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Design and Implementation of Intelligent Medical Equipment Maintenance System - Double Consideration of Improving Efficiency and Reducing Cost

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Abstract: This paper aims to discuss the design and implementation strategy of intelligent medical equipment maintenance system, focusing on how to achieve significant improvement of medical equipment maintenance efficiency and effective reduction of operation and maintenance costs through technological innovation. The system integrates the Internet of Things, big data analysis and artificial intelligence algorithms to achieve real-time monitoring, fault warning and accurate maintenance and management of medical equipment. By remotely monitoring equipment operation status, timely detection and prediction of potential failures, reduce unplanned downtime, and ensure continuity of medical services. At the same time, intelligent scheduling of maintenance resources, optimize maintenance processes, reduce labor and material consumption, and effectively control operation and maintenance costs. This study also emphasizes the ability of data-driven decision support to provide scientific basis for hospital managers and help medical device management to be refined and intelligent. This paper aims to improve the use efficiency and safety of medical equipment through the design and implementation of intelligent medical equipment maintenance system, while creating significant economic and social benefits for medical institutions, and contributing to the high-quality development of the medical industry.

1. Introduction

With the rapid development of medical science and technology, intelligent medical equipment, as an important part of modern medicine, plays an irreplaceable role in improving diagnostic accuracy, optimizing treatment plans and improving patient satisfaction. However, the wide application of smart medical devices has also brought serious challenges in maintenance management[1]. The

traditional maintenance mode relies on manual inspection and post-maintenance, which is not only inefficient and easy to cause service interruption, but also increases operation and maintenance costs and restricts the improvement of the overall operation efficiency of medical institutions[2]. In order to meet this challenge, it is very important to develop an efficient and intelligent medical equipment maintenance system. The system needs to have real-time monitoring, data analysis, fault warning and accurate maintenance and other comprehensive capabilities, can detect potential problems in advance, rapid response to failures, to achieve continuous and stable operation of equipment. This can not only significantly reduce unplanned downtime and ensure the continuity and stability of medical services, but also reduce labor and material consumption by optimizing maintenance processes and resource allocation, creating significant economic benefits for medical institutions[3]. Based on this, this research is committed to designing and implementing a set of efficient and low-cost intelligent medical equipment maintenance system through the comprehensive use of advanced technologies such as the Internet of Things, big data analysis and artificial intelligence. The system will deeply integrate technology and business, build a new model of intelligent equipment maintenance management, and provide a new solution for the medical industry. Through this study, it is expected to bring significant economic and social benefits to medical institutions, and promote the technological progress and innovative development in the field of medical equipment maintenance. At the same time, we also look forward to providing reference and reference for relevant industries, and jointly promoting the development of the medical industry to a more intelligent and efficient direction.

2. Technical background and literature review

2.1 Research status at home and abroad

In recent years, the intelligent medical equipment maintenance system as an important product of the integration of medical information and intelligence, its development process has shown a vigorous vitality. From the initial simple monitoring and alarm functions to the current integrated system integrating real-time monitoring, fault prediction and accurate maintenance, the intelligent medical equipment maintenance system has been iteratively upgraded, gradually realizing the transformation from passive maintenance to active maintenance[4]. In terms of key technologies, the deep integration of cutting-edge technologies such as the Internet of Things, big data analysis and artificial intelligence provides strong technical support for the intelligent medical equipment maintenance system (Table 1).

Table 1. Technical application table of intelligent medical equipment maintenance system

Research aspect	Key technology	Application case
Internet of things technology	Devices are interconnected	The hospital achieves 24-hour continuous monitoring to reduce equipment failure rates and downtime
Big data analysis technology	Deep mining equipment operation data	Through data analysis and prediction, make maintenance plans in advance to avoid disruption of medical services
Artificial intelligence algorithm	Failure prediction and accurate maintenance decisions	Accurately locate and solve problems, reduce maintenance costs, and improve the quality of medical services

The Internet of Things technology realizes the interconnection of medical equipment and provides the possibility for real-time data collection and transmission, while the big data analysis technology reveals the inherent laws and potential risks of equipment operation through the deep mining of massive equipment operation data. With its strong learning and reasoning ability, artificial intelligence algorithm provides scientific decision basis for fault prediction and accurate maintenance. In recent years, many successful application cases of intelligent medical equipment maintenance system have emerged at home and abroad. For example, hospitals have realized 24-hour uninterrupted monitoring of key medical equipment by introducing intelligent maintenance system, which has significantly reduced the failure rate and downtime of equipment[5]. At the same time, through data analysis and prediction, the maintenance plan was developed in advance, effectively avoiding the interruption of medical services caused by equipment failure[6]. These cases not only verify the effectiveness and feasibility of the intelligent medical equipment maintenance system, but also provide a valuable reference for the subsequent research and application.

2.2 Theoretical basis and technical support

In the construction of intelligent medical equipment maintenance system, the Internet of Things, big data analysis and artificial intelligence algorithm constitute a solid theoretical foundation and technical support. The Internet of Things technology provides a new perspective for the maintenance and management of medical equipment by realizing the interconnection of medical equipment. It enables the equipment's operating status, performance parameters and other data to be transmitted to the monitoring center in real time and accurately, laying a solid foundation for subsequent data analysis and processing[7]. In medical equipment maintenance, the application of Internet of Things technology not only improves the efficiency and accuracy of data acquisition, but also greatly expands the boundaries of maintenance management, and realizes the comprehensive monitoring from a single device to the entire medical equipment cluster. Big data analysis further taps into the value of equipment operation data. Through deep mining and analysis of massive and multi-dimensional data, big data analysis can reveal the inherent laws and potential risks of equipment operation, and provide a scientific basis for fault prediction and maintenance decisions. In the field of medical equipment maintenance, the application of big data analysis enables maintenance personnel to discover possible problems in equipment in advance and formulate corresponding preventive measures, so as to avoid the impact of equipment failure on medical services[8]. The artificial intelligence algorithm is the key to achieve accurate maintenance. By constantly learning the historical data and operating status of the equipment, it can identify various failure modes and characteristics, and formulate an accurate maintenance plan accordingly. In medical equipment maintenance, the application of artificial intelligence algorithms has greatly improved the accuracy and efficiency of maintenance, enabling maintenance personnel to locate and solve problems more accurately, thus reducing maintenance costs and improving medical service quality[9].

3. System requirement analysis

3.1 Investigation of medical equipment maintenance status

In order to have an in-depth understanding of the current status and potential problems of medical equipment maintenance, it is essential to conduct systematic status research[10]. This process will employ a combination of research methods to ensure data comprehensiveness and accuracy. First, a detailed questionnaire should be designed and distributed, which should be tailored to the equipment management department, maintenance team and front-line medical

personnel in the medical institution, aiming to collect their direct feedback and opinions on the maintenance work of medical equipment. The contents of the questionnaire should cover multiple dimensions such as maintenance process, response time, fault prediction accuracy, and cost effectiveness. Secondly, select some representative medical institutions to conduct in-depth interviews. These interviews should directly face the decision-makers, practitioners and users of equipment maintenance. Through face-to-face communication, the specific challenges encountered in medical equipment maintenance, the measures taken, the effect evaluation and the future improvement direction are deeply learned. Open and honest discussions should be encouraged during interviews in order to capture the most real and urgent needs. In addition, it is recommended to conduct on-site observation as a supplementary means of research, and directly observe the operating status, maintenance environment and operation process of medical equipment through field visits to medical institutions, so as to obtain more intuitive and specific information. On-site observation can help identify potential problems, such as improper equipment layout and insufficient maintenance tools, which are important factors affecting maintenance efficiency and quality. After collecting questionnaires, interview records and on-site observation data, these data should be systematically sorted and analyzed, and common problems and challenges can be identified by comparing and analyzing the maintenance status of different medical institutions. At the same time, we should also pay attention to the successful experience and innovative practices in individual cases to provide reference and inspiration for the subsequent system design and optimization. Based on these analysis results, the improvement direction and goal of the medical equipment maintenance system can be clarified, and more accurate and efficient maintenance solutions can be provided for medical institutions.

3.2 Function and performance requirement analysis

In the construction of medical equipment maintenance system, clear functional and performance requirements are the key to ensure the effective operation of the system, which should include: (1) real-time monitoring of functional requirements. The system must be able to monitor the running status of medical devices in real time, collect and display key parameters of the devices in real time, such as operating voltage, current, temperature, and running time. This helps maintenance personnel to know the health status of the devices in time, and provides data support for subsequent maintenance decisions. (2) Fault warning function requirements: Based on big data analysis and artificial intelligence algorithm, the system should be able to identify the abnormal mode of equipment operation in advance, predict potential failure risks, and send early warning information to relevant personnel. This function requires a high degree of sensitivity and accuracy in the system to effectively avoid the impact of equipment failures on medical services. (3) Accurate maintenance management function requirements: The system should provide accurate maintenance plan formulation and execution functions, according to the actual operating status of the equipment and historical maintenance records, tailored for each equipment maintenance plan. At the same time, it supports the automatic allocation and tracking of maintenance tasks to ensure the timeliness and effectiveness of maintenance work. (4) Real-time requirements: In the maintenance of medical equipment, real-time is crucial. The system needs to ensure that data collection, processing, and sending of early warning information can be completed in a very short time, so that maintenance personnel can quickly respond to and deal with equipment problems. (5) Accuracy requirements: the data and early warning information provided by the system must be accurate to avoid resource waste or security risks caused by false or missed alarms. Therefore, the system needs to adopt advanced data processing and analysis technology to ensure the reliability of the results. (6) Stability and reliability requirements: As the core system of medical equipment maintenance, its

stability and reliability are directly related to the continuity and safety of medical services. The system needs to have a high degree of fault tolerance and self-recovery ability to ensure stable operation in a variety of complex environments. At the same time, the system should be regularly maintained and upgraded to cope with new technical challenges and security threats.

4. System design

4.1 Design of system architecture and function modules

The design of the medical equipment maintenance management system follows the principles of high integration, modularity and expansibility. The system adopts a four-layer architecture model, including data acquisition layer, processing and analysis layer, application service layer and user interaction layer.

Starting from the data acquisition layer, it is responsible for capturing critical operational data from various medical devices in real time and accurately, ensuring the comprehensiveness and timeliness of information. This data is then passed to the processing analysis layer, which uses advanced big data processing technologies and artificial intelligence algorithms to deeply mine and analyze the data to identify abnormal patterns in the operation of the equipment, predict potential failure risks, and assess the overall health of the equipment. In the application service layer, the system integrates a number of core function modules, including real-time monitoring module, fault warning module and accurate maintenance management module. The real-time monitoring module displays key parameters of medical devices in real time through an intuitive graphical interface, enabling maintenance personnel to understand the running status of the devices at a glance. Based on the results of the processing and analysis layer, the fault early warning module automatically triggers the early warning mechanism and sends early warning information to relevant personnel to ensure that potential faults can be paid attention to and dealt with in time. The precision maintenance management module tailors the maintenance plan for each equipment according to the real-time operation data and historical maintenance records of the equipment, and supports the automatic allocation and tracking of maintenance tasks, improving the efficiency and accuracy of maintenance work. Finally, as a bridge between the system and users, the user interaction layer provides a friendly and easy-to-use operation interface to support users in equipment monitoring, fault inquiry, maintenance plan formulation and adjustment. At the same time, the system also designed a data management and decision support module, which is responsible for storing, managing and analyzing the massive data generated by the system, providing comprehensive equipment maintenance reports and decision support information for the management, helping medical institutions optimize resource allocation, improve service quality and reduce operating costs. Overall, the design of the system fully considers the complexity and diversity of medical equipment maintenance needs, aiming to improve maintenance efficiency and service quality through intelligent and automated means.

4.2 Design of database, interface and protocol

In the design of medical equipment maintenance management system, the database structure and the design of interface and protocol play a crucial role, which together constitute the basis of stable operation of the system and efficient data circulation. In terms of database, the structure of relational database should be planned and the principles of database design should be followed to ensure the consistency and integrity of data. By creating multiple core data tables, such as device information, running status, fault records, and maintenance plans, the key data of medical devices can be recorded comprehensively and accurately, and the logical relationship between the data can

be built through reasonable foreign key association. Secondly, each data table needs to be carefully designed to ensure the applicability, scalability and efficiency of the fields, laying the foundation for the stable operation of the system and future functional expansion. In terms of interface design, we follow industry best practices and use standard interfaces such as RESTful apis to interact with external systems. At the same time, a clear interface specification is developed, including request methods, parameters, response formats, and error handling mechanisms, to ensure seamless docking with external systems and accurate data transmission. At the same time, the security of the interface should also be considered, and advanced authentication mechanisms, such as OAuth2.0, should be adopted to protect the access rights of the interface and prevent data leakage and illegal access. For the communication within the system, it is necessary to define a unified communication protocol to ensure the efficient and reliable transmission of data between modules. The protocol should specify the message format, transmission mode, message type, and error handling mechanism in detail to provide clear guidance for the flow of data within the system. Through strict protocol specifications, the communication consistency and data accuracy between the modules in the system are guaranteed, which provides a strong guarantee for the overall performance and stability of the system.

5. System implementation

5.1 Technology selection and platform construction

When implementing the medical equipment maintenance management system, technology selection and platform construction constitute the cornerstone of the project start-up stage. First, the adoption of Java as a development language is mainly based on its strong cross-platform capabilities, mature ecosystem, and broad industry application base. Java not only offers a wealth of standard and third-party libraries, but also has an active developer community that can provide valuable support and resources in the event of technical difficulties. In order to further improve the development efficiency, you can choose Spring Boot as a development framework. Spring Boot greatly simplifies the initial setup and development process of Spring applications through the concept of "convention is superior to configuration". It provides features such as automatic configuration, no code generation, and rich third-party library integration, which can focus on the implementation of business logic rather than complicated configuration and dependency management. In terms of development environment construction, we should strive to create an efficient and unified development platform. First, you can choose IntelliJ IDEA as an integrated development environment (IDE), which provides a convenient development experience for developers with powerful code editing, debugging and version control capabilities. Secondly, using Maven for project management, through the pom.xml file to precisely manage the project dependency and construction process, to achieve the automatic construction and deployment of the project. Finally, Git is used for code version control to ensure that team members can share and collaborate securely and efficiently. This series of technology selection and platform building measures have laid a solid foundation for the subsequent system development work.

5.2 Function implementation, testing and optimization

In the development cycle of medical equipment maintenance management system, the stage of function realization, testing and optimization is crucial, and the efficient promotion of this stage is inseparable from the careful selection and construction of development language, framework and development environment in the early stage. Java as a development language, with its strong type safety, cross-platform ability and rich ecosystem, provides a solid foundation for system

construction. The introduction of Spring Boot framework, with its rapid development, automatic configuration and integration of third-party libraries, accelerates the implementation process of functional modules, so that the development team can focus more on the innovation and optimization of business logic. At the same time, the construction of the development environment also plays an indispensable supporting role. As an integrated development environment, IntelliJ IDEA not only provides powerful code editing, debugging and refactoring tools, but also extends development capabilities through a plug-in system, allowing developers to efficiently write and test code. Maven as a project management tool, through the management of the project object model (POM) file, to achieve the automatic resolution of project dependencies, construction and deployment, to ensure the stability and consistency of the development environment. The application of Git version control system promotes the versioning management of code, enabling team members to work together and merge code changes in time, improving development efficiency. After the function is implemented, JUnit and other test frameworks should be fully utilized to conduct a comprehensive unit test and integration test on the system to ensure the correctness and stability of each functional module (Table 2).

Table 2. Test result records and optimization measures

Function module	Test content	Test result	Optimization measure
Real-time monitoring	Data acquisition accuracy, real-time display	Passed/Failed	Adjust the data acquisition frequency and optimize the interface display
Fault warning	Sensitivity and accuracy of early warning mechanism	Passed/Failed	Adjust the warning threshold and optimize the algorithm model
Precise maintenance management	Maintain schedule rationality and task allocation efficiency	Passed/Failed	Optimize the maintenance plan generation algorithm based on historical data
Real-time and accurate	Data processing speed, data accuracy	Passed/Failed	Optimize database query and improve data processing efficiency
Stability and reliability	System operation stability, fault recovery capability	Passed/Failed	Strengthen the exception handling mechanism and improve the fault tolerance of the system

In view of the problems found in the test, optimization and adjustment should be carried out in time to improve the performance of the system and user experience. The synergistic effect of this series of technology selection and environment construction provides a strong guarantee for the successful implementation of medical equipment maintenance management system.

6. System application and effect evaluation

The implementation of medical equipment maintenance management system has shown remarkable benefits and wide application value in medical institutions. From the perspective of application scenarios, the system goes deep into the whole life cycle management of medical equipment, covering every link from procurement to storage to scrap processing, realizing real-time update and centralized management of information, and greatly improving management efficiency. In terms of efficiency improvement, the system significantly shortens the maintenance cycle and

improves equipment utilization and operational stability through online fault reporting process, automatic allocation of maintenance tasks and intelligent reminders of preventive maintenance plans. At the same time, the system accurately manages the equipment maintenance cycle and spare parts inventory, effectively avoids the waste of resources, reduces the maintenance cost, and extends the service life of the equipment through data analysis, further reducing the replacement cost. In terms of user feedback, the system has won wide praise for its simple operation, friendly interface and powerful data report function, which not only improves the satisfaction of staff, but also provides powerful decision support for management. In this way, the application of medical equipment maintenance management system has brought an overall improvement in efficiency, cost and user satisfaction to medical institutions.

7. Conclusion

This paper deeply discusses the design and implementation process of intelligent medical equipment maintenance system, aiming at improving the efficiency of equipment management in medical institutions and reducing operating costs through technological innovation. In the process of system development, this paper emphasizes the use of Java and Spring Boot as technology stack to build efficient and scalable system architecture. At the same time, through detailed demand analysis, functional design and strict testing and optimization, to ensure the stability of the system and user experience. The successful application of the system not only realizes the real-time update and centralized management of equipment information, but also significantly improves the management efficiency through the automatic and intelligent maintenance process. More importantly, the system effectively reduces the maintenance cost and prolonging the service life of the equipment by precisely controlling the maintenance cycle and spare parts inventory, bringing significant economic benefits to medical institutions. With the continuous progress of medical technology and the strengthening of the trend of intelligence, the intelligent medical equipment maintenance system will play a more important role. In the future, we will continue to optimize system functions, improve user experience, provide medical institutions with more comprehensive, efficient and intelligent equipment management solutions, and help the high-quality development of medical undertakings.

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