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Research on the Application of Virtual Simulation Technology in the Practical Teaching Model of Industrial Robot Major

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Abstract: With the rapid development of the intelligent manufacturing industry, the demand for technical talents in industrial robot technology has become increasingly urgent. Focusing on the application value of virtual simulation technology in the practical teaching of industrial robot major and combining with the national vocational education reform policies, this paper explores the innovative role of virtual simulation technology in the practical teaching model from four dimensions: teaching cost optimization, safety improvement, scenario expansion, and evaluation innovation. The research shows that virtual simulation technology can effectively solve the "three highs and three difficulties" problems in traditional practical teaching, promote the in-depth development of the integration of industry and education, and provide strong support for cultivating high-quality technical and skilled talent in the field of industrial robots.

Keywords: Virtual simulation technology; Industrial robot major; Practical teaching

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1. Introduction

Against the background of the in-depth advancement of the strategy of manufacturing power, industrial robot technology has become the core support for the development of intelligent manufacturing. The *Notice on Accelerating the Key Tasks of the Reform of Modern Vocational Education System Construction* issued by the Ministry of Education in 2023 clearly states that by 2025, about 200 national demonstration virtual simulation training bases will be built to promote the innovation of practical teaching models for technical and skilled talents in vocational colleges [1]. At the same time, the *"Robot +" Application Action Implementation Plan* requires accelerating the cultivation of robot technology talents to meet the needs of the transformation and upgrading of the manufacturing industry [2]. Traditional practical teaching of industrial robots is faced with problems such as high equipment cost, high training risk, and limited scenario coverage, which makes it difficult to meet the requirements of the rapid industrial development for talent cultivation. By constructing digital teaching scenarios, virtual simulation technology provides a new path for breaking through the bottlenecks of traditional teaching and innovating practical teaching models, and is of great significance for improving the quality of talent cultivation in industrial robot major.

2. The application value of virtual simulation technology in the practical teaching of industrial robot major

2.1. Optimizing the allocation of teaching resources and reducing the pressure of practical training costs

Virtual simulation technology provides a new solution for optimizing the allocation of resources in the practical teaching of industrial robot major, effectively alleviating the resource constraints in traditional teaching. Under the traditional mode, the purchase and maintenance of industrial robot equipment require a large amount of funds, and the update speed is difficult to keep up with the development of technology. However, the digital practical training platform built by virtual simulation technology can realize cross-school and cross-regional sharing relying on the professional teaching resource database of vocational education, which greatly improves the resource utilization rate [3]. The virtual simulation system jointly developed by schools and enterprises can transform the real production scenarios of enterprises into teaching resources, enabling schools to carry out diversified teaching without repeatedly purchasing different types of equipment. This sharing mechanism not only reduces the pressure of schools' hardware investment but also allows students to be exposed to a wider range of technology types and equipment models, realizing the optimal allocation and efficient utilization of educational resources.

2.2. Enhancing the safety of practical training operations and building a controllable teaching environment

Virtual simulation technology significantly improves the safety of practical teaching in industrial robot major and creates a safe and controllable practical training environment for students. The operation of industrial robots involves risks such as high voltage and high-precision mechanical movement. Even with strict standards in traditional practical training, there is the possibility of equipment damage or personal injury caused by operational errors. By virtue of a highly realistic virtual environment, virtual simulation technology enables students to conduct operation training in simulated scenarios, completely avoiding potential hazards in actual operations [4]. Students can practice skills like programming, debugging and maintenance repeatedly, and also simulate the consequences of operational errors to accumulate emergency experience under safe conditions. Meanwhile, it eliminates students' psychological concerns about making operational mistakes, helping them focus on improving their skills.

2.3. Expanding practical teaching scenarios and achieving accurate alignment with industrial demands

Virtual simulation technology greatly broadens the scope of scenario coverage in the practical teaching of industrial robot major, realizing the accurate connection between teaching and industrial demands. Restricted by the number of equipment and site conditions, traditional practical training can only carry out basic operation training, and it is difficult to simulate complex industrial scenarios and advanced production processes. However, virtual simulation technology can construct a variety of industrial application scenarios—ranging from the operation of a single piece of equipment to the operation of a complete production line, and from standardized operations to personalized customized production—covering all typical application scenarios of industrial robots in an all-round way. With the help of digital twin technology, the real production lines of enterprises can be replicated into virtual teaching scenarios at a 1:1 ratio, allowing students to have access to cutting-edge intelligent manufacturing systems on campus. In addition, it can also simulate the collaborative work of robots of different brands and models, as well as peripheral equipment, helping students master the operation and maintenance skills of complex systems such as flexible manufacturing and intelligent production lines [5]. This not only makes up for the shortcomings of traditional practical training but also enhances students' adaptability to job positions.

2.4. Innovating the teaching evaluation system and supporting personalized cultivation

Virtual simulation technology promotes the innovation of the practical teaching evaluation model for industrial robot majors and provides strong support for personalized teaching. Traditional practical teaching evaluation mostly relies on teachers' subjective observation and final result assessment, which fails to comprehensively record and analyze students' learning processes. The virtual simulation system can collect students' operation data in real time, including detailed information such as operation steps, parameter settings, and completion time, and build a comprehensive learning process evaluation system [6]. By analyzing this data, teachers can accurately grasp students' mastery of skills and their weak points, and provide targeted guidance. At the same time, the system can automatically adjust the training difficulty and content according to students' learning progress and ability level, and plan personalized learning paths. This data-based formative evaluation model not only makes teaching evaluation more objective and comprehensive, but also stimulates students' enthusiasm for independent learning, realizes the teaching method of "teaching students in accordance with their aptitude," and helps to improve the overall quality of talent cultivation [7].

3. Application paths of virtual simulation technology in the practical teaching of industrial robot major

3.1. Construction of a school-enterprise collaborative virtual simulation resource development system

The construction of a school-enterprise collaborative virtual simulation resource development system requires the establishment of a full-chain cooperation mechanism, with digital twin technology as the link to achieve an accurate connection between industrial needs and teaching resources. Enterprises need to deeply participate in the entire process of resource development. They should not only provide 3D data of real production scenarios (such as layout parameters of automobile welding production lines and precision requirements for electronic component assembly) but also send senior engineers to participate in the logical construction of virtual scenarios, ensuring that details like equipment movement parameters and fault manifestations are consistent with actual production [8]. Schools, on the other hand, are responsible for transforming industrial resources into teaching resources. By decomposing complex production processes (e.g., breaking down robot welding technology into sub-modules such as coordinate system calibration, trajectory planning, and parameter debugging), they design learning paths that conform to cognitive laws. A dynamic maintenance mechanism of "quarterly updates + annual iterations" should be established. Enterprises regularly provide feedback on changes in production technology, such as updates to the safety collaboration distance standards for collaborative robots, and schools work with technical teams to optimize virtual scenarios, ensuring the timeliness of resources [9]. This collaborative model not only solves the problem that resources developed independently by schools are divorced from industrial reality but also lowers the technical threshold for enterprises to participate in talent cultivation, forming a positive cycle where "production data is transformed into teaching resources, and teaching resources feed back to production needs."

3.2. Building a hierarchical and progressive virtual simulation training module

In accordance with the law of vocational competence development, a three-tier virtual simulation training system featuring "basic cognition–systematic application–innovative breakthrough" is constructed. The basic level focuses on equipment principles and basic operations, developing modules such as virtual disassembly and assembly of robot ontology structures, coordinate system establishment, and motion command programming. Students disassemble core components like servo motors and reducers through 3D animations, understand mechanical transmission principles in interactive operations, and receive real-time feedback from the system on operational standardization (e.g., prompts for joint motion limits), which helps them establish operational intuition [10]. The comprehensive level takes typical industrial scenarios as carriers and designs multi-equipment collaborative training modules. For example, the virtual debugging of an automobile welding production line requires completing parameter matching between the robot and the visual inspection system, as well as logical linkage with the PLC control system. Students need to solve comprehensive problems such as welding trajectory deviation and beam imbalance, thereby cultivating systematic thinking. The innovative level sets up open-ended tasks, such as optimizing the grasping path of custom workpieces and designing robot obstacle avoidance schemes in unstructured environments, and provides parametric modeling tools to support scheme verification. A "virtual skill competition" mechanism is introduced, with a virtual question bank that meets national competition standards built in. Students can take on competitive tasks like optimizing the efficiency of handling and palletizing, and planning spraying paths. The system generates competence assessment reports to align with industry benchmarks [11]. This hierarchical design not only avoids the "difficult entry" problem of traditional training but also provides development space for students with different abilities, realizing the phased improvement of skill cultivation.

3.3. Design of virtual simulation teaching content integrating industry standards

A mapping mechanism between industry standards and teaching content shall be established to transform national standards, industrial norms, and enterprise Standard Operating Procedures (SOPs) into rigid constraints for virtual simulation. In terms of safety specifications, virtual maintenance training strictly complies with the Safety Requirements for Industrial Robots. Students must complete preliminary steps such as power-off verification and safety fence confirmation to access the operation interface; non-compliant operations will trigger safety warnings and force the process to be rolled back [12]. The integration of technical specifications is reflected in the standardization of operational details. For instance, the programming of welding robots must conform to the Operating Specifications for Welding Robots. The system automatically detects the parameter compliance in the program (e.g., the matching degree between welding current and material thickness) and provides reference values based on industry standards. Enterprise standards are implemented through "digital twin scenarios." In the virtual training of new energy battery module assembly, parameter settings strictly align with the actual SOPs of enterprises (e.g., the tightening torque error must be controlled within ±5%), and students' operation data is compared with enterprise production standards in real time. A teaching closed-loop of "error diagnosis–standard interpretation–correction feedback" is designed. When students' trajectory planning fails to meet process requirements, the system pops up to display the original text of relevant industry standards and links to the analysis of typical cases [13]. This immersive standards-based training helps students consolidate their awareness of norms through repeated operations, enabling them to quickly adapt to job requirements after graduation.

3.4. Establishing a practical teaching organization model integrating virtual and physical elements

An innovative three-stage teaching process of "virtual preview–virtual-physical verification–virtual review" is developed to achieve in-depth integration of virtual simulation and real-world practical training. Before class, students complete a task preview via the virtual platform. They familiarize themselves with the layout of industrial robot workstations in a 3D environment, conduct programming rehearsals, and develop operation plans. The system predicts potential issues (such as path interference risks), helping students enter the hands-on session with targeted questions. During class, a verification process of "virtual programming–real execution–data comparison" is implemented. The welding program written in the virtual environment is imported into a real robot. By comparing the trajectory accuracy from virtual simulation with the weld pool morphology from real welding, factors that are not fully simulated in the virtual environment (such as mechanical errors and load changes) are analyzed, deepening students' understanding of related technologies. After class, a virtual review is carried out. To address positioning deviation problems encountered in hands-on operations, a parameter adjustment test matrix is built on the virtual platform. The influence of different PID parameters on motion accuracy is verified using the variable control method, and an optimization plan is formulated [14]. This model gives full play to the advantages of virtual simulation in safe error trial and the value of physical feedback from real equipment, solving the pain points of traditional practical training such as "more observation than practice" and "fear of trying after making mistakes." Meanwhile, the virtual platform enables remote sharing of high-quality practical training resources, alleviating the shortage of equipment in primary-level colleges and universities and expanding the coverage of high-quality educational resources.

3.5. Improving the data-driven virtual simulation teaching evaluation mechanism

A full-process data collection and multi-dimensional evaluation system is built to achieve precise and personalized teaching evaluation. The virtual simulation system is equipped with a built-in data collection engine, which records in real time more than 20 indicators such as the integrity of operation steps, the accuracy of parameter settings, and the timeliness of fault handling, forming a personal skill database. A three-dimensional evaluation profile is generated through data modeling: The operation standardization dimension analyzes the implementation rate of safety steps and the compliance with standard procedures; The technical proficiency dimension evaluates the time spent on task completion and the number of parameter adjustments; The problem-solving dimension counts the accuracy of fault diagnosis and the innovation of solutions. Differentiated teaching interventions are implemented based on the profiles: students with weak safety standards are given special virtual training packages, while students with insufficient technical proficiency are given more practice opportunities in basic modules. At the class level, a competence heat map is generated, allowing teachers to intuitively identify the group's weak links (e.g., the generally long time spent on visual system debugging) and optimize teaching priorities accordingly [15]. A comprehensive evaluation mechanism combining "process evaluation + summative assessment" is established. Process data accounts for 60% of the total score to reflect the learning trajectory, while the summative assessment adopts the form of a virtual comprehensive project to fully evaluate vocational competence. This data-driven model not only overcomes the subjective bias of traditional evaluation but also realizes a closed-loop improvement of "teaching diagnosis–resource optimization–competence enhancement," continuously improving the quality of teaching.

4. Conclusion

This paper conducts a study focusing on the application paths of virtual simulation technology in the practical teaching of industrial robot majors. It constructs a comprehensive system for the implementation of this technology from five dimensions: the development of school-enterprise collaborative resources, hierarchical and progressive practical training modules, integration of industry standards, virtual-real integrated teaching organization, and data-driven evaluation. This system effectively addresses the pain points of traditional practical teaching, such as disjointed teaching resources, high safety risks, and subjective evaluation. It aligns with the requirement of "technology empowering practical training" specified in the *Action Plan for the High-Quality Development of Modern Vocational Education*, and provides a feasible solution for the cultivation of industrial robot talents under the integration of industry and education. In the future, further exploration can be made into the in-depth integration of AI and virtual simulation, optimizing the function of scenario adaptive adjustment, continuously improving the accuracy of teaching, and contributing to the development of a team of high-quality technical and skilled talents under the strategy of building a manufacturing power.

Disclosure statement

The authors declare no conflict of interest.

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