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Artificial Intelligence and Smart Education Empower the Safe and Open Management of Comprehensive Laboratories

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Abstract: As a core component of the teaching and research system in universities, comprehensive laboratories serve as key carriers with dual attributes of being both "practical teaching platforms" and "research innovation platforms". However, with the expansion of their construction scale and accelerated reforms in recent years, issues related to safety and open management have become prominent. This article focuses on exploring and researching how artificial intelligence and smart education can empower the safe and open management of comprehensive laboratories in universities. It aims to help address various safety management issues faced by open laboratories, improve the safety management level of laboratories and the work efficiency of administrators, and provide technical support for laboratories to move towards intelligence.

Keywords: Artificial Intelligence; Smart Education; Laboratory Safety; Laboratory Management

1. Introduction

Comprehensive laboratories in higher education institutions function as multifaceted and distinctly interdisciplinary core practical platforms. They encompass a wide array of academic fields and experimental techniques, and their notable characteristics—disciplinary integration, technological diversity, and flexibility in experimental projects—render them essential links between theoretical instruction and scientific innovation. These laboratories provide students with opportunities to transform knowledge into practical skills while supporting educators and researchers in conducting cutting-edge scientific inquiries. Additionally, they serve as exceptional mediums for dismantling disciplinary barriers and fostering interdisciplinary collaboration, thereby establishing a solid foundation for innovative teaching methodologies and addressing critical research challenges. This, in turn, injects robust momentum into the overall enhancement of research capabilities within universities. However, as institutions of higher learning continue to increase their investments in the development of comprehensive laboratories and accelerate reform initiatives, the issues surrounding safe and open management of these facilities have become increasingly pronounced. Under traditional management models, factors such as complex personnel turnover, diverse equipment types, and variable experimental processes present significant challenges to safety risk identification, real-time dynamic supervision, and emergency response. Consequently, these challenges have emerged as critical bottlenecks that hinder the high-quality operation of laboratories and compromise the safe and orderly conduct of educational and research activities[1-3].

Artificial Intelligence, or AI, is an interdisciplinary field that integrates various domains, including computer science, cybernetics, information theory, linguistics, neurophysiology, psychology, mathematics, and philosophy[4]. As modern science and technology continue to evolve, artificial intelligence is spearheading a new wave of technological and industrial revolutions with its formidable capabilities in data processing, intelligent analysis, and autonomous decision-making. This transformation profoundly alters human production, lifestyle, and learning methods, propelling society into an era characterized by human-machine collaboration, cross-disciplinary integration, and co-creation and sharing. The integration of artificial intelligence technologies into the educational system has catalyzed significant changes within the field, shaping a realistic vision of smart education and fostering

a new ecosystem of education driven by human-machine synergy[5]. In this context, smart laboratories emerge as a concept grounded in distributed collaborative planning, utilizing laboratories as foundational elements and relying on intelligent devices. By integrating information technology, machine vision, and pattern recognition—key components of artificial intelligence—these laboratories aim to create a cohesive ecosystem that combines operational systems, middle ground management, and intelligent forecasting[6].

Therefore, this paper will explore and examine how artificial intelligence and smart education can flexibly empower the safe and open management of comprehensive laboratories in higher education. It is hoped that this research will contribute to addressing the various safety management challenges faced by open laboratories and provide technological support for advancing laboratories toward greater intelligence.

2. Empowering Comprehensive Laboratory Safety and Open Management through Artificial Intelligence

2.1 Establishing Intelligent Monitoring and Real-Time Warning Systems

2.1.1 Intelligent access control for laboratories

In comprehensive laboratories within higher education institutions, automated access control based on permissions, occupancy limits, and environmental safety is a crucial measure for ensuring the security and proper functioning of the laboratory. The permission management system allows for flexible configuration and adjustment of personnel access rights, employing various identity verification technologies such as card swiping, fingerprint recognition, palm print recognition, facial recognition, and password entry, or combinations thereof. This enhances the accuracy and security of identity verification, ensuring that only individuals who have undergone training and assessment and have been granted the appropriate permissions can access specific areas or utilize designated equipment. This approach mitigates the risk of identity impersonation and elevates the overall management standards of the laboratory.

2.1.2 Intelligent monitoring of personnel behavior

Intelligent recognition of personnel behavior encompasses behavior identification, attire verification, and intrusion detection. By leveraging computer vision and machine learning technologies, the system continuously monitors whether laboratory personnel exhibit any abnormal behaviors—such as running, fighting, or fainting—while also ensuring that experimental procedures are conducted correctly. Additionally, it verifies whether personnel are properly wearing protective gear and monitors for unauthorized use of laboratory instruments or intentional damage to equipment. The system also keeps a vigilant eye on whether individuals enter areas designated for the storage of flammable or explosive materials, high-pressure equipment, valuable experimental apparatus, or critical experimental zones. Upon detecting any predefined abnormal behaviors or situations, the system automatically issues alerts, promptly notifying laboratory management personnel for immediate assessment and intervention to address potential emergencies.

2.1.3 Intelligent environmental monitoring

Intelligent environmental monitoring involves the assessment of various factors, including temperature and humidity, air quality, light intensity, and the concentration of smoke and combustible gases. The monitoring center utilizes data analysis algorithms to integrate and analyze data from multiple sensors in real time. By employing machine learning algorithms, the system establishes environmental models that predict trends in these parameters. When environmental conditions exceed predefined thresholds, the system automatically activates appropriate control devices. For example, if temperature and humidity levels become excessive, the system can engage air conditioning or dehumidifiers to restore balance. In cases where harmful gas concentrations exceed safe limits or in the event of a fire, the system can initiate ventilation systems for air exchange or activate fire suppression systems, promptly notifying laboratory management personnel for immediate action. Additionally, if light levels are too high, the system can automatically close curtains or dim the lights. Furthermore, intelligent monitoring of doors, windows, and utilities can be implemented, allowing laboratory management to receive timely updates on the laboratory's real-time conditions through a scheduled feedback system.

2.1.4 Intelligent equipment status monitoring

The monitoring platform acts as the core of the

entire surveillance system, offering functionalities such as data display, alarm management, report generation, historical data retrieval, and equipment management. Management personnel can access the platform to monitor equipment reservation statuses, operational conditions, parameter trends, alarm notifications, and scheduled maintenance alerts in real time. This facilitates a comprehensive understanding of the laboratory equipment's overall status. Additionally, the platform can automatically issue alarm notifications based on predefined parameters, alerting laboratory personnel to promptly address equipment malfunctions and anomalies while also reporting these issues to laboratory management for further action.

2.1.5 Intelligent monitoring of reagents and equipment status

Intelligent monitoring of reagents and equipment status is a pivotal aspect of smart management in university laboratories. By leveraging Internet of Things (IoT) technology, sensors, and data analytics, this system enables comprehensive lifecycle monitoring of reagents and equipment, thereby ensuring experimental safety, enhancing management efficiency, and reducing resource wastage. For instance, it records real-time information such as reagent names, specifications, batch numbers, manufacturers, expiration dates, and storage locations (e.g., specific shelves in refrigerators or drawers in chemical cabinets), creating an electronic ledger. Utilizing QR codes, barcodes, or labels allows for a unique identification system, enabling swift scanning to access detailed information about reagents, including temperature and humidity monitoring, gas concentration levels, usage tracking, inventory alerts, expiration warnings, risk management, and automatic notifications regarding storage restrictions. Additionally, it captures real-time data on equipment names, models, purchase dates, and departments, linking them to unique identification tags while managing records of usage, borrowing, and online reservation requests.

2.1.6 Intelligent robots for automated inspections

Intelligent patrol robots hold significant value in comprehensive university laboratories, enhancing safety measures and management efficiency. Equipped with high-definition and infrared cameras, these robots autonomously navigate predetermined patrol routes within the laboratory, providing comprehensive video surveillance and real-time monitoring of environmental parameters. They conduct continuous 24-hour patrols and immediately alert personnel in the event of any anomalies.

Firefighting robots in the laboratory employ a variety of sensors to accurately detect environmental hazards, including flames, rare gases, and toxic substances, and respond appropriately during critical situations. Upon detecting a fire source, the robot's controller directs the mobility module towards the fire, and when the flame sensor confirms the presence of flames, the controller activates the robotic arm and fire extinguisher to extinguish the fire[7].

2.2 Establishing a Risk Assessment and Prediction System

The intelligent monitoring system comprises various sensors and devices that generate vast amounts of data in real time, encompassing personnel behavior, environmental parameters, equipment operational status, and the condition of reagents and instruments—collectively referred to as multi-source heterogeneous data. The initial step involves the collection of this data, followed by the integration of diverse sources into a centralized data warehouse or distributed file system for subsequent analysis and processing. The results of this analysis should be presented in an intuitive and visually engaging manner, enabling management personnel to swiftly grasp the overall status of the laboratory and make timely decisions. Furthermore, by leveraging machine learning and deep learning techniques, the system can facilitate anomaly detection, correlation analysis, and predictive analytics, while also implementing a comprehensive multi-tiered alert mechanism to proactively mitigate potential risks before they escalate.

3. Empowering Comprehensive Laboratory Safety Management through Smart Education

3.1 Intelligent Safety Training and Assessment System

By leveraging online platforms and virtual simulation technologies inherent in smart education, an intelligent safety training and assessment system for laboratories can be established, encompassing comprehensive data collection and analysis throughout the learning process. Prior to entering the laboratory, students

are required to engage in online video training covering essential topics such as laboratory safety regulations, equipment operation protocols, and the handling of hazardous chemicals. Upon completion of their studies, administrators can autonomously create assessments from a question bank within the system, allowing participants to take examinations online and complete their evaluations, with results securely stored by the system[8]. Only students who pass the assessments will be granted access to the laboratory, thereby ensuring that all personnel possess fundamental safety knowledge and operational skills from the outset. This approach effectively enhances the safety awareness of both faculty and students, fostering a robust culture of safety within the laboratory environment[9].

3.2 Immersive VR/AR Training Scenarios

By integrating computer algorithms with machine learning, immersive VR/AR training scenarios can be generated, focusing on foundational laboratory safety, equipment operation, and emergency incident management. The design should feature a user-friendly interface and gesture-based controls, facilitating quick adaptation for students. Additionally, a variety of interactive elements, such as clickable buttons and virtual objects that can be manipulated, should be incorporated to enhance student engagement. Furthermore, the system should include error prompts and a scoring mechanism, utilizing haptic feedback and auditory cues to provide students with immediate, tangible feedback on their actions. This allows for timely adjustments in their operational behavior, ultimately improving the effectiveness of the training experience.

3.3 Establishing a Dynamic Permission Management and Reservation System

The system autonomously allocates varying levels of laboratory access based on multidimensional data, including students' grade levels, fields of study, research needs, and safety assessment scores. Simultaneously, students can utilize an online reservation platform to book laboratory time and equipment according to their specific requirements. The platform employs intelligent algorithms to automatically review reservation requests, taking into account factors such as laboratory usage, equipment maintenance schedules, and personnel capacity limits, and subsequently provides feedback on the reservation outcomes. Upon successful booking, the system sends reminders to students via SMS or app notifications, ensuring they arrive at the laboratory punctually. Should any individual fail to utilize their reserved time on three or more occasions, the system will implement appropriate measures in accordance with the laboratory equipment usage policies, effectively regulating the time students and faculty spend in the laboratory and facilitating unified management.

3.4 Remote Guidance and Collaborative Experiments

Leveraging remote teaching technologies inherent in smart education, the system enables remote guidance and collaborative experimentation within the laboratory. During experimental procedures, should students encounter challenges, they can seek assistance from specialized laboratory instructors through video calls or online chat. Instructors can remotely observe students' experimental activities, providing real-time guidance and recommendations to address any difficulties faced during the experiment, with the system automatically recording these interactions for future reference in similar situations. Furthermore, for interdisciplinary and geographically dispersed experimental projects, students and instructors from different regions can engage in remote collaborative experiments via a virtual laboratory platform. In this immersive environment, participants can collectively operate experimental equipment, observe phenomena, and analyze data, transcending temporal and spatial constraints to enhance the efficiency of experimental teaching and research.

3.5 Intelligent Safety Alerts and Knowledge Dissemination

3.5.1 Multi-source data-driven intelligent triggers

Behavioral Data Triggers: For instance, if a camera detects a student measuring reagents without wearing gloves, the system will promptly issue a notification through the laboratory screen and the collection app, stating, “Please don your gloves immediately to prevent splashing and potential harm from the solution”. Simultaneously, this behavior will be recorded,

providing a basis for targeted safety knowledge dissemination in the future.

Environmental Data Triggers: For example, if a gas sensor identifies that the concentration of toxic gases in the chemistry laboratory exceeds safe levels, the system will not only activate an audible and visual alarm but also push information regarding symptoms of toxic gas exposure and emergency response measures to the faculty and students present. Additionally, guidelines for ventilation procedures will be displayed in a scrolling format on the laboratory's electronic screen.

Equipment Data Triggers: For large precision instruments, when abnormal fluctuations in parameters such as current or temperature are detected, indicating a potential malfunction, the system will send an alert to the personnel using the equipment. This alert will include a warning about the equipment's irregularities, along with a troubleshooting manual and solutions for common issues, thereby assisting faculty and students in promptly addressing the situation and preventing safety incidents.

3.5.2 Layered and categorized push notifications

Based on the roles of teachers and students, as well as their professional fields and the level of their mastery of safety knowledge, the notifications are stratified. New students are mainly pushed basic content such as laboratory basic safety regulations and the use of protective equipment; researchers focus on advanced knowledge such as high-risk experimental operation norms and cutting-edge safety technologies. At the same time, according to the discipline classification, relevant knowledge or safety operation knowledge is pushed to ensure the targeted nature of the notifications.

3.5.3 Scenario-based associated push notifications

Based on scenarios such as environment, operation, location, and time, precise safety prompts or small pieces of knowledge are triggered. When students are conducting distillation experiments in the laboratory, the system automatically pushes safety key points for distillation operations and the usage norms for flammable reagents; if a small-scale fire simulation drill is conducted, knowledge such as the selection method for fire extinguishers and the planning of fire escape routes is immediately pushed, allowing knowledge learning to be closely integrated with actual scenarios and enhancing learning effectiveness.

3.5.4 Interactive learning

Regularly set up online question-and-answer sessions, knowledge competitions, and simulation exercises. After the knowledge is pushed, initiate "Lab Safety Knowledge Quick Questions", where teachers and students participate in answering, and the system provides immediate feedback on answer explanations and ranking of scores; regularly organize online safety simulation drills, such as virtual fire escape and handling of chemical leaks, to enhance the practical ability and emergency response speed of teachers and students.

4. Application of Blockchain Technology

Blockchain technology is a platform that offers secure storage and sharing of experimental data. It has advantages such as decentralization, immutability, transparency, security, and programmability. Once experimental data is recorded on the blockchain, it cannot be tampered with or deleted, ensuring the credibility and integrity of the data. It provides an innovative solution for the secure storage of IoT data and effectively overcomes many shortcomings of traditional storage methods [6, 10].

5. Conclusion

The construction and management of university laboratories play a crucial role in enhancing students' experimental skills, cultivating their innovation abilities, and improving the school's educational level, teaching quality, and research capabilities. The traditional management model relies on manual inspections and experience-based judgments, which is difficult to meet the dynamic and diversified laboratory safety requirements. However, this paper systematically proposes an innovative concept of integrating artificial intelligence with smart education, and the constructed integrated system realizes the transformation of safety management from passive response to proactive prevention through real-time data perception, intelligent analysis and decision-making, and precise knowledge delivery, creating a favorable environment for students' learning and research.

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