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Application of Big Data Technology in Computer Laboratory Management

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Abstract: University computer laboratories undertake the core functions of practical teaching, scientific research innovation, and talent cultivation. However, their management and operation face prominent problems such as fragmented information systems, lagging data collection methods, decision-making reliant on experience, and low levels of security intelligence. Traditional management models struggle to adapt to the reality of expanding laboratory scale and diversified service demands. The introduction of big data technology provides a new technical approach for refined laboratory management. Based on a systematic analysis of the current status and problems of computer laboratory management, this study constructs a four-layer management system architecture covering the infrastructure layer, data warehouse layer, virtual resource layer, and application service layer. IoT sensors and business systems enable multi-source data acquisition, Hadoop ecosystem technologies support massive data storage and processing, clustering analysis and neural network algorithms mine data value, and containerization and cloud desktop technologies ensure flexible deployment of experimental environments. Focusing on core scenarios such as experimental teaching, equipment assets, and open sharing, functional modules such as teaching process monitoring, equipment health assessment, reservation scheduling linkage, and resource sharing reuse are designed. Research shows that big data technology promotes laboratory management from experience-based judgment to data quantification, and from passive response to proactive prediction, providing an implementation path and technical support for refined and intelligent laboratory management.

1. Introduction

University computer laboratories play multiple roles, including practical teaching, scientific research and innovation, and talent cultivation. They serve as a core support platform for computer science discipline construction and the training of engineering talents. With the deepening implementation of higher education development strategies such as "New Engineering Education" and "Double First-Class," the position of experimental teaching in the talent training system is becoming increasingly prominent[1]. The scale of computer laboratories continues to expand, serving faculty and students from multiple disciplines across the university. The types of experimental courses and software environment requirements are exhibiting a high degree of complexity. At the same time, the connotation of laboratory operation and management is constantly extending, involving multiple business dimensions such as teaching arrangement, equipment maintenance, material allocation, security, and open reservation, which places higher demands on management refinement and response timeliness[2].

However, current university computer laboratory management generally faces realistic challenges such as lagging information technology, dispersed data resources, and insufficient dedicated personnel. Various business systems operate independently, and there is a lack of interconnection between platforms for teaching management, equipment assets, and access control monitoring, forming typical "information silos" and "digital divides." Management personnel still need to rely on experience-based judgments and manual statistics to deal with daily affairs, making it difficult to achieve a comprehensive perception and dynamic regulation of the laboratory's operational status. The space for improving management efficiency and service capabilities is limited[3].

The rapid development of big data technology provides a new technical path to solve the above problems. By collecting, integrating, and deeply analyzing the multi-source heterogeneous data generated in the laboratory operation process, it is possible to reveal equipment usage patterns, teaching behavior characteristics, and resource allocation bottlenecks, providing quantitative bases for management decision-making[4]. The collaborative application of technologies such as the Internet of Things and cloud computing further enhances the real-time nature and operability of data, promoting the transformation of laboratory management from passive response to active prediction and from experience-driven to data-driven paradigms. Exploring the application path of big data technology in computer laboratory management is of significant theoretical value and practical significance for improving laboratory operational efficiency and supporting high-quality talent cultivation.

This study focuses on the application of big data technology in university computer laboratory management, aiming to build a data-driven laboratory management system framework and explore key technology implementation paths and management function module design. The research content mainly includes three aspects: First, it systematically reviews the basic characteristics and outstanding problems of current computer laboratory management, and analyze the necessity and feasibility of introducing big data technology. Second, based on the big data technology system, design a laboratory management architecture covering four levels: infrastructure, data warehouse, virtual resources, and application services, and clarify the key technical methods for data collection, processing, and analysis. Third, focusing on core management scenarios such as experimental teaching, equipment assets, and open sharing, design data-driven function modules and propose specific application schemes.

2. Current Situation and Problems Analysis

2.1 Basic Characteristics

The computer laboratories in universities serve as the core carriers of practical teaching, and their management and operation exhibit distinct structural characteristics. In the context of the widespread establishment of multi-campus systems, computer laboratories are typically distributed across multiple teaching buildings in different campuses, resulting in spatial dispersion that directly increases the management radius for equipment inspection, environmental monitoring, and personnel scheduling. Within the same university, there often exist various types of laboratories such as basic teaching laboratories, professional laboratories, and innovative open laboratories. Each type of laboratory has different functional positioning and service targets, and the management requirements also vary.

The diversity of experimental courses is another significant feature of computer laboratory management. Computer-related professional courses, basic computer courses for public use, interdisciplinary cross-course courses, and various training projects all need to be carried out in the laboratory environment. Different courses have significantly different requirements for operating systems, development tools, and application software. The same laboratory may need to switch multiple software environments within a week, and some courses also require specific network topologies or server configurations[5]. The frequency and complexity of environment deployment and switching far exceed those of ordinary multimedia classrooms.

The heavy management tasks and limited personnel allocation create a prominent contradiction. Computer laboratories not only undertake routine experimental teaching tasks but also support various diversified activities such as paperless examinations, discipline competition training, innovation project incubation, and social training services. Routine maintenance of equipment, software updates and upgrades, emergency handling of faults, management of material entry and exit, and safety inspection records are ongoing affairs. In contrast, the staffing of dedicated experimental technicians is generally tightened, and some universities adopt outsourcing services to supplement maintenance capabilities. However, core management tasks still need a small number of dedicated personnel to undertake, and the workload and responsibility boundaries continue to expand.

2.2 Major Problems in Current Management

The fragmentation of information systems leading to data isolation is the core issue in current laboratory management. The arrangement of experimental teaching relies on the educational administration management system, the registration and use of equipment assets are on an independent material management platform, the operation of laboratory opening and reservation runs on a specialized business system, and the access control, attendance, and video surveillance are on different security platforms of different manufacturers. The databases of each system are isolated from each other, and the data formats and interface standards are not unified. The equipment information, usage records, and maintenance history of the same laboratory are scatteredly stored in multiple heterogeneous systems. When managers conduct data verification and statistical analysis, they often need to switch operations between multiple systems and manually compare data differences, which not only leads to low efficiency but also easily introduces human errors.

The outdated data collection methods have exacerbated the distortion and lag of management information. A considerable proportion of data in the existing management systems still rely on manual entry, the equipment usage status needs managers to conduct on-site inspections and record, the attendance of experimental teaching depends on teachers' manual registration, and the material consumption data is filled in through end-of-month inventory. The manual collection method not only consumes manpower but also cannot guarantee the real-time and accuracy of data. Although some intelligent equipment have been deployed, such as access card reading and video surveillance, the collected data is only used in a single business scenario and fails to be integrated and utilized with other system data, and the potential value of the data has not been fully exploited.

The excessive reliance of management decisions on experience paths restricts the improvement of management level. The equipment purchase plan of the laboratory mainly refers to historical purchase records and teachers' subjective needs, lacking quantitative analysis of the actual usage rate, failure rate, and maintenance cost of the equipment. The arrangement of experimental courses mostly aims to avoid time conflicts as the primary goal, and rarely considers equipment load balancing and energy consumption optimization. The resource allocation of the open laboratory often follows the fixed time period and fixed machine position mode, making it difficult to dynamically respond to the actual usage needs of students. This experience-based management model exposes the drawbacks of slow response and decision-making deviations when facing complex situations such as multi-campus collaboration and multi-type laboratory coordination.

The intelligent level of laboratory safety and environmental management also needs to be improved. The existing security systems are mostly limited to access control and video recording functions, and there is insufficient support for real-time monitoring of laboratory internal environmental parameters, intelligent identification of abnormal behaviors, and coordinated handling of emergencies. Changes in temperature and humidity may affect the stable operation of equipment, but there is a lack of automatic linkage with environmental control equipment. The activities of personnel during the night opening period cannot be sensed in real time, and safety hazards are difficult to be discovered in a timely manner. The management of chemicals, consumables, etc. is still mainly based on ledger registration, and the traceability ability throughout the process is weak.

2.3 The Necessity and Feasibility of Introducing Big Data Technology

The data-driven management model has significant advantages over the traditional experience-based model. Through continuous data collection and quantitative analysis of the entire process of laboratory operation, key indicators such as equipment utilization efficiency, teaching resource matching degree, and personnel behavior patterns can be objectively presented, providing factual basis for management decisions. Data analysis can reveal deep-seated problems hidden in daily operations, such as abnormal increase in the failure rate of certain equipment, tight usage of the laboratory during specific periods, and frequent errors in software configuration for certain courses. This supports managers in accurately identifying the root causes and taking targeted improvement measures. The establishment of data models can also achieve forward-looking management functions such as equipment life prediction, peak usage warning, and resource scheduling optimization, shifting laboratory operation from passive response to active regulation.

Big data technology has extensive application scenarios in laboratory management. The student on-machine behavior data generated during experimental teaching can be used to analyze learning engagement and operational compliance, providing support for teaching feedback. Equipment operation logs and fault records can be used to construct a health assessment model for equipment, optimizing maintenance cycles and spare parts reserves. The reservation records and actual visit data of open laboratories can reveal students' usage preferences and time distribution patterns, guiding dynamic adjustment of resource allocation. The multi-dimensional data fusion analysis of access control, monitoring, and environmental sensors can achieve comprehensive judgment and abnormal warning of laboratory security situations.

The continuous improvement of university information infrastructure has laid a practical foundation for the application of big data technology. In recent years, universities have increased investment in laboratory renovations and information construction, and infrastructure such as comprehensive wiring, intelligent monitoring, access control systems, and environmental sensors has gradually become widespread, providing hardware support for multi-source data collection. The deployment of cloud computing platforms and the construction of data centers have enhanced the storage and computing capabilities of massive data[6]. Some universities have begun to explore the integration and upgrade of business systems such as experimental teaching management platforms, asset management systems, and open reservation platforms, and the technical barriers for data sharing and business collaboration are gradually being broken. The knowledge structure of laboratory technicians is also constantly being optimized, and their proficiency in data analysis tools and management information systems is gradually improving, providing human resources support for the implementation of big data technology.

3. Management System Construction

3.1 Architecture Design

The construction of the computer laboratory management system should be guided by a top-level design, establishing a technical architecture with clear layers, data integration, and service integration. Referring to the mature paradigms of the Internet of Things and big data platforms, the comprehensive service management platform for the laboratory can be divided into four logical layers: infrastructure layer, data warehouse layer, virtual resource layer, and application service layer. The layers communicate with each other through standardized interfaces to achieve data flow and functional coordination.

The infrastructure layer is the physical foundation for the system operation, covering all hardware devices and sensing terminals in the laboratory environment. This includes comprehensive wiring systems, intelligent electrical control devices, environmental sensors, video surveillance devices, access control controllers, and IoT terminals, as well as server clusters, network equipment, and cloud desktop nodes. The core function of this layer is to achieve comprehensive perception of three types of objects: people, equipment, and environment. It collects multi-dimensional data such as equipment operation status, environmental parameter changes, personnel entry and exit records, and teaching operation logs in real time, providing raw data sources for the upper-level analysis[7].

The data warehouse layer is responsible for the aggregation, cleaning, and integration of multi-source heterogeneous data. The data collected by the infrastructure layer includes structured data and unstructured data. Structured data mainly comes from business databases such as the educational administration system, asset management system, and reservation platform, and can be extracted and transformed regularly using ETL tools. Unstructured data comes from monitoring videos, sensor streams, network logs, etc., and needs to be stored and managed using Hadoop distributed file system and HBase columnar database. The data must undergo pre-processing procedures such as integrity verification, consistency detection, and missing value filling before entering the warehouse. For multi-source descriptions of the same entity, such as the correspondence between administrative classes and teaching classes, a unified data dictionary and mapping rules need to be established to eliminate semantic conflicts and redundant records. The cleaned and integrated data is organized in a wide-table format to provide a high-quality data foundation for subsequent analysis and mining.

The virtual resource layer uses virtualization technology to achieve logical abstraction and dynamic scheduling of physical resources. Through Docker containerization deployment and Kubernetes cluster management, infrastructure such as servers, storage, and networks are encapsulated as elastic and adjustable virtual resource pools. Software environments, development tools, data sets, etc. required for experimental teaching are stored in image form, supporting on-demand rapid deployment and environment isolation. The virtualization layer provides standardized service interfaces to the upper-level applications, including distributed computing services, experimental environment management services, teaching resource access services, etc., reducing the technical complexity of application development and operation and improving resource utilization efficiency.

The application service layer is oriented towards various business scenarios of laboratory management, providing data-driven functional modules and decision support tools. This layer realizes specific functions such as experimental teaching monitoring, equipment asset management, open laboratory operation, and security guarantee linkage based on the analysis results in the data warehouse and the service capabilities of the virtual resource layer. Managers can monitor the operation status of the laboratory in real time through a unified portal interface, receive abnormal warning information, perform remote control operations, generate data reports, and conduct trend analysis.

3.2 Key Technologies and Implementation Methods

Data acquisition technology is the prerequisite for achieving comprehensive perception in the laboratory. The Internet of Things sensor network can monitor environmental parameters such as temperature, humidity, light, and smoke in the laboratory in real time. The data is aggregated to the Internet gateway through the MQTT protocol. The intelligent electrical control system collects power status and energy consumption data of equipment on a minute-by-minute basis, supporting remote on-off control and abnormal electricity usage alerts. The access control system records the time and identity information of personnel entering and leaving, and the facial recognition terminal can capture more detailed data on students' entry and exit. The business data generated by the teaching management system, such as course scheduling, student course selection, and experimental report submission, is directly connected to the data platform through API interfaces or database connection methods. The clocks of all collection terminals and business systems need to be synchronized to ensure that multi-source data can be aligned and analyzed in the time dimension.

The data processing technology system is built with Hadoop ecosystem as the core. Data extraction uses DataX or Sqoop tools to achieve batch data transmission between relational databases and the Hadoop platform. Real-time data streams are connected through the Kafka message queue and processed in a streaming manner by Spark Streaming or Flink. During data cleaning, integrity constraints are used to detect logical conflicts, and the naive Bayes classification algorithm is used to intelligently fill in missing values to ensure data quality meets the analysis requirements. The structured data after cleaning is stored in the Hive data warehouse, supporting SQL-based query and analysis; non-structured data is stored in the HDFS file system and accessed in real time through HBase. The entire data processing flow is achieved through the scheduling system for task orchestration and dependency management, ensuring the timeliness and stability of data processing.

Data analysis technology focuses on extracting management decision value from massive data. Clustering analysis can be used to identify typical patterns of laboratory usage behavior, such as dividing user groups based on students' on-machine duration, operation frequency, software usage type, etc., providing a basis for personalized resource allocation. Neural network algorithms can construct a device fault prediction model, inputting features such as device operation duration, temperature changes, and operation frequency, and outputting the probability of fault occurrence, supporting preventive maintenance[8]. The semantic engine analyzes text data such as teaching forums and experimental reports, extracting common student questions and knowledge blind spots, assisting in the optimization of teaching content. The analysis results are presented through visualization tools such as Tableau and ECharts, presenting key indicators in forms such as trend charts, heat maps, and dashboards.

3.3 Management Function Module Design

The experimental teaching management module focuses on the collection and analysis of teaching process data. The system automatically records behavioral data such as student computer usage duration, operation paths, software usage frequency, and submission time of experimental reports, generating individual learning profiles and overall class analysis reports. Teachers can view real-time information on classroom activity distribution, common error operation statistics, and experimental progress differences, and dynamically adjust teaching rhythm and tutoring focus. The module supports aggregating historical teaching data by course dimension and analyzing the effectiveness differences of different teaching methods to provide quantitative basis for teaching reform. The duplicate detection function for experimental reports integrates text similarity detection algorithms to assist teachers in academic integrity verification.

The equipment and asset management module realizes the full life cycle management of laboratory hardware resources. The system collects real-time operating indicators such as equipment power-on/off status, CPU load, memory usage, and disk usage, and constructs a device health assessment model. When a device continuously shows abnormal operating indicators or the frequency of faults increases, the system automatically generates an alert ticket to prompt managers for preventive maintenance. The equipment utilization analysis function can statistically analyze equipment usage rate, idle time distribution, and peak load conditions by time, course, and laboratory, providing data support for equipment purchase plans and update and elimination decisions. The spare parts inventory management module records the entry and exit of consumables and automatically generates purchase suggestions based on equipment failure prediction data.

The open laboratory management module supports the orderly conduct of extracurricular innovation activities. Students can reserve laboratory seats through the platform, and the system predicts the reservation demand for each time period based on historical usage data, dynamically adjusting the opening hours and number of open seats. After successful reservation, the reservation information is linked with the access system, and students can enter the laboratory by face recognition or card swipe within the reserved time period. The entry and exit times are automatically recorded, generating personal usage records and statistics on laboratory opening and human-machine usage. The intelligent monitoring system deployed in the laboratory monitors personnel activities in real time, triggering alarms when abnormal stays or unauthorized entries are detected. The electrical control system automatically controls the opening and closing of air conditioning, lights, and equipment power based on reservation information and real-time occupancy status, achieving energy-saving operation.

4. Conclusion

This study systematically explored the application paths of big data technology in the management of university computer laboratories. Currently, the management of computer laboratories faces multiple challenges such as scattered information systems, backward data collection methods, reliance on experience for decision-making, and low levels of security intelligence. The traditional management model is unable to adapt to the reality of expanding laboratory scale and diversified service demands. The introduction of big data technology provides a new technical paradigm to solve these problems. This study constructed a four-layer management system architecture covering the infrastructure layer, data warehouse layer, virtual resource layer, and application service layer. It clarified the technical path from multi-source data collection, cleaning and integration to analysis, mining, and functional implementation. Internet of Things sensors, intelligent terminals, and business system logs constitute the data collection front end. Hadoop ecosystem technology supports the storage and processing of massive data. Clustering analysis, neural networks, and other algorithms achieve deep extraction of data value. Containerization and cloud desktop technologies ensure the elastic deployment of the experimental environment. Around core management scenarios such as experimental teaching, equipment assets, and open sharing, functional modules such as teaching process monitoring, equipment health assessment, appointment scheduling linkage, and resource sharing reuse were designed. A data-driven management solution covering the entire chain of laboratory operation was formed.

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