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The Construction and Practice of the QHSE Information Management Platform for Oil Fields

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Abstract

In order to improve the informatization and standardization level of oilfield enterprise safety management, this paper designs and implements a QHSE management system based on the open-source framework RuoYi. The system uses Spring Boot + Thymeleaf + MySQL technology stack, integrates Apache Shiro permission control module, and adds new core functions such as check entry, experience sharing, and "checking-rectification-verification" closed-loop management. It focuses on solving the inherent problems of data acquisition and synchronization in oil field under complex geographical environment. The security and rationality of the access rights of users with different roles are ensured through the permission hierarchical control and data-level isolation mechanism. The supporting mobile App has been put into use, which improves the convenience and real-time performance of on-site operation. The system is deployed in Windows environment, and the page response time is short and the operation is stable. The practical application shows that the system effectively standardizes the safety management process and improves the efficiency of hidden dangers rectification.

Keywords

Security management system; Access control; The inspection, rectification and verification mechanism

1. Introduction

With the continuous expansion of the development scale of oil and gas resources in our country, the problems of quality, health, safety and environmental management faced by oil field enterprises in the process of production and operation are becoming more and more prominent. Therefore, promoting the information and intelligent transformation of QHSE management system of oil production has become an important means to improve the safety level of oil field enterprises.

In recent years, oil production enterprises at home and abroad have developed and constructed some intelligent safety management systems to realize QHSE systems with functions such as hidden danger warning [1]. Some researchers have developed safety management platforms suitable for chemical and energy industries based on B/S architecture, and preliminaries have realized information integration and standardized process management [2]. However, the function modules of the existing domestic systems are relatively single, the deployment cost is high, and the scalability is poor, which is difficult to meet the actual needs.

The main difficulty of this platform is the inherent problem of data acquisition and synchronization in oil fields under complex geographical environment. Due to the operation area spanning four provinces and widely distributed in remote areas such as deserts and Gobi, the communication infrastructure is weak and the network coverage is uneven, which makes the traditional data transmission methods difficult to ensure real-time performance and stability. At the same time, the information sources are diverse, involving sensors, manual reporting, external system docking and other channels, and the data formats are heterogeneous and the acquisition frequency is different, which further increases the difficulty of unified aggregation and processing. How to achieve reliable data acquisition and efficient synchronization under weak or disconnected network conditions has become a key bottleneck in the system design. Existing technologies still have limitations in the face of multi-source heterogeneous data integration, cross-region data consistency guarantee and low-latency response requirements. It is urgent to build a set of data acquisition and synchronization mechanisms that adapt to complex environments to support the stable operation of the platform.

The development of open-source frameworks provides a new way for the rapid development of industry-specific management systems. As a widely used Spring Boot open-source framework in China, RuoYi has the advantages of clear structure, perfect permission model, and easy secondary development. It has been widely used in the construction of various customized information systems. However, the application in the field of oilfield QHSE management is still in its infancy, and there are few relevant studies, and there is a lack of functional design and business process optimization schemes for oilfield operation characteristics [3]. Based on RuoYi framework, this paper designs and implements a set of QHSE integrated management platform for oil field enterprises. At the same time, the mobile terminal App is developed to improve work efficiency. The system has been put into operation in oil field enterprise, which runs stably, responds quickly and gets good feedback from users.

2. Overall system architecture design

2.1. Overview of System Architecture

The management platform adopts the classic three-tier architecture mode, including the presentation layer, the business logic layer and the data access layer. The overall structure is clear, the module division is reasonable, and the coupling degree is low, which is convenient for the maintenance and expansion of the system [4].

The presentation layer is based on Thymeleaf template engine and Bootstrap framework, which supports responsive layouts and provides a good user experience across multiple devices.

The business logic layer is the core of the system, which encapsulates the key functions of inspection and entry, non-conformance rectification, experience sharing and the closed-loop process of " inspection, rectification and verification ". Through the MVC architecture of Spring Boot, the maintainability and extensibility of the system are improved.

The data access layer realizes database operations based on MyBatis, and defines data access logic through interfaces and XML mapping files or annotations, shielding the differences of underlying databases and enhancing the flexibility and portability of the system.

As a whole, the three-tier architecture of the system has clear responsibilities and efficient communication, which not only meets the business requirements of oilfield enterprise safety management, but also has good scalability and maintainability.

2.2. Technology selection and development environment

In order to ensure the stability and security of the system, this paper comprehensively considers the support degree of the open-source ecosystem, the activity degree of the community and the adaptability of enterprise-level applications, and selects the appropriate technology stack. The front-end uses Thymeleaf template engine combined with Bootstrap framework to support server-side rendering, improve page loading speed, and have responsive layout capabilities, which can be well adapted to a variety of terminal devices. The back end is based on Spring Boot to quickly build Web applications, which is convenient to integrate, and flexible data access control is realized with MyBatis. MySQL 8.0 is selected as the database, which is a lightweight relational database with high performance, high stability and good transaction processing ability, suitable for small and medium-sized project requirements. In terms of permission control, Apache Shiro framework is used, which is mature and stable, supports login authentication and fine assignment of role permissions, and is convenient for system integration and expansion. The deployment environment chooses Windows Server and Tomcat 9, which takes into account the convenience of deployment and the stability of operation, and is compatible with the existing IT infrastructure of the enterprise. The mobile application was developed independently on the mobile terminal to meet the needs of remote operation of field operators and effectively improve the availability and real-time performance of the system. In terms of data acquisition and synchronization, a multi-protocol adaptation mechanism combined with Kafka message queue and NTP time synchronization mechanism was used to realize time synchronization between multiple nodes, ensure the temporal consistency of collected data, and ensure the accuracy and reliability of data. The overall technology selection takes into account performance, security, maintainability and scalability, which provides a solid technical support for the stable operation of the system.

2.3. System Deployment structure

The system adopts a typical B/S architecture [5]. The back-end services are deployed in the Windows Server operating system, Spring Boot applications are run through Tomcat containers, and MySQL is used as the back-end database to store system data.
The system provides two modes of access (as shown in Figure 1)

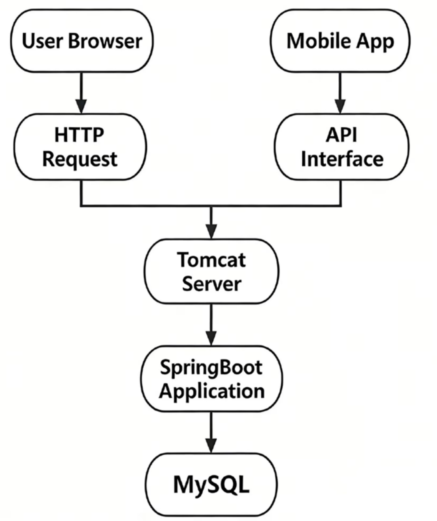

Figure 1. Access method

(1) Web access: Enterprise management personnel and security personnel can access the management platform through the browser to carry out operations such as inspection task issuance, hidden danger rectification and approval, experience sharing and publishing [6];
(2) App terminal access: staff and users receive inspection tasks in real time, upload photos for rectification, and submit feedback through the mobile client, so as to realize data synchronization and collaborative office between mobile terminal and Web terminal.

3. Design and implementation of system function module

QHSE integrated management platform focuses on the actual management requirements in oil field production, and builds a number of core businesses (as shown in Figure 2), covering inspection task management, hidden danger rectification closed-loop, experience sharing, system authority control and mobile terminal adaptation [7]. Each module has clear responsibilities and collaborative interaction, forming a complete information management system, improving the efficiency and standardization of enterprise security management. From the perspective of users, this chapter will elaborate on the design goals, usage scenarios and implementation methods of the core function modules of the platform, and show how the system can meet the safety management requirements of oil field enterprises under multi-roles and multi-scenarios.

Figure 2. Core business

The inspection entry module is the basic function of the system, which is mainly used to record the execution of daily safety inspection tasks (as shown in Figure 3). Users can create inspection tasks according to various dimensions such as department, plan and case, and support the combination of multiple conditions to query history records to assist managers in decision-making analysis. The module supports task assignment, progress tracking and other functions, which significantly improves the standardization and execution efficiency of inspection work.

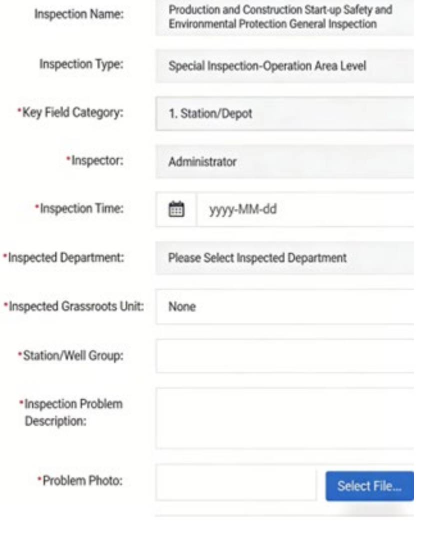

Figure 3. Check the input module

The non-conformance rectification module is the core business of the system, focusing on the realization of the whole process closed-loop mechanism of " inspection, rectification and verification ". Once security risks are found, the system will generate rectification tasks and assign them to relevant responsible persons, and set rectification deadlines [8]. After the rectification is completed, the responsible person can upload the rectification results (including text descriptions and on-site pictures), which will be reviewed and confirmed by the superior to ensure the quality of the rectification. This module significantly improves the efficiency and standardization level of hidden dangers processing through a process-driven way.

As an important part of knowledge management, experience sharing module aims to promote experience precipitation and exchange interaction within the enterprise. Users can post safety management experience, accident cases and other content, and support comments and likes. Articles are organized by categories, such as "emergency plans" and "equipment maintenance", and the system recommends high-quality content according to the popularity of browsing. This module provides knowledge support for continuous improvement of enterprises.

In order to improve the work efficiency and flexibility of staff, a mobile App is developed for the system [9]. It supports functions such as remote viewing and checking tasks, taking photos and uploading rectification results, and synchronizes with the background database in real time to ensure data consistency. For some unstable network scenarios, the App also has an offline cache function, which can automatically submit data after network recovery to ensure the continuity of work. The introduction of mobile terminal makes oilfield safety management more convenient and efficient, especially suitable for field operation environment.

Through the design and implementation of multiple core function modules, the platform fully covers the management needs of oil field enterprises in quality, safety and environmental protection, meets the standardization requirements of business processes, and improves the availability and security of the system.

4. Implementation of key Technologies

In the development process of the platform, a number of key technologies are implemented, including authority control, the design of "inspection, rectification and verification" process, operation log recording and security protection mechanism, and the design of data acquisition and synchronization mechanism in complex environment. The reasonable application of these technologies can effectively ensure the stable operation of the system and the efficient execution of the business process. From the perspective of technical implementation, this chapter will deeply analyze the selection basis, implementation principle and specific application scenario of each key technology, and show the technical innovation and engineering practice value of the system.

4.1. Login and Permissions

The login verification process ensures that users can access system resources safely and efficiently, and provides the authentication basis for subsequent operations. The user logs into the system through the browser or client, enters the account password and submits the request. The system parses the information by the login Action and invokes the UserService service to verify the user identity. If there is a match in the database, the user object is returned. Otherwise, the login failure message is returned.

After successful verification, the system inquires the associated role according to the user ID for permission control (as shown in Figure 4), and stores the user information into the Session to facilitate the subsequent rapid identification of identity and permission. At the same time, the login log, including time, IP address, etc., is recorded to facilitate audit tracking.

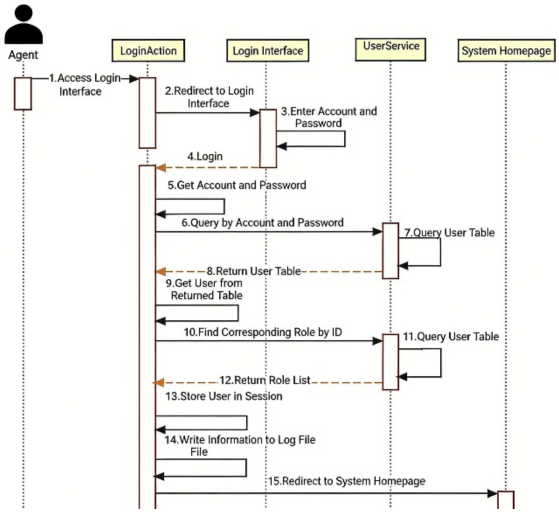

Figure 4. Login verification

The closed-loop process of " inspection, rectification and verification " is one of the core business processes of the system, which runs through the whole safety management process [10]. In order to realize the standardization and automation of this process, the system introduces the state machine mechanism, and divides the hidden danger processing into multiple states such as "to be rectified", "in rectification", "to be verified" and "completed". When the inspectors find a safety hazard, the system creates a rectification task and assigns it to the relevant responsible person, sets a rectification deadline and triggers a reminder notice. The notification mechanism supports messages, emails and short messages in the station to ensure that the responsible personnel can respond in time. In the rectification process, the system provides form linkage and data backfilling functions, allowing responsible persons to call history check data and upload rectification pictures. After the rectification is completed, the results are reviewed by the superior management, and the process is closed after confirmation. The whole closed-loop mechanism improves the response speed and execution efficiency of hidden danger management.

Access control is the basic link of system security. In order to meet the requirements of multi-role Access and data isolation in oil field enterprises, the system adopts a unified authority management system, and combines RBAC (Role-Based Access Control) model (as shown in Figure 5) to realize fine-grained permission allocation [11]. Users can obtain corresponding function permissions through role inheritance, and administrators can flexibly configure the operation scope of different roles through the interface.

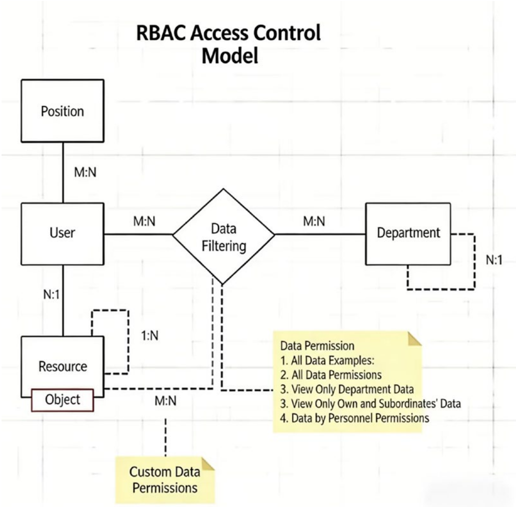

Figure 5. Permission allocation

4.2. Reliability and Security

Aiming at the problems of poor communication conditions, diverse data sources and difficult data acquisition in oil field, a set of data acquisition and synchronization mechanism adapted to complex network environment was designed and implemented. The mechanism adopts a multi-protocol adaptation strategy and supports multiple communication protocols such as MQTT, HTTP RESTful API and OPC UA to ensure uniform access to heterogeneous data [12]. The front-end acquisition device has the function of local cache and breakpoint continuation, which can ensure data integrity and improve reliability in unstable network scenarios. In terms of data transmission and synchronization, the system introduces Kafka message middleware to realize asynchronous decoupling processing, and combines NTP protocol for time synchronization to ensure the consistency of multi-node data timestamp [13]. This mechanism significantly improves the problems of data delay and loss in weak network environment, and provides key technical support for the stable operation of the platform in complex scenarios.

In terms of system security, the platform constructs a multi-level security protection system [14]. It supports the separation of function-level and data-level permissions to ensure that different roles can only access resources within their authorized scope. The system has established a complete operation log mechanism, and all key operations (such as login, data modification, task assignment, etc.) are recorded and stored in the database to support subsequent audit traceability [15]. For sensitive data access, the system implements data-level access control to ensure data confidentiality and integrity.

Through the integrated application of several key technologies such as authority control, closed-loop process design, multiple communication protocols, log and security mechanism, QHSE integrated management platform not only ensures the security and stability of the system, but also provides a strong technical support for the safety management of oil field enterprises. The implementation of these technologies provides useful experience for the construction of information management systems in similar industries.

5. Conclusion

This system significantly improves the efficiency of oil enterprises in safety production management, and solves the problem of data acquisition and synchronization in oil fields under complex geographical environment. By digitizing traditional manual, record, and approval processes, we enable rapid delivery of tasks, real-time tracking of performance, and immediate feedback on corrective actions. It significantly shortens the time cycle of solving problems and improves the transparency and traceability of the entire security inspection process. In terms of user experience, both enterprise managers and field staff can enjoy a more convenient and efficient operation experience. Enterprise managers can view all kinds of data statistical analysis reports anytime and anywhere through the Web front-end for decision support. On-site personnel can receive tasks and upload corrected photos with the help of mobile devices, which greatly facilitates the work flow. In addition, in terms of security, the multi-level permission control mechanism of the system ensures the safe access to sensitive information, and the security of data transmission is guaranteed through encryption technology, which effectively prevents the risk of data leakage.

In summary, this paper constructs an information management system with reasonable structure, perfect function, safe and controllable, which effectively meets the digital transformation needs of oil field enterprises in quality, safety and environmental protection management, and lays a foundation for continuous optimization and technology evolution of the system. With the continuous development of information technology, the system has shown good application prospects and promotion value in more industries and scenarios.

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