Design and Implementation of an Intelligent Laboratory Management System Based on UWB Technology

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***Abstract*—In recent years, the rapid development of educational informatization and the widespread adoption of Internet of Things (IoT) technologies have accelerated the transformation of university laboratories toward intelligent management. However, traditional laboratory management systems still suffer from limited automation, insufficient safety mechanisms, and poor real-time responsiveness. To address these issues, this study proposes an intelligent laboratory management system based on Ultra-Wideband (UWB) technology, which offers high-precision positioning and low-latency communication. The proposed system integrates IoT-based functionalities across six core modules, including access control, asset management, environmental monitoring, and user management. By deploying UWB tags and sensors throughout the laboratory environment, the system enables real-time tracking of personnel and equipment, automatic activation of laboratory devices, and intelligent safety alerts. A pilot deployment in three university laboratories demonstrated improvements in access efficiency, energy conservation, equipment security, and user satisfaction. The results validate the system's effectiveness in enhancing intelligent laboratory management and provide a scalable model for future smart educational infrastructure.**

***Keywords*—UWB; intelligent management; laboratory management system; IoT**

I. Introduction

Laboratories are a critical component of higher education institutions, serving as essential venues for transforming theoretical knowledge acquired in the classroom into practical skills. They play a vital role in cultivating students' hands-on abilities and fostering innovation. As the core infrastructure for practical teaching, the quality of laboratory hardware and software construction directly influences the effectiveness of talent development. Enhancing equipment configuration and implementing intelligent management systems are fundamental for building world-class universities and maintaining educational competitiveness.

With the rapid advancement of educational informatization and the increasing integration of the IoT, universities are transitioning towards intelligent laboratory environments. These environments aim to provide secure, efficient, and automated support for teaching and experimentation. While technologies such as RFID, Bluetooth Low Energy (BLE), and Wi-Fi have been explored for functions like access control, equipment tracking, and environmental monitoring, existing systems often operate in isolation, lack real-time responsiveness, and suffer from accuracy and reliability issues. Many laboratories continue to rely on traditional management methods, which are inefficient and prone to human error.

Although various technologies have been applied in laboratory management, most existing solutions remain fragmented and fail to offer integrated, real-time control across personnel, assets, and environmental variables. Moreover, the potential of UWB technology—a wireless communication protocol known for its high-precision positioning and robustness against interference—has not been fully leveraged in comprehensive university laboratory management systems. This study aims to address this research gap by proposing and implementing a UWB-based intelligent laboratory management system that unifies access control, asset tracking, environmental linkage, and safety monitoring under a centralized IoT architecture.

The remainder of this study is organized as follows: Section II reviews related works on laboratory management systems and the application of positioning technologies. Section III outlines the current challenges in university laboratory environments. Section IV describes the design and architecture of the proposed UWB-based intelligent laboratory management system, including hardware and software components. Section V presents the implementation, and Section VI presents the pilot deployment of the system in three university laboratories, along with observed effectiveness. Section VII discusses the results and limitations. Section VIII concludes the study and outlines directions for future research.

II. Related Work

A. Laboratory Management Systems

With the increasing demand for efficiency and safety in laboratory operations, various digital laboratory management systems have been developed. Traditional approaches often rely on QR code scanning, RFID tags, or BLE beacons to manage asset inventory and personnel access. While these systems offer partial automation, they are limited by factors such as short detection range, interference susceptibility, and a lack of real-time integration [1]. Additionally, many systems operate in isolation, with fragmented control over equipment, environmental conditions, and user access.

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B. Indoor Positioning Technologies

Accurate indoor positioning is critical for enabling real-time management functions in smart laboratories. Technologies such as Wi-Fi, RFID, and BLE have been widely studied and implemented. However, their performance in complex indoor environments is often degraded due to signal attenuation, multipath effects, and limited spatial resolution. In contrast, UWB technology provides centimeter-level positioning accuracy, low latency, and robust resistance to interference. According to recent studies, UWB is increasingly adopted in indoor real-time location systems (RTLS), making it a promising alternative for precise device and personnel tracking in enclosed environments [2].

C. Integrated IoT-Based Smart Systems

The integration of IoT technologies has expanded the capabilities of laboratory management, allowing for centralized monitoring and control of diverse systems such as access control, lighting, environmental sensing, and equipment usage. Prior research has explored IoT frameworks applied to educational or industrial laboratories, but many of these solutions are limited to single-function implementations, such as environmental monitoring or smart lighting. Few studies have successfully implemented a comprehensive system that integrates access control, environmental regulation, asset tracking, and safety alerting within a unified smart platform [3].

D. Research Gap

Although UWB and IoT technologies have been individually applied in laboratory and industrial contexts, the combination of these technologies into a unified, intelligent laboratory management platform remains underexplored. Existing systems often lack integrated architecture and fail to leverage the high-precision capabilities of UWB for dynamic spatial control and automation. This study aims to address this gap by designing and implementing a fully integrated laboratory management system that utilizes UWB and IoT technologies to enhance laboratory efficiency, safety, and user experience in a university environment [4].

III. Current Status and Challenges in the Intelligent Development of University Laboratories

However, laboratory management in universities still faces several challenges:

a) Inconvenient and inefficient access control: Most current access control systems rely on password verification, card-based identification, or biometric authentication. These methods present issues such as complex information input procedures, password leakage risks, and card loss. Although biometrics enhance security, limitations in recognition algorithms and accuracy often necessitate secondary verification via passwords or cards, negatively impacting user experience [5].

b) Lack of real-time and efficient asset management: Current asset management systems in university laboratories mainly depend on QR codes, RFID, or BLE technologies. QR codes require close-range scanning, RFID suffers from limited precision and high costs, while BLE offers longer-range detection but is vulnerable to signal interference. These traditional methods fall short in supporting real-time tracking and intelligent monitoring of laboratory equipment [6].

c) Limited intelligent management capabilities: Due to limited personnel, many universities have adopted basic intelligent control systems, such as automated lighting and HVAC (Heating, Ventilation, and Air Conditioning). However, these systems often operate in a static or rigid manner, lacking the ability to dynamically adjust based on actual usage scenarios, which limits energy efficiency and overall effectiveness [7].

d) Inadequate safety management mechanisms: Many laboratories lack effective early-warning and safety alert mechanisms. Real-time monitoring of personnel is often absent, and the systems are unable to prevent unauthorized individuals from entering high-risk areas, posing potential safety hazards [8].

To address the aforementioned challenges, this study proposes an intelligent laboratory management system based on UWB technology, leveraging its high-precision positioning and high-speed data transmission capabilities. In terms of access control, the system enables precise management of personnel entry by allowing only individuals carrying authorized UWB tags to access the laboratory. For asset management, UWB tags are affixed to valuable equipment, enabling the system to track the real-time location and usage trajectory of devices, thereby preventing misplacement or loss and enhancing asset security. In intelligent management, real-time acquisition of personnel and equipment location data through UWB technology facilitates the optimization of spatial layout and intelligent resource scheduling, significantly improving management efficiency and space utilization.

IV. Design of an Intelligent Laboratory Management System based on UWB Technology

A. UWB Technology

UWB is a short-range, high-bandwidth wireless communication technology that transmits information by emitting very short-duration pulses over a wide frequency spectrum, typically ranging from 3.1 GHz to 10.6 GHz. Unlike conventional narrowband systems, UWB does not rely on a continuous carrier wave, allowing it to achieve exceptionally high time-domain resolution [9].

UWB is particularly well-suited for applications requiring high-precision positioning, low latency, and low power consumption. It offers centimeter-level accuracy in distance measurement, making it ideal for RTLS, indoor positioning, access control, and asset tracking. The technology is inherently resistant to multipath interference and can penetrate non-metallic obstacles such as walls or furniture, ensuring robust performance in complex indoor environments [10].

Advanced UWB systems support various positioning techniques, including Time of Flight (ToF), Time Difference of Arrival (TDoA), and Angle of Arrival (AoA). These capabilities enable 3D spatial tracking and secure ranging, and are increasingly integrated into IoT devices, smartphones, and industrial systems.

Driven by standardization efforts (e.g., IEEE 802.15.4z) and growing industry adoption, UWB is emerging as a key enabling technology for intelligent environments, including smart homes, smart factories, and smart laboratories.

B. Performance Comparison Between UWB and Mainstream Wireless Positioning Technologies

Mainstream wireless positioning technologies currently include UWB, BLE, Wi-Fi, and RFID. UWB offers superior ranging accuracy, strong anti-interference performance, and low power consumption, making it particularly suitable for high-precision scenarios such as access control and equipment tracking.

In terms of positioning accuracy, both UWB and RFID perform well; however, RFID lacks real-time tracking capabilities. When access control systems are based on BLE, Wi-Fi, or RFID, their limited accuracy and latency may lead to false unlocking events. In contrast, systems using NFC cards or smartphones require users to bring the device into close proximity with the reader, which reduces operational convenience [11].

C. System Architecture Design

Based on the characteristics of UWB technology and the requirements of laboratory management, the proposed system adopts a layered architecture consisting of four levels: the device layer, communication layer, platform layer, and application layer.

The device layer is responsible for the deployment and operation of equipment within the laboratory. It collects device status and environmental data while supporting various intelligent functions. This layer includes subsystems such as UWB-based access control, UWB ranging, environmental monitoring, smart lighting, smart air conditioning, and smart sockets [12].

The communication layer enables data transmission between devices and the platform. It supports both wireless and wired network connections, as well as IoT protocols. To enhance the efficiency and reliability of data transmission, this layer incorporates IoT gateways and edge gateways for transmission optimization.

The platform layer serves as the core functional component of the system. It includes modules for access control management, device management, environmental monitoring, user management, data acquisition and storage, real-time safety monitoring, system configuration, and integration interfaces. This layer relies on a private IoT cloud to enable centralized data processing and management. It also provides API interfaces, message queues, notification services, and protocol support [13].

The application layer delivers interactive interfaces and application functions for end users. It supports multiple user terminals, including PC clients, mobile apps, dashboards, voice assistants, and notification services. Users can monitor the laboratory in real time, manage devices, and perform security control operations through these interfaces. The overall system architecture is illustrated in Fig. 1.

D. System Operation Flow Design

The access control system is a key module within the intelligent laboratory management system. Leveraging UWB's high-precision positioning and ranging capabilities, it not only serves as the first line of defense for laboratory safety but also functions as a trigger point for other system operations. Through accurate identity authentication and permission control, the access control system ensures laboratory security while enabling the coordinated activation of devices and environmental regulation. As such, the access control module is a critical focus of the system design [14]. The operational flow of access control is illustrated in Fig. 2.

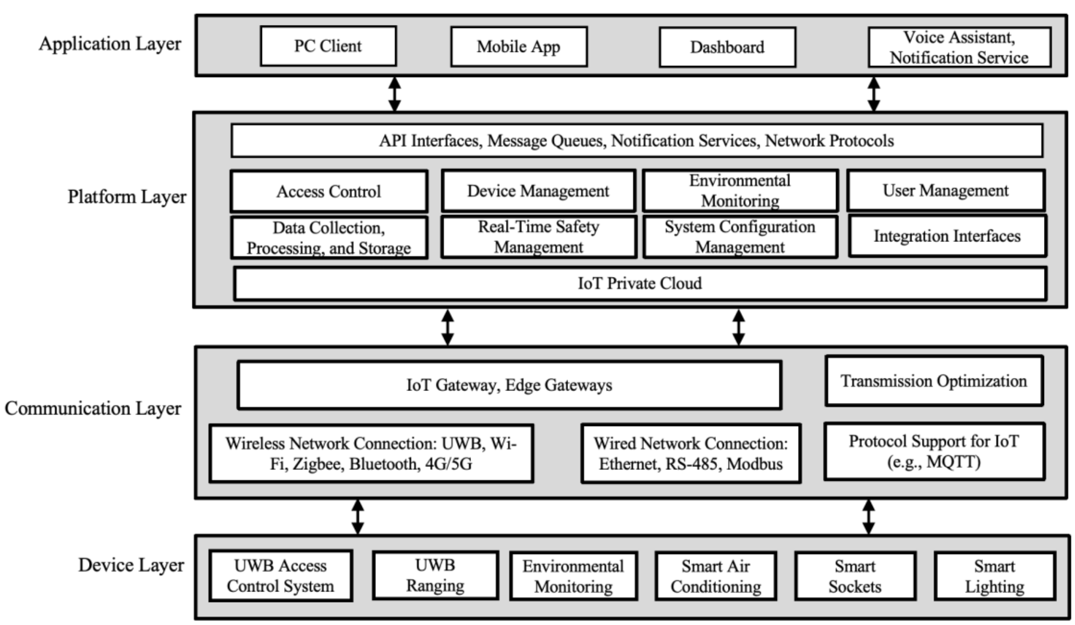

Fig. 1. System architecture of the UWB-based intelligent laboratory management system.

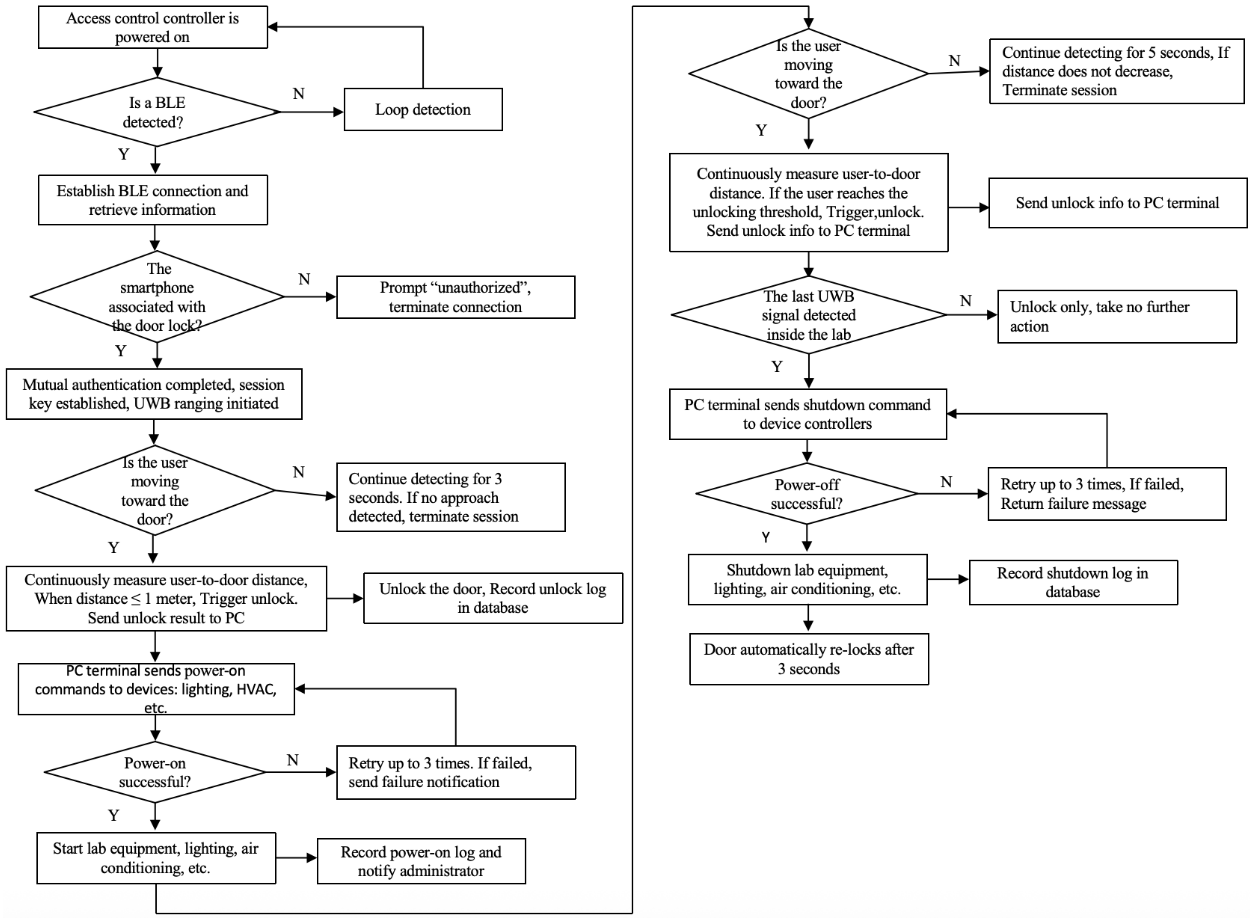

Fig. 2. Access control lock or unlock workflow diagram.

a) Initialization and connection phase: Upon power-up, the access control controller enters working mode and continuously scans for BLE broadcasts from smartphones or signals from UWB tags. If a valid signal is detected, the system establishes a BLE connection and reads relevant information from the smartphone. If no signal is found, the system continues to loop in scanning mode [15].

Subsequently, the controller queries the access rights stored in the database to determine whether the device is authorized. If not associated, the system returns an "unauthorized" message and terminates the connection. If authorization is confirmed, mutual authentication is performed, a session key is established, and UWB ranging is initiated.

b) Ranging phase: The system uses UWB ranging to assess the user's motion status, specifically whether the user is approaching the door. If not, the system continues monitoring for 3 seconds. If the distance to the door does not decrease, the session is closed. If the user is walking toward the door, the system continues to measure the distance. When the user reaches the threshold distance (one meter), the system issues an unlock command, opens the door lock, and sends an unlock log to the central PC terminal [16, 17]. Simultaneously, it sends power-on commands to device power controllers, entrance lighting, and HVAC systems.

c) Door opening and device activation phase: After sending the power-on commands, the system verifies whether power-on is successful. If the command fails 3 consecutive times, a startup failure message is returned. If successful, it activates the lab equipment power, lighting, and air conditioning. Power-on logs are recorded in the database, and push notifications are sent to the administrator. The door unlocking action is also logged and notified accordingly [18].

d) Exit and device shutdown phase: After the user enters the lab and the door is closed, the system resumes tracking the user's movement. If the user moves toward the door from the inside and reaches the defined threshold distance, an unlock signal is triggered and returned to the PC terminal. The system then checks whether this user is the last remaining individual inside the lab. If not, no further action is taken beyond unlocking the door. If the user is identified as the last UWB-tagged user, the PC terminal issues power-off commands to the equipment, lighting, and HVAC controllers. The system then verifies whether the power-off operation is successful. If it fails three consecutive times, a failure message is returned. If successful, all relevant equipment is powered off, and shutdown logs are recorded in the database. Finally, the access system automatically re-locks the door after a three-second delay.

E. Design of other System Functions

a) Intelligent device displacement alarm: In the asset management module, UWB tags are attached to laboratory equipment to enable real-time distance monitoring between the equipment and the UWB ranging devices. When an abnormal change in distance is detected-exceeding a predefined threshold-an alert is triggered by the laboratory's alarm system. This indicates that a device may have been moved or has exited its designated area. The system notifies laboratory staff to take immediate action, effectively preventing unauthorized relocation or theft of valuable assets and ensuring equipment security [19].

The intelligent displacement alarm mechanism is illustrated in Fig. 3.

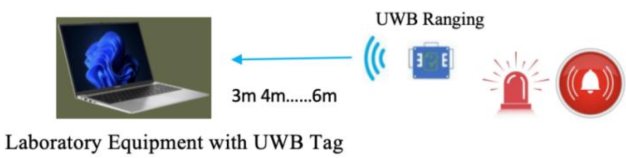

Fig. 3. UWB-based intelligent device displacement alarm.

b) Laboratory environmental linkage: Once the UWB-based access control system successfully unlocks the laboratory door, a series of predefined intelligent linkage mechanisms are triggered. The lighting system is activated and automatically switches to a preset brightness mode. The air conditioning system adjusts temperature and humidity levels based on predefined environmental thresholds.

Simultaneously, the laboratory equipment power management system is activated, initiating the startup of various experimental devices in a specified sequence. This ensures that all necessary equipment is fully operational and ready for subsequent experimental activities.

c) Intelligent zone safety warning: UWB-based ranging technology enables real-time and highly accurate measurement of the distance between personnel and potential hazard zones within the laboratory, such as areas containing high-voltage equipment or hazardous chemicals. When an individual approaches a predefined safety threshold, the system immediately triggers an audible and visual alarm to alert the person and ensure safety by discouraging further proximity to the danger zone. At the same time, a warning notification is sent to laboratory administrators [20, 21].

V. Implementation of the UWB-based Intelligent Laboratory Management System

A. Access Control System Functionality

The access control system is designed to manage the entry and exit of faculty and students in laboratory environments. The UWB controller retrieves device information from users carrying UWB-enabled smartphones or UWB tags and compares it with access authorization data stored in the cloud database. Administrators configure access rights and door operation time windows for each laboratory based on user roles. Authorized students and instructors can enter the laboratory during scheduled class hours simply by carrying their UWB-enabled device and walking towards the laboratory entrance. The UWB controller authenticates the user and performs real-time distance measurements. Once within the threshold range, the door unlocks automatically, enabling seamless, contactless entry. Outside of scheduled lab hours or in restricted laboratory areas, users without valid authorization-regardless of student or faculty status-are denied access by the system.

The data communication process involves interaction between the PC-based control terminal and the UWB controller over the network. This includes ranging operations, command transmission with MAC address binding, adding mobile device addresses to the UWB controller's whitelist, granting access and interaction permissions to mobile terminals, and enabling device-level interaction with the access control controller.

Additionally, the system supports real-time display and monitoring of access events-such as unlock and lock actions-performed by the UWB-based door lock, all visualized on the PC terminal [22, 23].

B. Asset Management Functionality

The asset management module includes daily management, intelligent device displacement alarms, and asset inventory statistics [24].

a) Daily management: Laboratory equipment is registered and linked to corresponding UWB tags. Information such as device identity, borrowing, return, and maintenance records is entered into the asset management system to improve administrative efficiency.

b) Intelligent device displacement alarm: The system periodically scans for UWB tags within the monitoring range. To avoid false alarms caused by transient signal fluctuations, a time tolerance mechanism is employed. An alarm is triggered only when the measured position deviates from the preset threshold-e.g., more than one meter-for a sustained duration exceeding three seconds.

c) Asset inventory statistics: The system automatically scans all UWB-tagged devices within the coverage area to assess their status and usage. By comparing this data with the system's equipment ledger, asset inventory can be completed quickly, significantly reducing manual workload while improving data accuracy and management efficiency.

C. Environmental Monitoring Functionality

The environmental monitoring module includes laboratory environment linkage and intelligent zone safety warnings.

a) Laboratory environment linkage: After the UWB-based access control system unlocks the laboratory, power-on commands are sent to controllers of lighting, air conditioning, and other equipment to initiate startup procedures. Additionally, lighting systems can be dynamically controlled based on a person's proximity to specific zones, enabling automatic switching on or off of designated lights.

b) Intelligent zone safety warning: Similar to the device displacement alarm, this function continuously measures the distance between individuals-carrying UWB tags or UWB-enabled smartphones-and designated detection base stations. When a person enters a predefined hazardous zone, the system issues real-time audible and visual alerts, while simultaneously notifying administrators.

D. Experiment Management Functionality

The experiment management module includes experimental course management, course scheduling, and reservation services. Experimental course management supports the creation, administration, and publication of experimental content. Course scheduling intelligently arranges experimental sessions based on laboratory resource availability to optimize space utilization and avoid conflicts. The reservation function allows users to book laboratory time and space online according to specific needs, enhancing accessibility and operational efficiency.

E. User Management Functionality

The user management module consists of user information management, permission management, and usage statistics. User information management enables the entry, modification, and maintenance of users' basic data. Permission management allows access rights to be assigned according to user roles-such as administrators, instructors, and students-effectively controlling access to different system functions. Comprehensive usage statistics provide data-driven insights into user behavior and system utilization, supporting informed decision-making in laboratory management.

F. System Management Functionality

The system management module includes system operation settings, data backup, and overall system administration. Operation settings cover configuration items such as system run times, permission rules, and device status monitoring. Data backup ensures the security of critical information, including user records, experimental data, and equipment logs. Comprehensive system administration functions include log management and security policy configuration to maintain system stability and integrity.

VI. System Deployment and Effectiveness

The UWB-based intelligent laboratory management system has entered the pilot stage in the Modern Educational Technology Laboratory. Three representative laboratories were selected for implementation: the Smart Language Teaching Lab, the Interactive Teaching Lab, and the Cross-Cultural VR Training Lab. These labs collectively cover an area of approximately 300 square meters.

A total of 112 experimental devices-including VR headsets, portable workstations, and mobile projectors-were equipped with UWB identification tags. The hardware deployment within a single laboratory is illustrated in Fig. 4.

The upgraded laboratory supports five categories of public English experimental teaching and course projects, including College English Listening and Speaking, Reading and Writing and Translation, English Speech and Debate, and English Interpretation of Traditional Chinese Culture. These courses collectively serve over 1,500 faculty members and students. During the pilot phase, a total of 650 class hours of experimental courses were successfully conducted using the system.

After one and a half years of pilot operation, the system has achieved significant improvements in various aspects, including daily laboratory management, safety, energy efficiency, user experience, and talent development.

a) Daily laboratory management: The system has substantially reduced the workload of laboratory staff. For example, equipment inventory time has decreased from one hour of manual counting to automatic report generation within five minutes.

b) Laboratory safety management: During the trial period, the system successfully identified and recovered two misplaced devices through the displacement alarm function, achieving a 100% equipment security control rate. The UWB-based intelligent zone warning mechanism triggered eleven audible and visual alarms, effectively preventing faculty and students from entering high-voltage danger zones.

c) Energy efficiency and environmental sustainability: The lighting system automatically turns on in occupied areas and off in unoccupied ones. The HVAC system adjusts temperature and humidity based on predefined thresholds, while experimental devices automatically shut down after periods of inactivity. These features have led to a 25% reduction in overall energy consumption, significantly lowering operational costs for the university.

d) User experience: Access efficiency has greatly improved as faculty and students can enter using UWB-enabled smartphones or tags. The average door unlocking response time has decreased from 3 seconds (with traditional access systems) to just 0.5 seconds, achieving a seamless and contactless entry experience.

e) Enhancement of talent development: In 2023 and 2024, the laboratory supported autonomous learning for more than 1,500 students and met the self-directed experimental needs for training and participation in over 10 national-level competitions, including major university contests. This not only maximized the utilization efficiency of experimental equipment but also significantly enhanced students' language application skills and innovative abilities. Over the two-year period, students participating in these competitions achieved outstanding results, winning 81 national first prizes, 116 second prizes, and 325 third prizes.

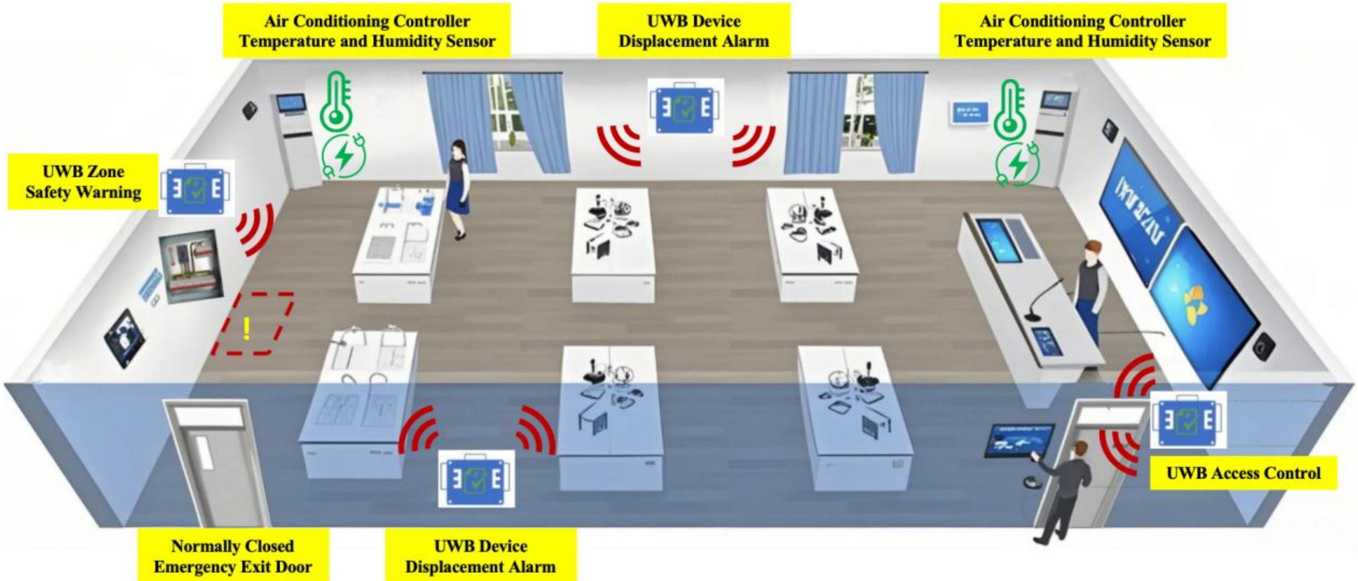

Fig. 4. Hardware deployment inside the intelligent laboratory.

VII. Discussion

A. Interpretation of Results

The deployment results of the UWB-based intelligent laboratory management system demonstrate that it significantly enhances key aspects of laboratory operations, including access efficiency, asset monitoring, energy conservation, and user experience. These improvements can be primarily attributed to the centimeter-level positioning accuracy and real-time tracking capabilities of UWB technology, which enable automated responses and reduce reliance on manual intervention. For example, the drastic reduction in equipment inventory time is a result of continuous UWB-based scanning and automated data logging, while energy efficiency gains stem from dynamic environment control triggered by real-time user proximity detection.

Moreover, the seamless integration of subsystems—access control, environmental regulation, asset tracking, and user management—under a centralized IoT architecture ensures not only operational convenience but also system scalability. This integration offers a holistic solution to the fragmented and disjointed management processes observed in traditional laboratory settings.

B. Comparison with Prior Work

Compared to conventional systems based on QR codes, RFID, or BLE, the proposed solution offers notable advantages in terms of accuracy, responsiveness, and automation. While BLE and RFID technologies are widely used, they often suffer from signal interference, limited range, and imprecise localization. In contrast, UWB supports high-resolution spatial tracking, which allows for intelligent zoning, safe distance monitoring, and more granular control over lab equipment and environmental settings.

Additionally, previous systems typically focus on a single management function, such as access control or environmental sensing. In this study, the integration of multiple modules—including real-time asset displacement alarms and intelligent safety zones—demonstrates how UWB can serve as the technological backbone for a unified smart laboratory framework. This positions the system as an innovative upgrade over existing solutions, with broader applicability in educational and research institutions.

C. Limitations

While the system exhibits promising performance, several limitations should be acknowledged. First, the deployment was limited to three laboratories within a single institution, which may constrain the generalizability of the findings to other settings or disciplines. Second, the evaluation focused primarily on operational efficiency and did not capture longer-term impacts such as cost-effectiveness, maintenance overhead, or learning outcomes. Third, despite its technical advantages, UWB deployment requires specialized hardware, calibration, and higher installation costs, which could pose barriers to adoption in resource-constrained environments. Future research should investigate scalable deployment strategies, integration with AI-driven analytics, and cross-campus interoperability to further enhance system applicability.

VIII. Conclusion

The intelligent laboratory management system based on UWB technology effectively addresses long-standing challenges in university laboratory administration. By leveraging UWB's high-precision positioning capabilities, the system standardizes access control procedures and enables efficient personnel management. Real-time distance data between individuals and equipment supports spatial layout optimization and dynamic resource scheduling, significantly enhancing the level of intelligent laboratory management.

Additionally, the system enables real-time asset tracking and proactive safety alerts through UWB-based detection, establishing a comprehensive security framework that contributes to the safe and stable operation of laboratory environments.

The intelligent transformation of university laboratories is an ongoing process. In the future, we aim to further explore the integration of UWB with other emerging technologies, continuously refine system functionalities, and enhance system stability and compatibility. These efforts will support broader adoption across interdisciplinary laboratories, deliver higher-quality and more efficient services to faculty and students, and inject new momentum into educational reform and high-quality development in higher education.

REFERENCES

[1] F. P. Madrin, M. Klemm, and E. Supriyanto, "Reliability improvement of UWB tracker for hospital asset management system: Case study for TEE probe monitoring," in Proc. 2021 4th Int. Conf. Inf. Commun. Technol. (ICOIACT), pp. 1‑6, 2021.

[2] M. F. R. Al‑Okby, S. Junginger, T. Roddelkopf, and K. Thurow, "UWB‑based real‑time indoor positioning systems: A comprehensive review," Applied Sciences, vol. 14, no. 23, pp. 11005, 2024.

[3] K.Saritha et al., "IoT enabled hospital asset tracking using advanced interdisciplinary approaches," E3S Web of Conferences, 2024, Paper 01007.

[4] T. Margiani, S. Cortesi, M. Keller, C. Vogt, T. Polonelli, and M. Magno, "Angle of arrival and centimeter distance estimation on a smart UWB sensor node," IEEE Transactions on Instrumentation and Measurement, vol. 72, pp. 1‑10, 2023.

[5] A. Kumar, S. Jain, and M. Kumar, "Face and gait biometrics authentication system based on simplified deep neural networks," Int. J. Inf. Technol., vol. 15, pp. 1005-1014, 2023. https://doi.org/10.1007/s41870-022-01087-5.

[6] D. M. Nixon Dutta, "A tracking solution of IT assets and resources management," Int. J. Math. Comput. Res., vol. 10, no. 7, pp. 2822-2831, 2022. https://doi.org/10.47191/ijmcr/v10i7.08.

[7] H. Dudycz, M. Hernes, Z. Kes, E. Mercier-Laurent, B. Nita, K. Nowosielski, et al., "A conceptual framework of intelligent management control system for higher education," in Artif. Intell. Knowl. Manage.: 8th IFIP WG 12.6 Int. Workshop, AI4KM 2021, Yokohama, Japan, 2021, pp. 35-47. https://doi.org/10.1007/978-3-030-80847-1_3.

[8] J. A. Martin, I. Schröder, and C. A. Merlic, "Proceedings of the 2021 Workshop on Laboratory Safety: Advancing Safety in Teaching and Research Laboratories," ACS Chem. Health Saf., vol. 29, no. 2, pp. 124-131, 2022. https://doi.org/10.1021/acs.chas.2c00003.

[9] A. Yuhanef, Y. Yulindon, D. Meidelfi, and M. Silvana, "The small UWB monopole antenna with stable omnidirectional radiation pattern," Int. J. Inform. Vis., vol. 6, no. 4, pp. 815-820, 2022. https://doi.org/10.30630/joiv.6.4.972.

[10] A. Volpi, L. Tebaldi, G. Matrella, R. Montanari, and E. Bottani, "Low-cost UWB based real-time locating system: Development, lab test, industrial implementation and economic assessment," Sensors, vol. 23, no. 3, pp. 1124, 2023.

[11] B. V. Krishnaveni, A. Venkatalakshmi, and B. R. Kumar, "Localization for IoT Based Systems Using UWB," in Contemp. Perspect. Sci. Technol. Res., vol. 2, pp. 12-26, 2022. https://doi.org/10.9734/bpi/cpstr/v2/11383f.

[12] J. Shackelford, P. Mathew, C. Regnier, and T. Walter, "Laboratory validation of integrated lighting systems retrofit performance and energy savings," Energies, vol. 13, no. 13, pp. 3329, 2020.

[13] N. M. Hussein, Y. M. Mohialden, and S. A. Salman, "Impact of IoT-based environmental monitoring on lab safety and sustainability," Babylon. J. Internet Things, vol. 2024, pp. 16-26, 2024. https://doi.org/10.58496/BJIoT/2024/003.

[14] Z. Changhong and X. Reneng, "Intelligent laboratory access control system based on ZigBee technology," in 2020 Int. Conf. Virtual Reality Intell. Syst., Zhangjiajie, China, 2020, pp. 688-690. https://doi.org/10.1109/ICVRIS51417.2020.00169.

[15] T. M. T. Dinh, N. S. Duong, and K. Sandrasegaran, "Smartphone-based indoor positioning using BLE iBeacon and reliable lightweight fingerprint map," IEEE Sens. J., vol. 20, no. 17, pp. 10283-10294, 2020. https://doi.org/10.1109/JSEN.2020.2989411.

[16] S. Salimi, S. Salimpour, J. P. Queralta, W. M. Bessa, and T. Westerlund, "Benchmarking ML Approaches to UWB-Based Range-Only Posture Recognition for Human Robot-Interaction," IEEE Sens. J., vol. 25, no. 1, pp. 1350-1358, 2024. https://doi.org/10.1109/JSEN.2024.3493256.

[17] S. Sung, H. Kim, and J. I. Jung, "Accurate indoor positioning for UWB-based personal devices using deep learning," IEEE Access, vol. 11, pp. 20095‑20113, 2023.

[18] J. Shackelford, P. Mathew, C. Regnier, and T. Walter, "Laboratory validation of integrated lighting systems retrofit performance and energy savings," Energies, vol. 13, no. 13, pp. 3329, 2020. https://doi.org/10.3390/en13133329.

[19] N. Karimpour, Z. A. Dagdevıren, V. Akram, and O. Dağdeviren, "A cloud-based asset tracking system for hospitals using ultra-wideband localization," Avrupa Bilim ve Teknol. Derg., vol. 26, pp. 425-430, 2021. https://doi.org/10.31590/ejosat.960454.

[20] A. Volpi, L. Tebaldi, G. Matrella, R. Montanari, and E. Bottani, "Low-Cost UWB Based Real-Time Locating System: Development, Lab Test, Industrial Implementation and Economic Assessment," Sensors, vol. 23, no. 3, pp. 1124, 2023. https://doi.org/10.3390/s23031124.

[21] S. Sung, H. Kim, and J. I. Jung, "Accurate indoor positioning for UWB-based personal devices using deep learning," IEEE Access, vol. 11, pp. 20095-20113, 2023. https://doi.org/10.1109/ACCESS.2023.3250180

[22] K. Reaz et al., "UWB Security and Enhancements," TechRxiv, 2024. https://doi.org/10.36227/techrxiv.171085006.63940566/v1.

[23] D. Coppens, A. Shahid, S. Lemey, B. Van Herbruggen, C. Marshall, and E. De Poorter, "An overview of UWB standards and organizations (IEEE 802.15.4, FiRa, Apple): Interoperability aspects and future research directions," IEEE Access, vol. 10, pp. 70219-70241, 2022. https://doi.org/10.1109/ACCESS.2022.3187410.

[24] N. Karimpour, Z. A. Dagdeviren, V. Akram, and O. Dagdeviren, "A cloud-based asset tracking system for hospitals using ultra-wideband localization," Avrupa Bilim ve Teknoloji Dergisi, vol. 26, pp. 425‑430, 2021.