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Research on Multi-Machine Collaborative Fault Perception and Dynamic Scheduling Response Method for Intelligent Production Lines on Higher Vocational PLC Training Platforms

Guifa Yao

Lingnan Institute of Technology, Guangzhou, 510663, China

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Abstract: The multi-machine collaborative operation of intelligent manufacturing production lines has put forward new requirements for higher vocational PLC training teaching, requiring a leap from single-machine control to system integration. At present, higher vocational PLC training platforms are mostly limited to the programming and debugging of a single PLC, lacking training functions for multi-station collaboration and fault response mechanisms. Oriented to the practical teaching needs of majors such as higher vocational electrical automation technology, this paper proposes a multi-machine collaborative fault perception and dynamic scheduling response method for intelligent production lines based on a PLC training platform. This method takes a multi-station PLC network as the hardware foundation and constructs a closed-loop control logic of "perception—decision—scheduling": it collects status signals of each workstation through distributed I/O and bus networks, uses fault identification logic to determine equipment anomalies and generate scheduling priorities; the master PLC performs task migration and path replanning for faulty workstations based on priority rules, realizing dynamic adjustment of multi-machine collaborative operations. Verification of this method on a training platform shows that it can effectively support comprehensive training projects such as multi-machine collaborative scheduling and fault response, and helps improve students' engineering practical ability at the system integration level.

1. Introduction

"Made in China 2025" has put forward higher requirements for the cultivation of intelligent manufacturing talents. Teaching in the field of industrial automation needs to achieve the organic integration of general education, professional quality, practical innovation, and individualized development. As the core equipment of industrial automation control, PLC-related courses are core courses for majors such as higher vocational electrical automation technology and electromechanical integration technology[1], and the practical training links account for a relatively large proportion of the entire course. However, existing PLC training benches mostly aim to cultivate primary-level PLC technical talents, with the main function of providing control

technology training centered on a single PLC. They lack the function of using communication buses to build PLC networks for networked control skill training, making it difficult to meet the needs of cultivating advanced PLC technical talents[2].

With the advancement of Industry 4.0, the application scope of automation equipment has gradually expanded, placing higher demands on professional skilled talents. There is an urgent need for talents who master PLC network-integrated automation technology to meet the needs of industrial development. In intelligent production line scenarios, multiple devices need to work collaboratively. Once a device fails, the system needs to quickly perceive the fault and dynamically adjust the scheduling strategy to maintain the overall operating efficiency of the production line. This collaborative control capability of "fault perception—dynamic scheduling" is precisely a relatively weak link in current higher vocational PLC training teaching[3].

Aiming at the teaching needs of higher vocational PLC training platforms, this paper proposes a multi-machine collaborative fault perception and dynamic scheduling response method. Based on PLC network communication, this method constructs a distributed fault perception mechanism and a priority-based dynamic scheduling strategy, aiming to enable the training platform to possess the teaching functions of multi-machine collaboration and fault response[4], and to provide methodological support for system-level comprehensive training in higher vocational electrical automation majors.

2. Relevant Research Basis

2.1 Technological Evolution of PLC Training Platforms

The design of existing PLC training benches has undergone an evolution from stand-alone to networked systems. Early training benches centered on a single PLC, mainly meeting the needs of basic programming and debugging teaching. With the improvement of teaching requirements, comprehensive training devices based on PLC network automation have emerged, organically combining multiple networks and multiple models of PLCs to build PLC network automation skill training functions[5]. They adopt an open design and can flexibly select various components according to engineering site processes and control requirements. Such training devices are usually equipped with Profinet networks, Profibus-DP networks, and hybrid networks to realize multi-model and multi-network PLC communication training functions. At the same time, PLC teaching experiment methods for multi-person collaborative simulation of industrial system control processes have also appeared. Through the teacher station system, complex control tasks are decomposed and distributed to each student station node, supporting multiple students to collaboratively complete complex control tasks[6].

2.2 Research Progress in Multi-Machine Collaboration and Fault Perception

In the industrial field, research on multi-machine collaborative control and fault perception mainly focuses on scheduling optimization and fault-tolerant control of production systems. Aiming at the typical disturbance factor of machine failure, some studies have designed a two-layer encoding structure based on process sequencing and machine allocation for dynamic scheduling. In the field of UAV collaborative task planning, some studies have proposed a task reallocation method based on an improved discrete particle swarm optimization algorithm combined with the Hungarian algorithm, using the Hungarian algorithm for rapid rearrangement of UAV formations under faults[7]. In the field of carrier aircraft scheduling, some studies have fully considered the impact of system disturbances such as faults and proposed a two-level interactive collaboration mechanism based on the contract net protocol to improve collaboration efficiency among multiple

agents. In addition, for fault detection of discrete event systems, some studies have proposed PLC-based process observation and fault detection implementation methods.

2.3 Deficiencies of Existing Research and Positioning of This Paper

Existing research provides a foundation for this paper in two aspects: first, the technical solution of PLC networked training platforms is relatively mature, providing hardware conditions for multi-machine collaborative training; second, multi-machine collaborative scheduling and fault perception have been explored in industrial scenarios[8]. However, research that integrates fault perception and dynamic scheduling response mechanisms into PLC training platforms to serve higher vocational practical teaching is still rare. The positioning of this paper is to design a lightweight fault perception and scheduling response method using a training platform as a carrier, so that it can operate stably in teaching scenarios while possessing sufficient engineering authenticity to cultivate students' system thinking.

3. Method Design

3.1 System Architecture

This method is implemented based on a multi-station PLC network training platform, and the system architecture is divided into three layers[9].

The device layer consists of several workstations. Each workstation contains a slave PLC, actuators (such as pneumatic manipulators, conveyor belts, servo motors, etc.), and sensors (photoelectric switches, limit switches, encoders, etc.). Material flow between workstations is realized through conveyor mechanisms.

The control layer consists of a master PLC responsible for global scheduling decisions. The master PLC and each slave PLC exchange periodic data through Profinet or Profibus-DP buses. The master station reads the status words (running/fault/idle) of each station and issues scheduling instructions to each station.

The perception layer consists of distributed I/O modules and a sensor network, responsible for collecting equipment status signals of each workstation, including motor current, air pressure values, position feedback, etc., which are preprocessed by the slave PLC and uploaded to the master PLC.

3.2 Fault Perception Mechanism

The core of fault perception lies in identifying anomalies from equipment status data. This method adopts rule-based status judgment logic to adapt to the computing capability of PLCs and the requirements for comprehensibility in teaching scenarios[10].

Fault type classification. Possible faults in the training platform are divided into three categories: equipment faults (such as motor overload, insufficient air pressure, sensor failure), process faults (such as material jamming, process timeout), and logic faults (such as interlock conditions not satisfied). Different types of faults correspond to different perception signals and processing priorities.

Status monitoring and judgment. Each slave PLC periodically collects key status parameters of its own workstation and compares them with preset normal operating ranges. When parameters exceed thresholds or timing logic is not satisfied, the slave PLC sets the status word of its workstation to "abnormal" and marks the fault type code, sending it to the master PLC through the bus. This distributed judgment method can reduce the computing burden of the master PLC and improve the response speed of fault perception.

Fault confirmation and debouncing. To avoid false alarms caused by instantaneous disturbances, a continuous sampling confirmation mechanism is adopted: only when the abnormal state continuously maintains for several scanning cycles (such as 3 cycles) is it formally determined as a fault and triggers a scheduling response.

3.3 Dynamic Scheduling Response Strategy

After receiving the fault signal, the master PLC executes dynamic scheduling decisions according to the fault type and the current production task status.

Priority determination. Each workstation is assigned a dynamic priority, which is jointly determined by the functional importance of the workstation, the urgency of the current task, and the scope of fault impact. The fault priority of key workstations (such as equipment that is the only one capable of completing a certain process) is the highest and requires immediate response; faults of auxiliary workstations can adopt a degradation strategy and be temporarily bypassed without interrupting the main process.

Task migration and replanning. According to the priority determination result, the master PLC executes one of the following scheduling actions: if the faulty workstation can be skipped, subsequent tasks are directly routed to the next workstation and the conveyor path is adjusted; if the function of the faulty workstation can be replaced by a backup workstation, the pending tasks of that workstation are migrated to the backup workstation and the buffer queues of each station are updated; if the fault makes the current batch unable to continue, the entire line is paused, a shutdown instruction is generated, and fault location information is output for students to troubleshoot.

Teaching visualization of scheduling response. On the human-machine interface (HMI) of the master PLC, the status of each workstation (normal/fault/offline), the current scheduling decision, and changes in system throughput are displayed in real time. Students can observe the scheduling process after a fault occurs through the HMI and understand the closed-loop logic of "perception—decision—adjustment."

3.4 Connection with the "5+3" Innovation and Entrepreneurship Model

The design of this method fully considers the connection with the "5+3" innovation and entrepreneurship teaching model. A 5-person team can respectively assume roles such as slave programming, master scheduling, fault simulation, status monitoring, and report writing; the three project levels correspond to different scheduling complexities: basic projects involve only single-point fault response, expanded projects involve multi-workstation collaborative scheduling, and innovation and entrepreneurship projects require students to design fault scenarios and scheduling strategies themselves, realizing a capability leap from "use" to "creation."

4. Training Verification and Effect Analysis

4.1 Training Platform Configuration

The verification environment is based on the PLC network automation training platform of a higher vocational college. The platform is equipped with several Siemens S7-1200 series PLCs, of which 1 serves as the master PLC and 3 serve as slave PLCs to control the conveyor belt, manipulator, and inspection workstation respectively, realizing communication through the Profinet network. The HMI adopts a Siemens Comfort Panel for status display and scheduling monitoring.

4.2 Fault Scenarios and Response Testing

The following typical fault scenarios are designed for testing:

Scenario 1: Single-workstation motor overload. The conveyor motor of the inspection workstation causes current to rise due to material jamming. The slave PLC determines it as an equipment fault within 3 scanning cycles, and the status word is set. After receiving the fault signal, the master PLC determines that the priority of this workstation is high, immediately suspends subsequent materials from entering the workstation, routes the materials that have already arrived to the backup buffer area, and outputs fault location information to the HMI.

Scenario 2: Sensor signal loss. The limit switch signal of the manipulator workstation is interrupted. The slave PLC detects that the signal continues to be at a low level and does not conform to normal timing, determining it as a sensor fault. The master PLC determines based on priority that the impact scope of this fault is limited and executes a degradation strategy: suspends the precise positioning function of the manipulator and switches to coarse positioning with manual confirmation to maintain basic operation of the production line.

Test results show that the fault perception mechanism can complete anomaly determination within 3-5 scanning cycles, and the scheduling response is triggered within 1 scanning cycle of the master PLC. The overall system response time is within an acceptable range, meeting the real-time requirements of training teaching.

4.3 Teaching Effect

This method was applied to the "PLC Comprehensive Application Training" course of the electrical automation technology major, with a 3-week training cycle. Students participated in 5-person teams, respectively assuming roles such as slave programming, master logic debugging, fault injection and verification, status monitoring, and document organization.

From the perspective of teaching effect, this method integrates the originally isolated single-station programming exercises into system-level collaborative tasks. During debugging, students need to understand the data interaction logic of multi-station communication, rather than merely the programming instructions of a single PLC. The introduction of fault perception and scheduling response enables students to come into contact with the key link of "exception handling" in industrial sites, making up for the deficiency of traditional training that "only practices normal processes but not abnormal responses."

A questionnaire survey after the training showed that 85% of students believed that this method helped them understand the operating mechanism of multi-machine collaborative systems, and 78% of students indicated that they had a clearer understanding of fault response logic.

5. Conclusion

This paper proposes a multi-machine collaborative fault perception and dynamic scheduling response method suitable for higher vocational PLC training platforms. Based on a multi-station PLC network, this method constructs a closed-loop control logic of "distributed perception—centralized decision-making—dynamic scheduling," enabling the training platform to possess the teaching upgrade capability from single-machine control to system collaboration. Verification results show that this method can effectively support comprehensive training projects such as multi-machine collaborative scheduling and fault response.

The limitations of this method lie in: fault perception adopts rule-based judgment logic, and its ability to identify complex coupled faults is limited; the degree of optimization of the scheduling strategy is not yet sufficient to cope with large-scale multi-fault concurrent scenarios.

References

[1] Ma L ,Zhang W ,Guo L , et al. Virtual Simulation of Intelligent Production Lines Using Unity3D: Development and Educational Evaluation[J].Computer Applications in Engineering Education,2026,34(4):e70224-e70224.

[2] Li W ,Li H . Dynamic Scheduling and Collaborative Control of Intelligent Production Lines Based on Proximal Strategy Optimization[J].Journal of Advanced Manufacturing Systems,2026,(prepublish)

[3] Lele Q . Exploration of PLC Application Technology Course Practical Training Teaching Design[J].Education Reform and Development,2025,7(4):77-83.

[4] Meiqin L , Mingshuo F ,Shuai L , et al. Enhancing Programmable Logic Controller Teaching in Vocational Colleges: Strategies for Deeper Understanding and Practical Application[J].Journal of Contemporary Educational Research,2024,8(12):9-13.

[5] Tian F, Chen J, Cao Z. Development of Teaching Platform for Electrical Control and PLC Training Courses[J].International Core Journal of Engineering,2024,11(1):189-198.

[6] Zhang Q, Li H, Shen S , et al. Multi-objective optimization of the mixed-flow intelligent production line for automotive MEMS pressure sensors[J].Applied Intelligence,2024,55(1):72.

[7] Zhang Y ,Zhang G ,Deng A , et al. Research and Practice of Online Course Resource Construction Based on PLC Technology Application Training[J].Curriculum and Teaching Methodology,2022,5(12)

[8] Yahya S , Jadmiko W S , Wijayanto K , et al. Design and implementation of training module for control liquid level on tank using PID method based PLC[J].IOP Conference Series: Materials Science and Engineering,2020,830(3):032065.

[9] Zhu J J. Electrical Control Technology and PLC Course Teaching Reform Strategy[J].Procedia Computer Science,2020,166(C):301-304.

[10] Sunomo , Asmara A . Home-made PLC laboratory training set for limited budget vocational education institution[J].IOP Conference Series: Materials Science and Engineering,2019,535(1):012025 (4pp).