

Original Paper

Development and Teaching Practice of Virtual Simulation Training Platform for Warehouse UAV under the Background of Industry-Education Integration

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Abstract

Aiming at the problems in the practical teaching of warehouse management, such as the real environment is difficult to simulate, the operation risk of Unmanned Aerial Vehicle (UAV) is high, and the inventory process is complicated, a practical teaching platform for UAV based on virtual simulation technology is constructed. The platform adopts a hierarchical architecture design, sets up multi-user function ports, establishes the standardized transformation path from real operation projects of warehousing enterprises to simulation teaching cases, and constructs a three-level progressive project-based training course system of basic, special, and comprehensive. Design the implementation plan of online and offline mixed teaching, and build a trinity multi-evaluation system of process, result, and comprehensive literacy. Students can complete the integrated training from flight control to inventory data collection and processing in a safe and repeatable virtual scene. The practice shows that the platform realizes the visualization and accurate guidance of the teaching process, effectively improves the students' ability to work in complex scenes, systematic integrated thinking and post competence, and forms a scalable integration mode of production and teaching, which provides a useful reference for the practical teaching reform of logistics management and industrial engineering majors.

Keywords

Virtual simulation technology, UAV, Warehouse management, Inventory count, Logistics Management,

Industrial Engineering

1. Introduction

As a key tool to promote intelligent logistics and warehouse automation management, warehouse UAV technology has been gradually integrated into many application scenarios such as inventory checking, cargo inspection, and warehouse location identification (Kalinov et al., 2020; De Guzman et al., 2024). With the continuous improvement of modern warehouse management requirements for operational efficiency and data accuracy, the industry is increasingly in urgent need of innovative and practical talents with UAV operation, spatial modeling, and inventory data processing capabilities (Wang & Chen, 2024). However, the traditional practice teaching still has obvious shortcomings in equipment management efficiency, visual monitoring of operation process, and integration with cutting-edge industry technology, so it is difficult to effectively support the training goal of new warehouse management talents. Especially in the complex environment such as a warehouse room, the teaching effect is further restricted by the problems of difficult simulation of real scenes, high risk of UAV operation, and difficult process reproduction (Li, 2024). Therefore, this research is devoted to building a practical teaching platform for storage UAV based on virtual simulation technology. By integrating virtual flight control, intelligent identification and full-process data simulation system, the teaching process is visualized, accurate and safe, and the practical teaching mode of deep integration of production and teaching is explored, so as to systematically improve students' engineering practice ability and post competence in the field of intelligent logistics and storage management, and provide a feasible path for the teaching reform of logistics engineering and engineering management majors.

At present, the application research of storage UAV in the field of education mostly focuses on single flight operation training or basic warehouse location identification task, and lacks systematic exploration of comprehensive training by putting it into a complete warehouse management business process. In recent years, although some scholars have tried to integrate emerging technologies into practical teaching, such as Sousa and Wilson (2024) preliminary application of unmanned aerial vehicles in logistics training, a systematic teaching scheme covering task planning, data collection, and inventory comparison has not yet been formed. Although Amer et al. (2025) put forward the concept of a virtual simulation practice teaching platform, its focus is mostly on environmental modeling and visual presentation, and the depth of integration with real warehouse layout, shelf structure and inventory data is still insufficient, so it is difficult to effectively solve the core problem of the disconnection between production and education. The key lies in the fact that the teaching of warehouse unmanned aerial vehicles faces practical obstacles such as difficult access to the real warehouse environment, high flight operation risk, and difficult reproduction of complex scenes. It is difficult for the traditional teaching mode to provide sufficient training opportunities under the premise of ensuring safety and cost control (Huber & Neumann, 2023; Garc á et al., 2025). Virtual simulation

technology can restore the warehouse operation scene with high precision, support students to carry out the whole simulation training from route planning to inventory data processing, and realize the dynamic visualization and task repeatability of the teaching process, thus effectively making up for the shortcomings of real equipment training in scene coverage, fault tolerance mechanism and process backtracking (Qi et al., 2018; Shabbir et al., 2025). Therefore, building a virtual simulation practice teaching platform that is highly compatible with the real workflow of smart warehouses has clear necessity and important application value for reducing the risk of training, improving teaching efficiency, and strengthening students' comprehensive practical ability in complex scenes.

In view of the above research deficiencies, this paper will carry out research from the following three aspects:

- (1) Building a whole-process virtual simulation teaching platform. Integrate the functions of route planning, virtual flight control, location identification, and inventory data comparison, and realize the closed-loop training of the whole process from task distribution to inventory output.
- (2) Design a high-fidelity warehouse scene and curriculum system. Based on the real warehouse layout and inventory data, a three-dimensional virtual scene is constructed, and practical courses covering typical inventory, exception handling, and error analysis are developed to improve the authenticity and task complexity of the teaching scene.
- (3) Establish a visual and repeatable training evaluation mechanism. Realize the full recording and playback of flight trajectory and operation sequence, build a multi-dimensional evaluation system based on process data, support precise guidance and task repetitive training, and reduce the risk of training and equipment dependence cost.

First, the virtual simulation technology is promoted from the auxiliary demonstration tool to the core level of the teaching system architecture, and the high-precision restoration of the warehouse training scene and the digital management of the whole process are realized; Secondly, a closed loop of integration of production and education driven by real warehousing business process and linked by simulated data flow is constructed, so that students can complete integrated training from route planning to inventory comparison in a safe and repeatable virtual environment, and their ability training can keep pace with the technological frontier of the industry; Thirdly, a visual and traceable process evaluation mechanism was established, which broke through the limitation of traditional training "emphasizing results over process", significantly reduced the risk of training and the cost of equipment dependence, and provided a virtual simulation solutions for practical teaching of warehousing logistics and engineering management majors.

It is expected that this study will build a set of practical teaching system solution for storage UAV based on virtual simulation technology, which can be widely popularized. Its theoretical value lies in that it can provide new design paradigm and methodology support for intelligent practice teaching; The practical value lies in the fact that this research can significantly improve students' comprehensive

practical ability and post competence in the intelligent warehousing environment, and at the same time, it can provide important reference for the practical teaching reform of logistics engineering and engineering management majors in similar colleges, and has positive significance for promoting the deep integration and popularization of virtual simulation technology and intelligent warehousing teaching.

2. Overall Design of Virtual Simulation Training Platform for Warehouse UAV

Combined with the application requirements of smart warehousing industry and the practice teaching rules of colleges and universities, this platform takes virtual simulation technology as the core, and integrates 3D modeling, flight mechanics simulation, warehousing business logic operation, human-computer interaction, big data management and other technologies, aiming at the pain points of traditional warehousing UAV, such as limited training site, high equipment cost, high operation risk, single training scene and difficult supervision of teaching process, etc., to carry out overall design. The platform follows the development idea of layered decoupling and independent modules, and builds an integrated virtual training environment, which completely covers the whole process training contents such as basic flight of storage drones, inventory in the reservoir area, cargo transshipment, security inspection, multi-machine collaborative operation, etc. At the same time, it opens up the data interface between schools and enterprises, and realizes the seamless connection between teaching and training and enterprise post standards.

2.1 Platform Design Principles and Overall Architecture

In order to ensure that the platform is stable, practical, and flexible to expand, and to meet the training of engineering management professionals and the job requirements of enterprises, five core design principles are formulated for this platform. Adhering to the principle of safety training, relying on the virtual environment to avoid risks such as drone collision, crash and cargo falling, supporting students to practice repeatedly and reducing the pressure of safety management in training; Adhere to the principle of post adaptation, benchmark the operation process, operation norms and assessment standards of smart warehousing industry, and ensure that the training content fits the actual post application; Implement the principle of combining reality with reality, be compatible with the linkage between physical control equipment and virtual terminal, take into account the practical feel and simulation effect, and connect virtual training with offline training; Adopting the principle of hierarchical expansibility, each module is decoupled and independent, which can add scenes, models and training tasks as needed, and also facilitate the subsequent expansion of intelligent evaluation, cloud collaboration and other functions; Follow the principle of ease of use, the interface and operation logic are concise and clear, distinguish various user permissions, lower the threshold of use, and adapt to learners with different foundations.

Referring to the idea of hierarchical system design, combined with the characteristics of virtual simulation technology and the business logic of warehousing training, a four-layer core architecture is constructed, which is sequentially from bottom to top: virtual perception interaction layer, simulation operation layer, data service layer, and application function layer. At the same time, two supporting systems, the supporting standard system and the security system, run through the whole architecture, ensuring data interaction and unification and the system operation safety and stability. The overall architecture of the platform is shown in Figure 1.

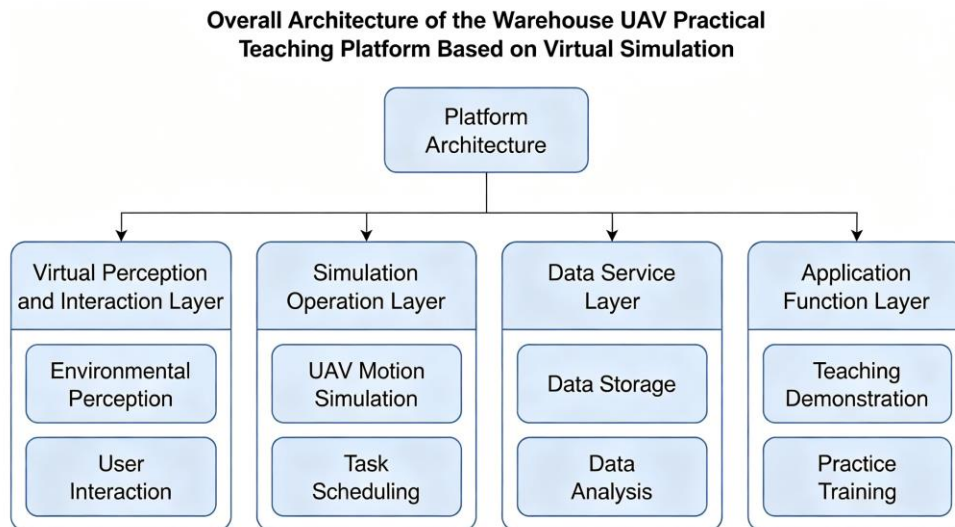


Figure 1. Construction Framework of Virtual Simulation Training Platform for Warehouse UAV

The four-layer architecture performs its own duties and is linked step by step: the virtual perception interaction layer provides the platform with visual scenarios and human-computer interaction portals; the simulation computing layer is the core engine of the platform, completing flight simulation and warehousing business operations; the data service layer is responsible for data storage, management and analysis; and the application function layer provides practical training services to different users. The two major support systems unify data interfaces and protocol specifications, and at the same time provide security protection for accounts, data, and operating behaviors to support the long-term stable operation of the platform.

2.2 Virtual Perception Interaction Layer Design

The virtual perception interaction layer is the underlying carrier for direct interaction between the platform and users and virtual scenes. It is equivalent to the “perception terminal” of the entire system. It mainly completes the three major tasks of three-dimensional scene construction, virtual equipment modeling, and human-computer hardware linkage to create an immersive warehousing training environment.

2.2.1 3D Warehousing Scene Modeling

Combined with mainstream smart warehouse forms, a full-scale three-dimensional scene reproduction is completed, including basic areas such as high-rise 3D shelves, flat storage areas, cargo sorting areas, entry and exit platforms, fire escapes, and emergency isolation areas; at the same time, supporting models such as pallets, turnover boxes, various storage goods, ground signs, monitoring equipment, and anti-collision facilities are restored. The scene supports the simulation of dynamic elements, such as pedestrian movement in the warehouse area, conveyor belt operation, lighting switching, etc., restoring the real dynamic warehouse operating environment. In addition, teachers are supported to customize the addition of obstacles, temporary storage areas, etc., to simulate complex training conditions.

2.2.2 Virtual Drone Equipment Modeling

Focus on the warehouse inventory special multi-rotor UAV to complete high-precision three-dimensional modeling and restore the fuselage structure, dynamic parameters, and handling characteristics. The model is equipped with special inventory equipment such as a high-definition camera, code scanning identification module, ranging and obstacle avoidance sensor, etc., which can synchronize flight attitude, power and sensing data in real time, accurately simulate cruise, fixed-point hovering, close-range code scanning and other operations, and adapt to the simulation inventory training of high and low shelves. Common types of multi-rotor UAVs are shown in Figure 2.



Figure 2. Common Multi-rotor UAV Types

2.2.3 Human-computer Interaction Module Design

This module realizes the linkage of physical control equipment + virtual system, and supports three control methods: professional drone flight controller, touch control console, and keyboard and mouse. When students use the physical handle to control, the operating instructions can be synchronized to the virtual drone in real time, with immediate feedback on flight attitude, steering, lifting, hovering, and other actions. The system provides three display modes: first-person perspective, third-person global perspective, and airborne camera perspective to meet the needs of different operational perspectives such as route planning, cargo grabbing, and warehouse inspections. All operating actions and

equipment status are collected in real time and transmitted to the upper layer, providing raw sensory data for subsequent calculations and data analysis.

2.3 Simulation Operation Layer Design

The simulation operation layer is the core operation engine of the platform. It undertakes the operation instructions and scene data issued by the virtual perception interaction layer, and completes flight physical operation, warehousing business logic operation, and environment variable simulation by algorithms. It is the key level that determines the authenticity of simulation and the professionalism of training. It is mainly divided into three functional modules.

2.3.1 UAV Flight Physics Simulation Module

The built-in mature flight mechanics algorithm accurately simulates the physical characteristics of the drone, such as air resistance, gravity, power output, attitude balance, etc., and truly restores basic flight actions such as takeoff, landing, hovering, turning, speed changing, and fixed-point docking. At the same time, it integrates intelligent obstacle avoidance algorithms and automatic route planning algorithms, which can simulate the obstacle avoidance behavior of drones around shelves, goods, pedestrians, etc. at close range; for high-altitude warehouse operation scenarios, the simulation of hovering accuracy is strengthened to match the core operational requirements of positions such as cargo grabbing and accurate inventory in the warehouse. Each control instruction of the students will drive the virtual equipment action after mechanical calculation.

2.3.2 Warehousing Business Logic Simulation Module

Combined with smart warehousing business processes, business computing logic is built to cover the core operation scenarios of warehousing drones. The first is the inventory calculation in the warehouse area: it simulates drone-borne code scanning, visually identifies cargo barcodes, automatically counts the quantity and category of goods in the cargo location, and generates an inventory ledger; the second is the cargo transfer calculation: simulates the entire process of cargo hook grabbing, suspended transportation, and fixed-point delivery to determine whether the goods are Whether it is offset and whether the delivery position is accurate; the third is security inspection calculation: simulates video capture, abnormal area marking, violation area warning and other functions; the fourth is multi-machine collaborative calculation: supports multiple virtual drones partition operations, relay transfers, and simulates cluster operation scheduling logic. The module can automatically determine the compliance of work processes and task completion, and output business calculation results in real time.

2.3.3 Complex Environmental Conditions Simulation Module

In order to improve the comprehensiveness of practical training, this module supports customized environmental variables and emergency conditions. Environmental parameters can simulate external conditions such as breeze, light intensity, and signal interference in the warehouse area to change the flight stability of the drone; at the same time, typical warehousing emergency scenarios can be set, such as temporary blocking of shelves, dumping of goods, equipment failure, temporary closure of the

warehouse area, interruption of flight signals and other abnormal working conditions to train students' emergency response capabilities. All environmental parameters and emergency scenarios can be configured by the teacher's backend to dynamically increase the difficulty of practical training.

2.4 Data Service Layer Design

The data service layer is the data center of the platform, uniformly receiving all data output from the simulation computing layer, completing classified storage, permission management, data statistics and behavior tracing, and providing data support for upper-layer application functions. Based on the differences in types and uses of warehousing training data, this platform adopts a type-based hybrid storage architecture and a complete data management system.

2.4.1 Multi-source Data Classification Storage

Different storage solutions are selected for the heterogeneous data generated by the platform to ensure reading and writing efficiency: a relational database is used to store structured business data such as teacher and student account information, class information, practical training courses, task lists, and assessment standards; a time-series database is used to store continuous time-series data such as drone flight trajectories, flight parameters, operation duration, and equipment status; distributed files are used to store large file data such as 3D scene files, training videos, homework results, inventory reports, and simulation screenshots. The classified storage mode enables efficient retrieval and long-term retention of massive training data.

2.4.2 Device and User Rights Management

Establish a unified user object model and permission system to divide roles and control permissions for teachers, students, and corporate personnel. Students only have permission to operate practical training, submit results, and view personal data; teachers have full management permissions such as task release, scenario configuration, process monitoring, grade correction, and data export; corporate personnel can only view cooperative training projects and job benchmarking data, and cannot modify the platform configuration. At the same time, a virtual equipment ledger is established to uniformly number and register the status of all virtual drones and simulation terminals in the platform to achieve digital management of virtual equipment.

2.4.3 Training Data Analysis and Process Tracing

The system automatically captures the entire process data of each training session, including operating steps, number of flight errors, task time, operation pass rate, emergency response time, and other indicators. It supports multi-dimensional data statistics and chart visualization display by class, individual, and training project; at the same time, it builds a training file traceability system. Each operation behavior and each task result are accompanied by a timestamp, operator, and scene parameters, forming a digital training file that can be queried and reviewed to provide a data basis for teaching evaluation and teaching research.

2.5 Application Function Layer Design

The application function layer is an interactive window for end users. Based on the underlying data and simulation capabilities, three independent clients are developed: teacher terminal, student terminal, and enterprise terminal. The three types of ports have data interoperability and permission isolation, covering all business scenarios of teaching management, independent training, and school-enterprise collaboration. The functional positioning of the three types of ports is shown in Table 1.

Table 1. Firefighting Facilities and Water Consumption in Various Areas of AS/RS

User port	Core positioning	Main functional modules	Specific function description
Teacher console	Teaching management, process supervision, assessment and evaluation	Practical training task management	Select warehousing scenarios and drone models, customize task parameters and difficulty, publish single/group training tasks, and import enterprise inventory cases
		Real-time status monitoring	Globally view drone flight status and operation progress, retrieve on-board images, automatically warn of abnormal operations, and support remote guidance and equipment management and control
		Assessment performance management	The system automatically scores with manual review, generates training reports and performance ledgers, and supports batch export of data
		Teaching resource management	Upload practical training courseware, operating specifications, and teaching videos to build a shared resource library
Student training system	Skills training, independent practice, and results submission	Basic flight training	Practice basic operations such as UAV take-off, hovering and route planning, and the system will give real-time error correction tips
		Inventory special training	Complete standard inventory operations such as cruise in the reservoir area, code scanning of cargo positions, cargo inventory and data recording
		Comprehensive project training	Carry out comprehensive training such as complex reservoir inventory,

			multi-machine collaborative operation and emergency handling, and support group online training
		Re-examination and submission of training	Play back the operation process, summarize the problems independently, and submit the inventory report and training results online
		Case standard import	Upload the real inventory items, job operation specifications and typical fault cases of the enterprise and turn them into teaching materials
Enterprise terminal docking interface	School-enterprise cooperation, post benchmarking and resource exchange	Competency benchmarking analysis	Combined with the training data, the post ability requirements are compared, and the analysis report of students' skill matching degree is output
		Data sharing access	Check the overall training level of students to provide reference for talent selection and internship; Synchronize industry new technology and new process to feed back teaching

3. Transformation of Virtual Simulation Teaching Case for Real Project of Warehousing Enterprise

In order to solve the problems that the traditional training content is out of touch with the actual work of the industry, and the standardization of training projects is low, this platform relies on virtual simulation technology, and deeply cooperates with warehouse enterprises to disassemble, adapt and reconstruct the first-line real operation projects such as warehouse drone inventory and inspection, and build a closed-loop transformation system of enterprise production projects, virtual simulation cases and classroom training tasks. Relying on this path, the teaching content is fully aligned with the enterprise post standards, operation processes and assessment requirements, and a project-based training mode under the integration of production and education is constructed, so that students can complete the real post training in the simulation environment and steadily improve their post practical ability and comprehensive professional quality.

3.1 General Idea of Transformation

The transformation of this project adheres to four core ideas: post orientation, process re-engraving, gradient adaptation, and integration of reality and reality. First of all, taking the inventory of the core positions in the UAV reservoir area of the smart warehousing enterprise as the foothold,

comprehensively sort out the complete operation process, job responsibilities, operation specifications, quality standards, and common abnormal working conditions of the enterprise to ensure that the transformed materials come from real production scenarios. Secondly, according to the teaching law, the enterprise project is modularized and disassembled, and the complete enterprise project with long period and high complexity is disassembled into teaching units that can be trained step by step, which reduces the difficulty of entry and adapts to the duration of classroom training and teaching rhythm.

At the same time, combined with the characteristics of the virtual simulation platform, the high-risk, high-cost and difficult-to-duplicate operation scenes are digitally reconstructed, the core operation logic and business requirements are retained, and the non-teaching redundant links are eliminated; Simultaneously transfer the enterprise assessment indicators and job evaluation standards to the simulation system to achieve “consistent job processes and unified evaluation standards”. Finally, based on the concept of hierarchical teaching design, the basic, advanced and comprehensive training tasks are set for students with different learning stages and different ability levels, forming a progressive content system from single skill training to full-process project practice, and finally realizing the efficient transformation of enterprise production projects into standardized and systematic virtual teaching cases.

3.2 Typical Warehouse UAV Project Case Design

This paper takes the inventory check of UAV warehouse, which is the most widely used in the warehousing industry, as the core typical project, and completes the transformation design from the real operation link of the enterprise to the virtual simulation training case. Around the whole process of the enterprise from pre-preparation, on-site operation to data collection and archiving, the virtual training content is designed one by one, and the technical integration points and teaching focus are clearly defined, so as to completely duplicate the enterprise operation mode. The specific transformation contents are shown in Table 2.

Table 2. Warehouse UAV Inventory Check Project Case Conversion Path

Real operation link of enterprise	Virtual simulation teaching implementation scheme	Integration of technology and teaching
Project preparation and scheme planning	Teachers/corporate tutors import original materials such as real reservoir drawings, shelf distribution, cargo list and inventory accuracy requirements, and the system automatically generates standardized virtual training project packages; Students check the project background and complete the preliminary route planning in combination	Training is conducted using primary project data from enterprises, moving away from idealized simulation scenarios, to cultivate students' abilities in project planning at the pre-project stage and to develop their engineering thinking.

	with the layout of the reservoir area.	
Equipment inspection and parameter debugging	In the virtual environment, students check the appearance, code scanning module, obstacle avoidance sensor, power and signal of the UAV item by item, and set parameters such as flying height, flying speed and cruising distance according to the shelf height and the environment of the reservoir area.	Re-enact the pre-job equipment inspection process of enterprises, strengthen post safety norms and equipment usage habits, and set parameters to benchmark the on-site operation standards of enterprises.
Cruise in reservoir area and code scanning inventory of cargo space	Control the virtual drone to cruise along the planned route, and complete fixed-point hovering, barcode/QR code scanning and cargo image acquisition for high shelves and dense cargo spaces in turn; The system records the inventory data of each location in real time.	Restore the real inventory operations, simulate complex scenes such as high and low shelves and dense reservoir areas based on the simulation environment, and train core operations such as precise hovering and close-range code scanning.
Abnormal working conditions handling	Common enterprise problems such as blurred cargo barcodes, blocked shelves, drone signal fluctuations, and partial cargo location errors are randomly triggered. Students complete on-site inspections, secondary inventory, and temporary route adjustments according to the enterprise's handling procedures.	Typical failures and emergency scenarios of enterprises are introduced to make up for the shortcoming of physical training that it is difficult to reproduce abnormal working conditions frequently and improve students' emergency response capabilities.
Data verification, analysis and report submission	The system automatically summarizes the original inventory data, and students compare the system ledger to complete data verification and difference analysis; in accordance with the enterprise's unified format, the inventory report is prepared online and submitted for archiving.	Connect the whole job process of "operation + data analysis + document output" to realize the transformation from simple control training to comprehensive business capability training.

3.3 Construction of Project-based Practical Training Course System

Based on the transformed virtual simulation case, combined with the practical teaching objectives of storage UAV and students' cognitive rules, a three-level progressive project-based practical training course system is built, which is divided into basic skill layer, special operation layer and comprehensive application layer. The contents of each level are connected with each other and the difficulty is improved step by step, as shown in Figure 3. At the same time, it is equipped with hierarchical teaching strategies and assessment standards to meet the needs of all-staff training and personalized training.

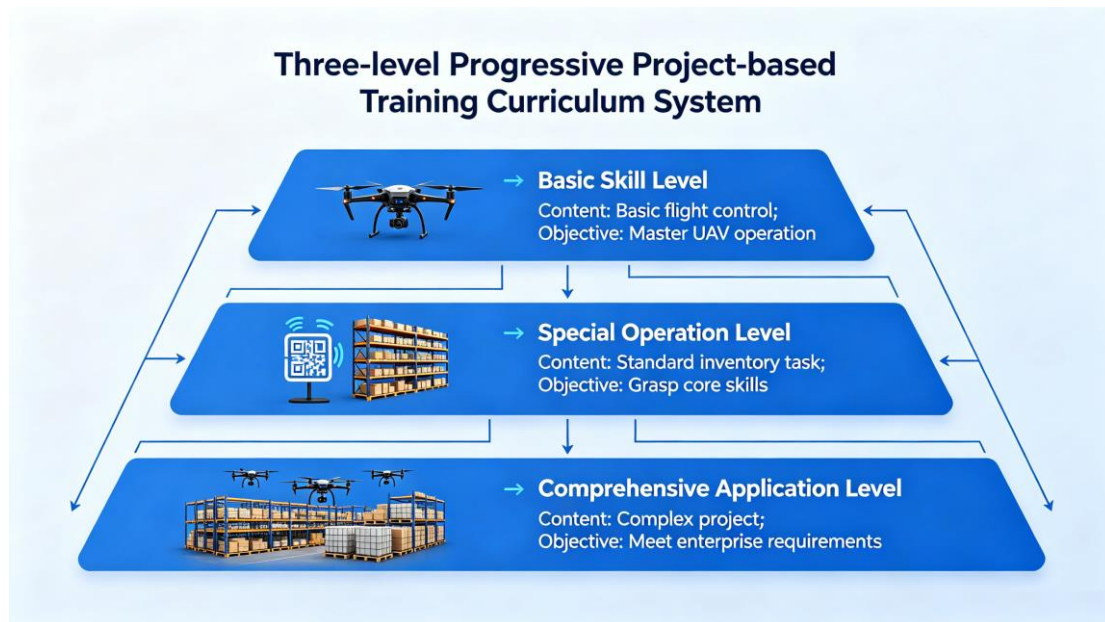


Figure 3. Project-based Training Curriculum System

Differentiated teaching should be carried out for students with different learning abilities: students with weak foundation should focus on basic skills and simple special tasks, increase the duration of simulation exercises, supplemented by step-by-step operation instructions; Middle-level students focus on completing all the contents of the special operation layer and strengthening the standardization of the process; Students with outstanding ability directly carry out comprehensive application-level training and arrange expansion tasks, such as customizing inventory routes and optimizing inventory schemes. Teachers rely on the platform to monitor the training progress of each group in real time, carry out online remote guidance and on-site Q&A, and realize teaching students in accordance with their aptitude.

The course system is synchronized with enterprise version operation manuals, inventory homework videos, job specification documents and other teaching resources, all of which are embedded in the virtual simulation platform resource library, and students can consult and study at any time. At the

same time, the company's job evaluation indicators are integrated into the practical training assessment to form a five-in-one evaluation system of operating specifications, task efficiency, data accuracy, emergency response, and report quality to ensure that teaching objectives, practical training content, assessment standards, and company job requirements are highly unified, and truly realize the deep integration of industry and education.

4. Teaching Application Implementation Plan

After completing the construction of the virtual simulation platform, the transformation of corporate project cases and the design of the project-based curriculum system, this study will put the warehouse inventory drone virtual simulation teaching platform into daily practical training and teaching scenarios for implementation. Combining the talent training plan for logistics management professionals with the practical training requirements for warehousing positions, a complete teaching implementation process was developed, a diversified assessment and evaluation system was built, and data statistics and effect analysis were carried out through questionnaire surveys, performance comparisons, interviews with teachers and students, etc., to comprehensively verify the actual value of the platform in optimizing the training model, improving students' practical abilities, and deepening the integration of industry and education.

4.1 Teaching Application Implementation Plan

This platform adopts an online and offline hybrid training model, combining three application forms: centralized classroom training, independent practice after class, and joint school-enterprise training. It designs a standardized teaching implementation plan around the whole process of before class, during class, and after class, adapting to the regular practical training class schedule and talent cultivation rhythm of colleges and universities.

4.1.1 Apply Organizational Form

(1) Classroom centralized training: collective teaching is carried out in class units, and a virtual simulation platform is deployed in a unified manner based on the computer room. Teachers uniformly publish practical training tasks, explain operating points and warehouse inventory operation specifications, and use the platform monitoring function to guide students in real time on site. The focus is on completing compulsory training content such as basic skills and special inventory operations to ensure that all employees master core skills.

(2) Independent practice after class: The platform opens access rights outside the school. Students can use their spare time to log in to the system for repeated practical operations, working condition simulation and process review, strengthen training on their own weak links, and break the restrictions of physical training venues, equipment, and time.

(3) School-enterprise joint practical training: School teachers and enterprise technical instructors jointly teach, introduce real complex inventory projects and typical failure cases of enterprises to carry out

comprehensive practical training, and conduct full-scale drills based on enterprise job standards to achieve a seamless connection between teaching and jobs.

4.1.2 Full-process Implementation Process of Teaching

The whole process is divided into three stages: pre-class preparation, in-class training, and post-class summary, forming a closed-loop teaching process. The specific process is shown in Table 3.

Table 3. Platform Teaching Application Implementation Process

Phase	Implementing entities	Specific work content
Pre-class Preparation	Teacher	Select training items, configure scene parameters, release learning tasks and preview materials according to the course progress; Set the training duration, assessment rules and difficulty level.
	Student	Consult the preview resources such as UAV inventory operation specifications and operation videos, and be familiar with the training task requirements and operation processes.
In-class training	Teacher	Explain the important and difficult points, monitor the training status of all students in real time, and provide remote reminder and on-site guidance for illegal operations and process errors; Dealing with platform operation problems.
	Student	Log in to the platform to complete the corresponding level training tasks, and carry out equipment inspection, route planning, cruise code scanning, data recording and other operations in turn, and consult in time when encountering problems.
Post-class Summary	Teacher	Check the training data, complete the evaluation, summarize the common problems and carry out centralized explanation; Collating training data for teaching analysis.
	Student	Play back the training operation video for independent review, improve the inventory report, and submit the training results and learning summary.

4.2 Construction of Teaching Assessment and Evaluation System

Abandoning the traditional mode of scoring only by the final results, and combining the advantages of traceability of the whole data of the virtual simulation platform, a diversified evaluation system of process assessment + result assessment + comprehensive literacy assessment is constructed. At the same time, the evaluation standards of different course levels are divided, taking into account skills mastery, process standardization and professional literacy, and the evaluation indicators

comprehensively meet the post evaluation requirements of benchmarking warehousing enterprises.

4.2.1 Overall Framework of Assessment System

The total assessment score consists of three parts: process assessment accounts for 50%, result assessment accounts for 35%, and comprehensive literacy assessment accounts for 15%. Relying on the platform to automatically collect data such as training trajectory, operation behavior, task time-consuming, etc., to achieve intelligent automatic scoring of most indicators, supplemented by manual review by teachers, to ensure fair, objective and efficient assessment. The architecture of diversified teaching assessment and evaluation system is shown in Figure 4.

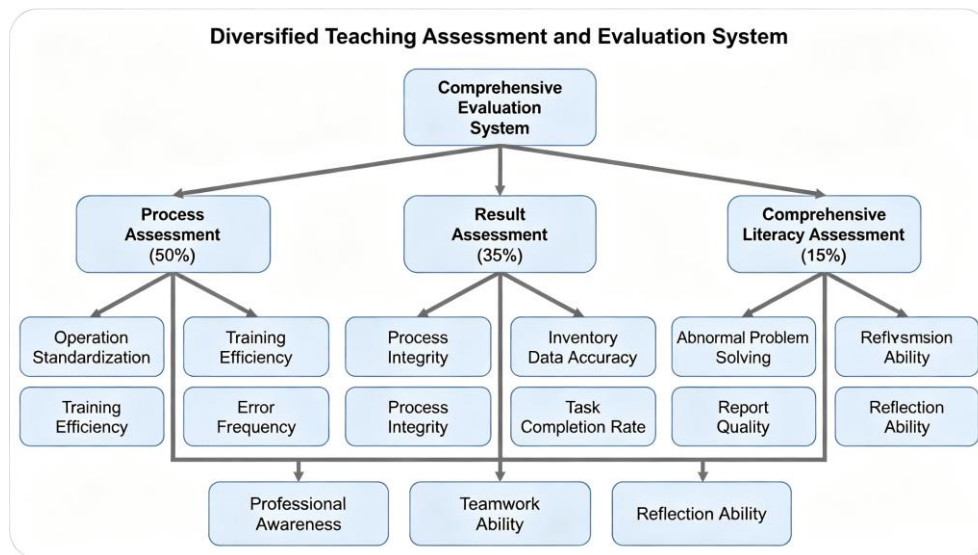


Figure 4. Architecture of Diversified Teaching Assessment and Evaluation System

4.2.2 Sub-item Assessment Explanation

(1) Process assessment: Based on the background data of the platform, count the students' whole process behaviors such as flight operation, equipment inspection and route planning, judge whether the operation conforms to the enterprise norms, count the number of problems such as invalid operation and illegal flight, and comprehensively score the students' daily operation habits and process control ability in combination with the time-consuming single-step task.

(2) Result assessment: With the final inventory data and task completion as the core, check the accuracy of cargo location information and cargo quantity, evaluate the rationality of the disposal scheme for abnormal working conditions, and score the format, content integrity and data analysis depth of the inventory report submitted by students.

(3) Comprehensive literacy assessment: Evaluate the team cooperation performance according to the team cooperation training scenario; Combined with the attitude of training, the situation of answering questions and the compliance with rules, the professional quality is comprehensively evaluated to meet

the comprehensive requirements of warehousing enterprises for employees.

4.2.3 Hierarchical Assessment Standard

Aiming at the three training levels, namely, basic skill level, special operation level and comprehensive application level, we set differentiated assessment thresholds, with the basic level focusing on operational proficiency, the special level on process standards, and the comprehensive level focusing on problem solving and comprehensive application ability, so as to realize the matching between assessment and curriculum system.

4.3 Application Effect Investigation and Data Analysis

In this study, 168 students from four classes of logistics management and industrial engineering in our university were selected as the research objects, and the control group (traditional physical training) and the experimental group (virtual simulation platform training) were set up to carry out a semester-long teaching comparative experiment. Combined with the statistics of training results, online anonymous questionnaire survey and in-depth interviews between teachers and students, data analysis is carried out from the dimensions of training effectiveness, teaching experience and ability improvement to verify the application effect of the platform.

4.3.1 Comparative Analysis of Training Results

The final comprehensive assessment scores of the two groups of students were sorted out and analyzed according to four levels: excellent (90 points and above), good (80~89 points), qualified (60~79 points), and unqualified (below 60 points). The results are shown in Table 4.

Table 4. Comparison of Assessment Results

Grade	Score Range	Control Group (Traditional Training)	Experimental Group (Virtual Simulation Training)
		Number of Students/Proportion	Number of Students/Proportion
Excellent	≥90	16 / 19.05%	37 / 44.05%
Good	80~89	28 / 33.33%	32 / 38.10%
Qualified	60~79	32 / 38.10%	14 / 16.67%
Unqualified	< 60	8 / 9.52%	1 / 1.18%

It can be seen from the data that the proportion of outstanding people in the experimental group has increased significantly, and the number of unqualified people has decreased significantly. Traditional physical training is limited by the number of equipment, venue and safety, and students have insufficient practical training time and fewer opportunities for trial and error; The virtual simulation platform supports all the staff to practice repeatedly and synchronously, and the students' proficiency in operation and the quality of task completion are obviously improved, and the overall training results are better than the traditional teaching mode.

4.3.2 Analysis of Questionnaire Survey Results

A total of 168 questionnaires were distributed in this survey, and the effective recovery rate was 100%. The evaluation was carried out around four dimensions: training safety, practical ability improvement, scene restoration degree and learning interest improvement. The results are shown in Table 5. Judging from the evaluation data, the safety of training has been unanimously recognized by all students, accounting for 100%; The recognition rate of learning interest improvement is 94.05%; The recognition rate of practical ability improvement is 92.26%; The recognition degree of scene restoration is 89.88%.

Table 5. Survey Results

Evaluation Dimension	Satisfaction/Recognition Rate (100%)
Training safety	100.00
Operational skill growth	92.26
Scene fidelity	89.88
Learning motivation	94.05

Overall, students gave excellent comprehensive evaluations of the virtual simulation training platform. The platform performed outstandingly in eliminating safety hazards in practical training, strengthening skills training, restoring real operating scenarios, and mobilizing learning initiative. At the same time, some students reported that there is a difference in feel between virtual control and physical drones. This issue can be an important direction for the subsequent optimization of the virtual-real combination teaching model.

4.3.3 Summary of Interviews with Teachers and Students

By interviewing teachers and external tutors of enterprises, the advantages of the platform are summarized: first, the platform realizes full visual supervision of the training process, teachers can accurately locate students' problems, and teaching guidance is more targeted; Second, the cost of equipment procurement, maintenance and site operation and maintenance is greatly reduced, and the difficulty of training organization is reduced; Third, the enterprise tutor thinks that after the simulation training, students have a more thorough understanding of the business process of warehousing inventory, the pre-job adaptation period is obviously shortened, and the post competence is effectively improved.

According to the comprehensive data, the practical teaching platform of storage UAV based on virtual simulation has effectively made up for many shortcomings of traditional training, and achieved remarkable results in improving teaching quality, strengthening students' job skills, reducing training costs and safety risks, and has good popularization and application value.

5. Conclusion and Prospect

This paper builds an integrated warehousing drone virtual simulation practice teaching platform in view of the real pain points of traditional practical training of warehousing drones, such as high equipment costs, prominent safety risks, single operating scenarios, and disconnection between school and enterprise teaching. Research has completed the design of the platform's hierarchical architecture, clarified the module functions of the virtual perception interaction layer, simulation computing layer, data service layer and application function layer, and built a multi-user collaboration port for teachers, students, and enterprises. At the same time, a standardized transformation path from corporate warehousing projects to virtual teaching cases has been established, a three-level progressive project-based practical training course system has been designed, and a complete online and offline mixed teaching implementation plan has been implemented to build a three-in-one multi-evaluation and evaluation system of process, results, and comprehensive literacy. Through comparative teaching experiments and questionnaire survey data analysis, it can be seen that the virtual simulation platform can significantly reduce practical training safety hazards, broaden students' practical training channels, and effectively improve students' practical ability and job adaptability in warehousing drone inventory operations. The overall recognition of the platform's practical training model by students exceeds 89%, which fully verifies the application value of this platform in logistics professional training and teaching, and provides implementable practical solutions for the reform of warehousing practical training courses.

This work still has certain limitations. There is still room for improvement in the hand-feel fit between the current virtual simulation environment and physical control equipment. The computing efficiency of multi-machine large-scale collaborative simulation needs to be optimized. There is insufficient reserve of teaching cases for subdivided warehousing special working conditions. Follow-up research will continue to improve in three aspects: first, deepen the interactive transformation of virtual and real integration, optimize the drone control hardware linkage algorithm, and narrow the gap between virtual and physical equipment operation feel; second, introduce lightweight cloud simulation technology to improve the operational fluency of multi-drone cluster operation scenarios and expand complex warehousing emergency conditions simulation cases; third, rely on long-term cooperation between schools and enterprises to continuously update on-the-job training projects, and introduce AI intelligent learning analysis modules to realize automatic identification of student training shortcomings and personalized task push. This platform will continue to iteratively optimize, further deepen the integration of industry and education, and provide support for the digital transformation of smart logistics professional training and teaching.

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