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Construction of Sintering Production Intelligent Monitoring and Prediction System Based on Vue Architecture

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Abstract: The sintering process is the core link in long-process steel production. Its production process involves multiple dynamic parameters, and traditional systems generate massive amounts of data daily with low utilization. To achieve data-driven production processes and intuitive visualization, this paper designs and develops an industrial-grade full-stack software system based on the Vue architecture. The system mainly consists of two core modules: the intelligent monitoring system for the sintering process and the intelligent prediction system for sintering capacity. The system front end uses Vue.js combined with Three.js technology to achieve dynamic rendering and slice display of the sinter ore 3D voxel model; in the data transmission layer, WebSocket technology is used to realize real-time streaming push of underlying working condition data and dynamic chart updates. The successful construction of this system provides the sintering workshop with a highly responsive, strongly visualized integrated monitoring and prediction platform.

Keywords: Vue Architecture; 3D Visualization; Real-time Monitoring; Software System Construction; Sintering Production.

1. Introduction

As a pillar industry of the national economy, the green and intelligent transformation of the steel industry is a key path for implementing the national strategy. The energy consumption of the sintering process accounts for a large proportion of the entire workflow, and its production indicators directly affect the smelting efficiency of blast furnaces. In the current production management system, although traditional Distributed Control Systems (DCS) play a role in basic data collection, they are often confined to the traditional management framework of 'reactive maintenance' and 'scheduled maintenance.' With modern industrial equipment trending toward larger scale, higher complexity, and faster operation, the drawbacks of traditional systems—such as poor real-time performance and lack of online intelligent state monitoring and predictive capability—have become increasingly prominent. This results in massive production data being unable to be converted into proactive preventive decision-making guidance, and this passive response mechanism can no longer meet the demand of modern enterprises for efficient and safe production [1].

To address this engineering challenge, it is particularly necessary to build a new sintering control system based on modern information technology. Research shows that deploying a full-line quality intelligent control system integrating data mining and intelligent algorithms can effectively extract the underlying patterns among complex process parameters; this is not only an effective way to stabilize sinter ore quality indicators and reduce production costs, but also an essential path to promoting the automation and intelligence of sintering production [2]. In this process of intelligence, converting abstract massive data into intuitive interfaces that engineers can easily understand is the core support for breaking data silos and achieving efficient human-machine collaboration. Based on the limitations of the traditional system and the urgent demand for deep visualization in modern industrial sites, this paper abandons the outdated offline static analysis mode and focuses on discussing how to use modern frontend Web technology stacks to build a highly responsive real-time intelligent monitoring and predictive visualization system.

2. Characteristics of Software System Architecture

(1) Frontend Presentation Layer Architecture

The system uses a lightweight, progressive Vue.js framework to build a single-page application (SPA).In order to improve development efficiency and code reusability, using Vue.js can effectively simplify the web front-end development process, reduce development difficulty, enhance development efficiency, achieve complete separation of front-end and back-end development of web systems, and improve the system's flexibility and scalability. [3]To enhance the user experience of industrial software and the readability of data information, the visual scheme of the system's frontend interface and interactive components is layered using multiple tones. This component-based development model significantly improves the reuse and rendering efficiency of various data dashboards and line chart components.

(2) 3D Rendering and Display Features

Traditional monitoring systems often lack an intuitive representation of the physical form of products. This system introduces WebGL and the Three.js library, specifically for hosting and rendering multi-angle 3D reconstructed models of sintered ore. WebGL technology supports rendering 2D and 3D graphics in browsers. At the same time, WebGL can directly call the underlying GPU graphics card instruction set to render graphics, compatible with both PC browsers and mobile browsers, with cross-platform and portability features.[4]Operators can break through the limitations of the two-dimensional plane and intuitively observe three-dimensional sectional phase diagrams with a strong sense of spatial and stereoscopic perception.

(3) The streaming characteristics of data communication

To support the high concurrency and high-frequency data refresh requirements of industrial sites, this system abandons the traditional HTTP polling mechanism and uses WebSocket to achieve full-duplex communication. This architecture allows the parameters collected by the underlying sensors to be streamed to the front-end dashboard with millisecond-level latency, ensuring that the color rendering and data updates on the front-end display remain highly synchronized. Can significantly improve real-time service performance and more efficiently utilize network load and server-side processing capabilities [5].

3. The Application Value of Software Systems in Modern Sintering Production

The construction of modern industrial software still has extremely high on-site application value. For modern sintering workshops, it sends out a very strong signal for digital transformation. First, we need to break the rigidity of traditional DCS system interfaces. Although the DCS functions are integrated with the dedicated control functions of fieldbus instruments, maintaining the real-time performance and advancement of the product to prevent the original system from being obsolete, traditional systems often lack intuitive mapping of abstract data, and their patterns are fixed and rigid. This is not conducive to operators making quick judgments.[6]This system uses modular dashboards and dynamic line charts to reasonably segment and reconstruct massive amounts of data, making it more in line with the aesthetics and human-machine interaction requirements of modern industrial control. Secondly, the system enhances data readability, making it more consistent with engineers' understanding of production processes. By encapsulating complex underlying logic under an intuitive UI, it improves the aesthetic and practical levels of modern industrial design.

4. The Application of Core Subsystems in Modern Sintering Production

(1) Application of Intelligent Monitoring System in the Sintering Process

The core goal of this system is to rely on modern Web technologies to achieve millisecond-level real-time visual analysis and dynamic monitoring of high-dimensional operating condition features. In modern sintering production, the frontend deeply integrates high-performance chart libraries such as ECharts and combines them with Vue's reactive data binding mechanism to dynamically render time series charts of key variables such as ignition temperature, material layer thickness, endpoint temperature, and negative pressure. To cope with the frequent refresh of massive industrial data, the system's underlying layer uses WebSocket full-duplex communication to ensure seamless streaming of sensor data to the frontend. At the same time, the system innovatively introduces a 'dual-track data visualization technology,' that is, overlaying actual operation curves with dynamic safety threshold boundaries on the same time axis. Operators can smoothly trace historical fluctuation points through interactions such as mouse dragging and wheel zooming, completely changing the traditional DCS system's rigid interface and difficulty in data tracking.

At the same time, the system has achieved a qualitative breakthrough in the microstructural monitoring layer. Traditional monitoring systems often can only provide macroscopic two-dimensional parameters and cannot intuitively display the physical morphology inside the product. This system leverages the WebGL and Three.js rendering engines to natively embed multi-angle sectional phase diagrams derived from three-dimensional voxel modeling (3D Voxel Reconstruction) on the front end. Specifically, the system directly loads the discretized 3D voxel feature space, obtained through multi-layer CT spatial analysis and multi-material clustering analysis, into the browser, constructing a highly realistic digital twin.

In terms of interactive experience, the system provides operators with great flexibility. Workshop engineers do not need to install any bulky desktop clients; they can use a browser to freely rotate, pan, and zoom without loss at 720 degrees, analyzing 3D cross-sections of the product from the front, left, and right sides in all dimensions. Furthermore, the system employs pseudo-color mapping technology to render 3D coordinate statistical data of key parameters such as TFe and Pb as color gradients on the 3D slices, making the geometry and depth distribution of pores and cracks immediately apparent. This non-destructive monitoring mode, based on intelligent modern rendering technology, perfectly replaces the lagging and destructive traditional offline manual sampling mode, greatly improving the detection efficiency of microscopic defects and the level of intelligent interaction in the workshop.

(2) Application of Intelligent Prediction System for Sintering Capacity

In the production forecasting and scheduling decision-making phase, industrial data dashboards often face the severe challenges of a broad audience (covering frontline operators and workshop management), high interaction frequency, and diverse application scenarios. To efficiently and accurately convert complex backend simulation results into a highly interactive frontend visual interface, this system has deeply restructured the UI/UX design of the forecasting system based on the reactive and component-based features of the Vue framework.

First, in terms of presenting and retrieving massive operational data, the system customizes and encapsulates a high-performance Data Grid component. For industrial environments where tens of thousands of streaming data entries are generated, the component adopts Virtual Scrolling and lazy loading technologies at the underlying level, rendering only the DOM nodes within the visible area as needed, completely resolving memory overflow and lag issues encountered by traditional web pages when handling large-scale industrial lists. This front-end database view not only supports smooth pagination transitions but also integrates multi-dimensional compound searches, column width auto-adjustable dragging, and threshold-based color highlighting for key quality indicators (such as TFe and ore return rate), making the browsing of massive historical parameters and real-time features extremely smooth.

The more core engineering breakthrough lies in the fact that the system has developed a dedicated 'time-space overlay' real-time data comparison module on the front-end interface. This module fully leverages front-end rendering performance and, using chart containers such as ECharts, performs high-precision on-screen overlay rendering of the system-generated future prediction curves with the actual operating condition curves returned by underlying sensors. By visually differentiating the predicted intervals from the actual intervals (for example, using a combination of dashed and solid lines or gradient-filled transparent bands), operators can very intuitively observe the fitting trajectory of historical data trends and future production capacity trends.

This innovative design completely breaks the limitations of traditional DCS systems that 'only display the past and cannot predict the future' for passive monitoring. With the built-in dynamic streaming processing mechanism of the system, once the front end detects that the predicted curve is approaching or exceeding the safety threshold boundary within a future time window, the corresponding components will immediately trigger millisecond-level visual cascade alerts (such as breathing flashes on the chart border or automatic topping of alert information streams). This design, which precisely maps the back-end extrapolation results to the front-end interactive interface, not only gives the system a highly modern technological dynamic warning appeal but also, from a software engineering perspective, substantially promotes the sintering production shift from traditional 'post-event traceability' to modern 'feedforward proactive intervention'.

(3) Visualization model of innovative operating condition data

The traditional industrial monitoring data display interface has evolved over decades, solidifying a presentation mode dominated by dense data tables and static 2D process diagrams. This highly homogenized design, lacking visual hierarchy, not only offers very poor frontend flexibility but also easily causes operators to experience severe visual fatigue and 'data cognitive overload' when faced with massive, high-frequency fluctuating multidimensional operating parameters in the sintering production process. This rigid interactive interface often forces engineers to painstakingly search for key information among a vast amount of numerical data, greatly reducing the efficiency of abnormal condition identification and the agility of process control.

In response to this industry's pain points, and after an in-depth analysis of the complex and ever-changing dynamic control requirements on the industrial site, this system carried out disruptive innovations in the presentation mode of underlying data during the front-end architecture design phase. Leveraging the powerful component orchestration capabilities and global state management mechanisms of the Vue.js framework (such as Vuex/Pinia), the system completely breaks the traditional DCS system's fixed mindset of 'one screen for everything' and 'everyone sees the same interface.' We decoupled and performed advanced visual reconstruction on thousands of key process monitoring points (such as ignition temperature distribution, negative pressure fluctuation curves, material permeability index, etc.), and flexibly mapped them to more diverse and highly customizable front-end visualization components.

Specifically, the system breaks the conventional data listing by introducing visually striking responsive dynamic dashboards and high-precision data heat maps. The dynamic dashboards can automatically perform smooth pointer animations and trigger cascading changes in alert colors based on real-time streaming data pushed through WebSocket; meanwhile, the heat map components transform originally abstract multidimensional parameter distributions or spatial temperature fields into intuitive color gradient maps. Moreover, thanks to modern front-end technologies, operators can even customize their own monitoring panel layouts through drag-and-drop and zooming, achieving a "unique view for every user" under different operating scenarios.

This multi-dimensional, dynamic-static combined panoramic data display strategy brings front-line workshop operators an unprecedented and highly immersive interactive experience. It not only effectively eliminates the friction in human-computer interaction caused by traditional interfaces, making the evaluation of complex process states intuitive and efficient; but also, through the support of modern web rendering engines and the coordination with advanced UI color palettes, endows the overall data flow display with a strong sense of technology and fashion, truly leading industrial control software in making the modern aesthetic leap from 'passively usable' to 'actively user-friendly'.

5. Conclusion

The rapid development of the Industrial Internet of Things (IIoT) has enabled industrial power systems and underlying production equipment to acquire massive amounts of real-time data, providing a solid data foundation for in-depth process feature analysis and digital twin construction. However, traditional industrial monitoring configuration software and offline analysis methods often reveal computational bottlenecks and extremely high front-end rendering resource consumption when dealing with TB-level time-series data and complex three-dimensional spatial mappings generated by sensor networks, making it difficult to meet the stringent requirements of modern workshops for high concurrency, high-frequency interaction, and low-latency display.

Addressing the common pain points of this industry, this paper transcends the limitations of traditional metallurgical process research. From a global perspective of modern industrial software engineering, it deeply integrates cutting-edge web technology stacks to completely reconstruct the sintering monitoring system. By introducing the lightweight Vue.js progressive framework to build a highly cohesive front-end presentation layer, leveraging Three.js and the WebGL hardware acceleration engine to overcome performance bottlenecks in microscopic 3D rendering, and extensively applying WebSocket full-duplex communication technology to enable end-to-end streaming data transfer, this paper successfully designs and independently develops two core industrial applications: an intelligent monitoring system for the sintering process and an intelligent prediction system for sintering capacity.

Long-term on-site testing and actual network deployment results fully demonstrate that this full-stack software system not only exhibits extremely outstanding system robustness and smooth rendering when processing tens of millions of industrial big data concurrently, but also provides front-line operators with a real-time interactive experience with very low latency through disruptive multidimensional visual interactions (such as 3D voxel slicing lossless viewing and spatiotemporal superimposed dynamic feedforward warning). The successful implementation of this system not only effectively breaks the data silos between the equipment layer and the decision-making layer, significantly reducing system deployment and maintenance costs, but also provides a reference-worthy and highly promotable modern software engineering practice paradigm for the digital and intelligent transformation of complex metallurgical processes, possessing extremely profound practical engineering application value.

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