturing process, rapid design of 3D equipment/parts library.

The majority of elevators are electric drive, wire rope traction structure, and the mechanical part is composed of traction system, guide system, door system, car, balance system, electrical control system, and safety protection system.

At present, most of the elevator control system uses two control methods. One is to use a microcomputer as a signal control unit to complete elevator signal collection, operating status, and function setting, to achieve elevator automatic dispatch and collective selection operation functions, and drag control is done by the frequency converter; the second is to use a programmable controller (PLC) to replace the microcomputer to realize the signal collective selection control.

The elevator group control system is a typical optimization scheduling problem. The controller needs to make an allocation plan using some or a certain index which include the call request of each floor, the current position of the car, the current running state of the car, the number of tasks assigned to the corresponding elevator, etc. Figure 7 shows a schematic diagram of an example of the operation of the elevator group. The controller needs to make a decision after receiving the call instruction and designate a certain elevator to respond to the newly generated call instruction. The elevator group control system generally adopts an overall management method for each elevator, and its control system is divided into two parts: software and hardware.

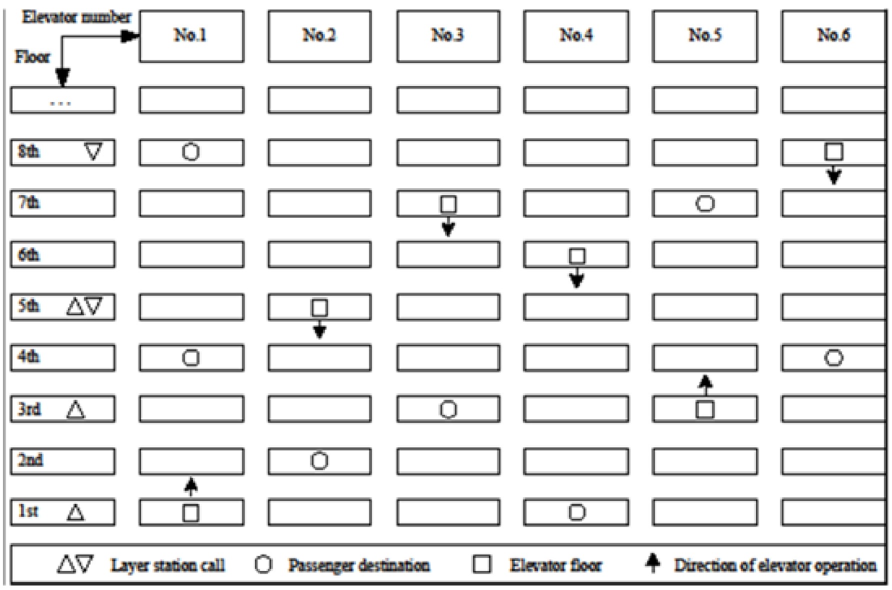

Figure 7: Schematic diagram of elevator group operation.

Elevator Group Control System

The core content of the experimental project includes the construction of multiple elevator models, the connection of the elevator model, the virtual PLC, and the elevator group control optimization algorithm. The construction of the elevator model and the connection with the virtual PLC are realized through VC software. The elevator group control optimization algorithm can be solved by the multi-objective optimization algorithm. Take the multi-objective optimization dispatching algorithm as an example to illustrate.

The elevator group control system can have different evaluation indicators according to the different requirements of the service objects under different traffic conditions or usage conditions. To reconcile the contradictions between various evaluation indicators, different coefficients are assigned to different traffic operation modes, then a multi-objective optimization calculation is carried out. In this paper, the important control target of the Elevator Group Control System is considered:

X_1: Average waiting time of passengers (average waiting time, AWT) X_2: Average ride time of passengers (average riding time, ART) X_3: System energy consumption (total energy consumption, TEN)

By weighting, the multi-objective optimization problem is transformed into a single-objective problem, and its comprehensive evaluation function can be expressed as:

$$Y = \lambda_1 X_1 + \lambda_2 X_2 + \lambda_3 X_3$$

where, $\ddot{e}_1, \ddot{e}_2, \ddot{e}_3$ are the weighting coefficients and $\ddot{e}_1 + \ddot{e}_2 + \ddot{e}_3 = 1$.

Multi-objective optimization focuses on different indicators in different operating modes, so different comprehensive evaluation functions should be set for each operating mode. It mainly includes the selection of evaluation indicators and the determination of the weight coefficient table, the input of characteristic quantities and standardization, and the calculation of ladder assignment.

Use W_{M_i} to represent the system evaluation index in the M_i mode, $W_{i,1}, W_{i,2}$, and $W_{i,3}$ respectively correspond to the weights of the three evaluation indexes, whose range is [0,1] and $W_{i,1} + W_{i,2} + W_{i,3} = 1$. For example:

$$W_{M_i} = \left(W_{i,1} + W_{i,2} + W_{i,3}\right) = \left(0.3, 0.2, 0.5\right)$$

The above formula means that in Mi idle time mode, TEN is mainly considered, and AWT is secondly considered.

For example, assuming the current idle time mode, the characteristic quantities of all 6 elevators for a certain outbound call are shown in Table 1.

Table 1: The characteristic quantities of all elevators for a certain outbound call.

Dispatching Index/Evaluation Index	E1	E2	E3	E4	E5	E6
WTj	12	20	58	22	8	36
RTj	5	9	7	48	23	94
ENj	1	2	4	2	1	3

The integrated input feature quantities after standardized calculation are: $C_{E_1} = (0.90, 1, 0.99)$, $C_{E_2} = (0.74, 1, 0.97)$, $C_{E_3} = (0.08, 1, 0.87)$, $C_{E_4} = (0.70, 0.95, 0.97)$, $C_{E_5} = (0.95, 0.99, 0.99)$, $C_{E_6} = (0.38, 0.86, 0.93)$.

The comprehensive dispatch indicators are: $E_{i1} = 0.965$, $E_{i2} = 0.892$, $E_{i3} = 0.659$, $E_{i4} = 0.885$, $E_{i5} = 0.978$, $E_{i6} = 0.751$. Among them, $E_{i5} =0.978$, which is the maximum value, and so j=5, that is, the fifth elevator is the best choice for dispatching elevators.

Conclusion

First-class mechanical engineering experimental teaching platform, system, and content are important supports for the high-level personnel training system for mechanical majors, and they are also important content of first-class undergraduate education. The practice platform construction and project implementation of mechanical engineering-oriented to solve complex engineering problems play an important role in promoting the reform of engineering practice teaching and improving students' engineering literacy, improving the ability to solve auxiliary engineering problems, and achieving the organic combination of knowledge ability and accomplishment. Through many years of practical teaching reform and implementation, we have consolidated the software resources of the mechanical engineering practice platform. At the same time, based on the various practical projects offered by the platform, we have also improved students' interests, and arrive the ability to solve practical engineering problems by applying the knowledge learned and self-learned comprehensively, and cultivate the students the ability to find problems, analyze the problems and then solve the problems, promoting the formation of students' engineering thinking paradigm and the research means of "model-algorithm-engineering case".

On the basis, a variety of teaching achievements have been achieved, including 5 awards for teaching achievements above school level, 3 practical books and 12 teaching research papers, and meanwhile the engineering ability of practical teachers have been promoted. Students have obtained excellent results in the competitions at all levels, including having won more than 30 awards at the provincial and ministerial and students granting 100 patents to the first author, including more than 20 patents for invention. The rate of students pursuing further studies reached 40% and employment rates reached 96%.

Acknowledgment

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Conflict of Interest

No conflict of interest.

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