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Practice and Innovation in Laboratory Management for Industrial Robots Under the Modern Industrial College Model

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Abstract

To promote the effective application of industrial robot technology in integrated engineering teaching methods within universities, this study analyzes the background of modern industrial colleges deepening industry-education integration and advancing collaborative education. Using the KUKA industrial robot laboratory as a platform, a practical teaching model of "PDCA cycle with flipped classroom" is proposed. Through innovative approaches such as safety management system optimization and digital twin applications, after four years of teaching practice, the industrial robot laboratory has maintained high-quality experimental and practical training courses even under high operational loads. This management model can serve as an important reference for laboratory management in modern industrial colleges.

Keywords: industrial robots, modern industrial college, laboratory management, PDCA

1. Introduction

Engineering laboratory courses in application-oriented undergraduate universities are crucial for enhancing students' practical engineering skills. Industrial robotics courses, as a key link between universities and enterprises, serve as a core platform for cultivating high-quality technical talents in smart manufacturing. The "hands-on training–project-driven–enterprise case" integrated practical model significantly improves the operational skills of students in application-oriented universities. This approach also shortens the pre-job training period for enterprises. However, industrial robotics laboratories commonly face challenges such as high equipment costs, insufficient industry experience among instructors, and outdated course content compared to industrial technological advancements. To address these issues, this paper takes the Industrial Robotics Laboratory of the School of Mechanical and Marine Engineering at Beibu Gulf University as a case study. Supported by the Modern Industrial College of Ship and Marine Engineering Equipment, a "PDCA Cycle + Flipped Classroom" teaching model is proposed. Additionally, by optimizing safety management systems and applying digital twin technology, a group project-based teaching model for industrial robotics courses is introduced. Standardized organizational management and a regular open-lab mechanism significantly improve equipment utilization and laboratory safety (Dauth, 2017). This provides replicable practical experience for application-oriented talent cultivation.

2. The Industry Education Integration Architecture of Industrial Robot Laboratory

The industrial robotics laboratory serves as a multifunctional platform, delivering practical training on robotics principles, university-wide elective courses, external operation/maintenance certification programs, and discipline-specific instruction for mechanical and automation majors. With escalating teaching demands and continuous hardware/software upgrades, the laboratory faces evolving management challenges requiring innovative solutions. As a pivotal hub for developing technical talent, it implements deep industry-academia collaboration by embedding authentic enterprise projects and technical standards into curricula, enabling students to master core competencies including teach programming, system integration, and operational management. Institutional coordination with government agencies ensures policy support and regulatory oversight for regional smart manufacturing initiatives. Through joint training programs, skill certifications, and collaborative R&D with enterprises, the laboratory optimizes resource sharing while enhancing workforce readiness. This synergistic model effectively bridges education, talent development, and industrial needs, delivering industry-aligned professionals and advancing smart manufacturing capabilities (Zhang, 2025). Figure 1 presents the laboratory's industry-education integration framework under the Modern Industrial College paradigm.

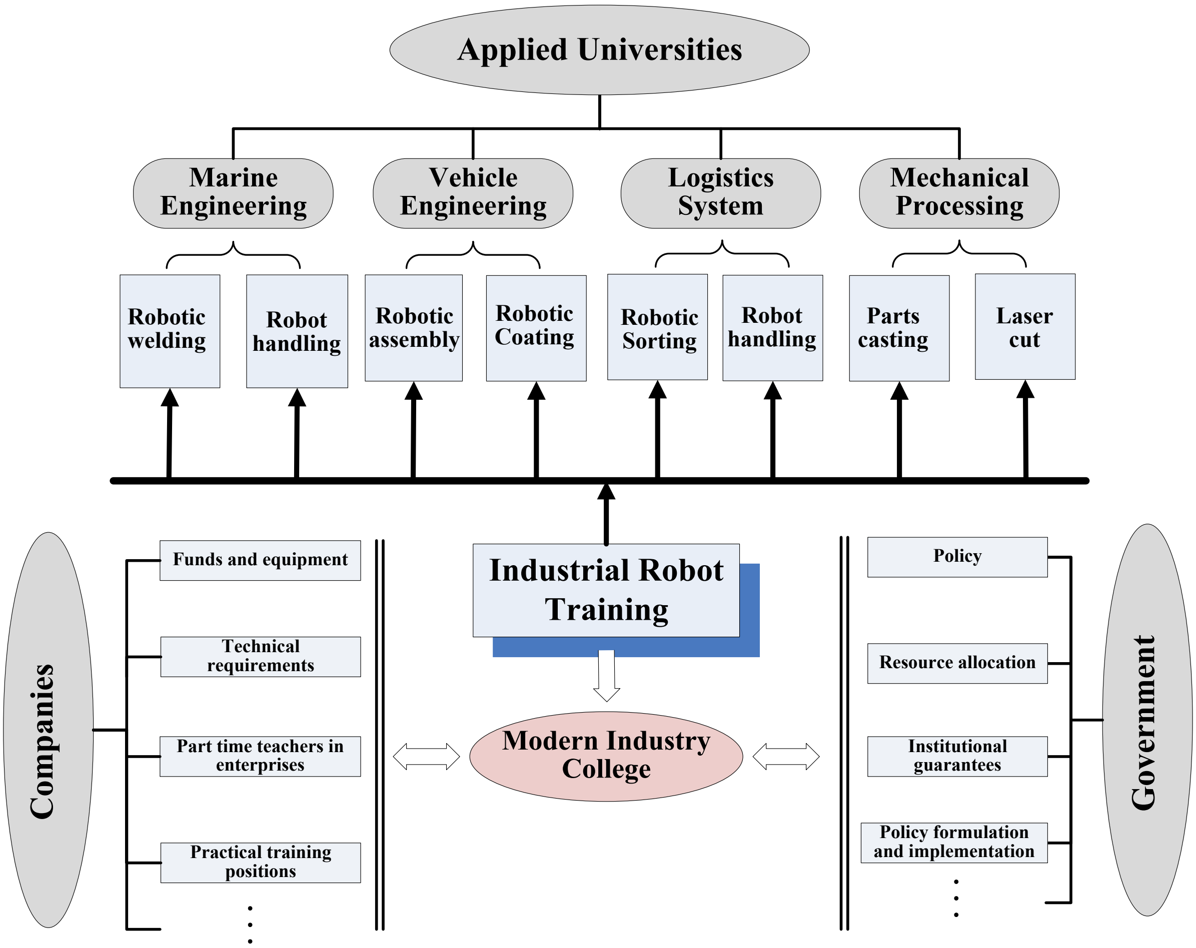

Figure 1. Industry-Education Integration Framework of Industrial Robotics Laboratory under the Modern Industrial College Model

2.1 Current Status and Existing Issues in Industrial Robotics Laboratory Management

Industrial Robotics Practical Education: Current Challenges and Management Issues Industrial robotics practical education differs significantly from traditional laboratory training courses, presenting unique management challenges for academic institutions. The adoption of new teaching models imposes higher requirements for safety management, equipment maintenance, and instructional organization. Taking the Industrial Robotics Laboratory at Beibu Gulf University as a case study, the following practical issues have been identified:

- Strong Practical Requirements with Insufficient Theoretical Foundation

Effective industrial robotics training relies heavily on hands-on operation and programming. However, the high cost of industrial robots, strict facility requirements, and insufficient supporting equipment hinder the implementation of diverse practical projects in application-oriented universities. Additionally, students' weak foundational knowledge in mechanisms and robotics principles often leads to operational errors, frequent fault code triggers, disrupted teaching schedules, increased maintenance costs, and higher laboratory operational pressures.

- Lack of Effective Industry-Academia Collaboration Models

The absence of standardized industry-academia collaboration mechanisms creates additional challenges. Industrial robots are highly integrated technological products, yet learning materials vary significantly across brands, with limited advanced programming resources available. Self-study materials (e.g., online resources) often do not align with the laboratory's equipment. Technical barriers differ between brands, while most labs suffer from single-brand setups and limited robotic tooling options, restricting their ability to support diverse practical projects.

- Disconnect Between Training Content and Industry Needs

Although application-oriented universities offer industrial robotics courses, the curriculum often lags behind real-world industry practices, leaving students inadequately prepared for job requirements. Industrial robotics integrates multidisciplinary knowledge (mechanical, control, and computer engineering) and is widely applied across industries. However, the lack of standardized protocols among different robot brands, coupled with insufficient laboratory equipment, makes it difficult to meet varied industry demands. Furthermore, complex issues arising during practical training often exceed the scope of conventional teaching resources, limiting post-class skill reinforcement.

- Inefficient Learning Process Management and Simplistic Assessment Methods

Current evaluation systems predominantly rely on summative assessments, such as practical exams or task completion rates, which fail to comprehensively measure students' integrated practical capabilities. Most institutions still adopt these one-dimensional evaluation approaches, neglecting finer learning process management and multidimensional competency assessment.

2.2 Integrating the Modern Industry-Academy Collaboration Model into Industrial Robot Laboratory Construction

With the rapid development of the smart manufacturing industry, the cultivation of industrial robotics professionals faces new challenges. Traditional laboratory construction tends to focus solely on fundamental skill training, resulting in a disconnect from actual industrial demands. The modern industry-academy collaboration model emphasizes deep integration between education and industry. Through joint laboratory development by academic institutions and enterprises, this approach significantly enhances the relevance and advancement of practical training. In industrial robotics laboratory construction, this model enables:

- Introduction of authentic enterprise project cases
- Adoption of cutting-edge technical standards
- Integration of industry expert resources
- Optimization of curriculum systems
- Strengthening of students' engineering competencies and innovative capacities

Simultaneously, leveraging the collaborative mechanisms of industry-academy institutes, laboratories can evolve into integrated platforms for: Technological R&D, Professional certification, Industry services. This facilitates precise alignment between talent development and industrial requirements. Looking ahead, we must further explore enduring collaboration mechanisms between academia and enterprises while advancing intelligent and open-access laboratory development to better support high-caliber application-oriented talent cultivation (Chen et al., 2019).

2.3 The Role of Enterprises in the Modern Industry-Academy Collaboration Model

The industry-academy collaboration for industrial robotics laboratory courses present in diverse forms. Through systematic analysis of current enterprise collaboration cases, three primary models emerge: Joint platform development model, co-created curriculum model, project-based immersive training model. These distinct approaches address varying educational needs and cooperation objectives, providing multifaceted pathways for cultivating industrial robotics professionals. Understanding their characteristics and applicability is crucial for institutions and enterprises to select optimal collaboration frameworks. The joint training platform development model is currently the most prevalent form of industry-academy collaboration for industrial robotics laboratory courses. This model features enterprises designing and providing training equipment that closely simulates actual industrial production to meet teaching requirements, while universities contribute venue space and basic infrastructure. Together, they collaboratively build dedicated hardware platforms for experimental teaching, enabling students to gain hands-on experience with industry-standard equipment and effectively bridging the gap between academic training and real-world industrial applications (Luo 2024).

The university's industrial robotics virtual simulation platform currently includes 11 KUKA industrial robot training platforms (10kg payload). Modular system architecture comprising: Articulated industrial robots, Intelligent handling robots (AGVs), Workstations, Inspection platforms, Welding simulation platforms. The platform design thoroughly considers teaching requirements, supporting: Specialized training in industrial robotics technology development, maintenance, and teaching operations. Integrated application training combining various industrial robots with machine tools and automated conveyor lines.

The platform notably incorporates multiple industrial robot types, including essential industrial robots, AGV intelligent handling robots, vision-based sorting robots, and gantry manipulators. Its modular design provides instructors with flexible configuration options for diverse training content, effectively supporting both individual skill development and comprehensive application capability building. Successful implementation of this model hinges on several critical factors: enterprises must bring extensive engineering expertise, pedagogical understanding, and the ability to adapt complex industrial systems for educational purposes; universities need to provide adequate space and infrastructure support; and both parties must establish long-term cooperation mechanisms for equipment maintenance and usage. However, the model does present certain limitations, most notably requiring substantial initial investment and ongoing updates to maintain technological relevance.

2.4 The Role of Government Agencies in the Modern Industry-Academy Collaboration Model

Government agencies serve as policymakers and resource coordinators, playing a pivotal role in promoting school-enterprise collaboration for industrial robotics laboratory courses through policy guidance, funding support, and platform establishment. Their involvement spans multiple dimensions: (a) quality supervision and evaluation, where educational authorities incorporate collaboration outcomes into university assessments, vocational certification bodies develop industrial robotics qualification systems, and quality inspection departments set training base standards; (b) international cooperation, including expert recruitment through the State Administration of Foreign Experts Affairs and cross-border knowledge exchange via initiatives like the "Sino-Foreign School-Enterprise Collaboration Platform for Smart Manufacturing". These multi-level interventions create an institutionalized, sustainable "government-guided, school-enterprise-driven" ecosystem that ensures standardization while providing policy and resource support.

3. Design of "Online-Offline Integration with Virtual-Physical Combination" Practical Teaching Model

To address key challenges in industrial robotics practical education—including equipment shortages, high safety risks, and low teaching efficiency—this paper proposes an "Online-Offline Integration with Virtual-Physical Combination" teaching model. The approach leverages virtual simulation platforms (e.g., RobotStudio, Visual Components) alongside physical industrial robot equipment to establish a four-stage progressive teaching framework: "foundational cognition → virtual training → physical operation → comprehensive innovation."

This innovative approach implements a three-phase operational framework: a. Online virtual simulation phase, where students master robotic fundamentals through digital twins and offline programming, reducing equipment wear; b. Offline hands-on phase for physical robot operation in safeguarded environments, converting virtual programs into real-world applications; c. Virtual-physical synergy phase enabling bidirectional data transfer for remote diagnostics. The model adopts a multidimensional evaluation system tracking process data, practical assessments, and project outcomes. Empirical results demonstrate 40% higher equipment utilization, 60% fewer safety incidents, and 25% increased excellence rates in competency assessments, proving its effectiveness in smart manufacturing education.

4. Innovation in Safety Management for Industrial Robotics Laboratories

To address prevalent safety challenges in industrial robotics laboratories—including high operational risks and insufficient protection. This study proposes an innovative "Prevention-Monitoring-Emergency Response" tripartite safety management system. Leveraging IoT and intelligent algorithms, the framework establishes multi-layered safeguards: a. An intelligent prevention system integrating RFID authentication, tiered operation authorization, and safety distance monitoring, where LiDAR detects personnel proximity to trigger automatic speed reduction or shutdown; b. A multimodal monitoring network deploying force/torque sensors, vision systems, and voice recognition to capture equipment vibration, noise, and trajectory data, achieving 92.3% anomaly detection accuracy through deep learning; c. A VR emergency training platform simulating 20 accident scenarios for immersive skill development in E-stop operation and troubleshooting. Empirical results demonstrate significant improvements: lab incident frequency reduced from 1.2 to 0.3 per 1,000 training hours, anomaly response time shortened to 0.5 seconds, and safety training efficiency increased by 40%. This intelligent sensing-virtual simulation integrated paradigm provides a robust technical solution for high-risk experimental environments.

5. Conclusion

This paper systematically investigates innovative development pathways for industrial robotics experimental teaching, establishing a progressive research framework encompassing "industry-academy collaboration model analysis → virtual-physical integrated teaching implementation → safety management mechanism innovation" to construct a novel experimental pedagogy system under the industry-education integration paradigm. Findings demonstrate that: (a) school-enterprise collaborative education mechanisms effectively address teaching resource shortages, (b) the "online-offline, virtual-physical" dual-mode teaching approach significantly enhances practical learning outcomes, and (c) intelligent safety management systems provide reliable protection for high-risk experimental environments. These innovations not only deliver replicable solutions for industrial robotics talent cultivation but also offer theoretical references for practical teaching reform in emerging engineering education. Future research should further explore AI applications in personalized instruction and adaptive assessment to continuously optimize the industrial robotics experimental teaching system.

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