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Structure Improvement and Optimization of Gantry Milling System for Complex Boring and Milling Machining Center

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Abstract: To enhance the efficiency and machining precision of the TX1600G complex boring and milling machining center, a study was conducted on the structure of its gantry milling system. This study aimed to mitigate the influence of factors such as structural quality, natural frequency, and stiffness. The approach employed for this investigation involved mechanism topology optimization. To initiate this process, a finite element model of the gantry milling system structure was established. Subsequently, an objective function, comprising strain energy and modal eigenvalues, was synthesized. This objective function was optimized through multi-objective topology optimization, taking into account certain mass fraction constraints and considering various factors, including processing technology. The ultimate goal of this optimization was to create a gantry milling structure that exhibited high levels of dynamic and static stiffness, a superior natural frequency, and reduced mass. To validate the effectiveness of these topology optimization results, a comparison was made between the new and previous structures. The findings of this study serve as a valuable reference for optimizing the structure of other components within the machining center.

Keywords: Machining center gantry milling system structure; Natural frequency; Stiffness; Multi-objective topology optimization

Online publication: September 25, 2023

1. Introduction

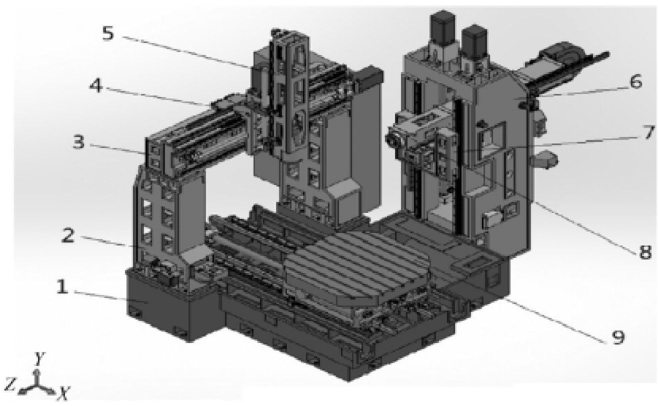
This paper focuses on investigating the gantry milling system structure of the TX-1600G complex boring and milling machining center. In line with real-world conditions, a modal was created using Solidworks, simplifying the gantry milling system structure by including the headstock beam and other milling components in various operational scenarios. Utilizing the density method in conjunction with compromise programming and efficiency function theory [1], each element's relative density within the three-dimensional (3D) mesh, as divided by Hypermesh, was chosen as the design variable. The constraint applied was a specific volume fraction.

Subsequently, the topology of the 3D mesh was optimized using the Optistruct module of Hyperworks. This optimization process resulted in a distribution diagram that highlights the optimal material placement for the gantry milling structure. The ultimate goal of this effort was to enhance the static characteristics of the gantry milling structure, thereby improving the machining precision of the boring and milling machining center.

2. TX-1600G complex boring and milling machining center structure and topology optimization mathematical model

2.1. TX-1600G complex boring and milling machining center

TX-1600G complex boring and milling machining center is a medium-sized complex machining center with independent intellectual property rights developed under the support of "National 863" program (**Figure 1**). This machining center employs a combination of gantry milling and horizontal boring techniques within a complex processing structure. Its main purpose is to manufacture intricate box-shaped components commonly found in military applications. These parts are typically processed with a single clamping, utilizing five-axis linkage for maximum efficiency.



1- bed body; 2- Milling column; 3- Beam; 4- milling table;
5-headstock; 6-boring column; 7- boring slide table;
8- Slider; 9- Working turntable

Figure 1. TX1600G boring and milling machining center model

The milling system plays a pivotal role within the boring and milling machining center, and its dynamic performance has a direct impact on the overall machining accuracy, motion stability, vibration resistance, and service life of the whole machining center [2]. Therefore, in the structural design phase, particular emphasis should be placed on prioritizing the dynamic characteristics and natural frequency of gantry milling system structure.

2.2. Mathematical model of multi-objective topology optimization

In practical engineering design, it is recognized that single-objective optimization may not effectively address diverse range of problems in practice. In this paper, the multi-objective topological optimization problem is simplified into a more manageable form using the efficiency function theory and the compromise programming method. This approach enables the attainment of a structurally advantageous layout with attributes such as reduced displacement, minimized resonance, and smaller overall volume. The efficiency function initially determines the infeasible values and optimal solutions for each sub-objective, considering the degree of achievement among these sub-objectives as a benchmark. Through a weighted methodology, the multi-objective topology optimization problem is converted into multiple single-objective topology optimization problems. Compromise programming is utilized to translate the absolute variable values from different sub-targets into a measure of similarity regarding the optimal solution for each sub-target, thereby unify the target measures of different sub-targets. Therefore, the mathematical model is selected as follows:

$$\min_{\rho=(\rho_1\cdots\rho_n)^T} R(\rho) = 2\left\{\omega^q\left[\sum_1^m \omega_k \frac{C_k(\rho) - C_k^{\min}}{C_k^{\max} - C_k^{\min}}\right]^q + (1-\omega)^q\left[\frac{\Lambda_{\max} - \Lambda(\rho)}{\Lambda_{\max} - \Lambda_{\min}}\right]^q\right\}^{\frac{1}{q}}$$

If the obtained $R(\rho)$ is smaller, the next order natural frequency and strain energy of each working condition will be higher completion degree, and closer to the optimal solution of each sub-target, then the obtained structure meets the actual requirements.

3. Working condition of gantry milling system structure

3.1. Load source and constraint of gantry milling system structure

The gantry milling system structure comprises the beam and left and right columns. When considering topological optimization for the gantry milling system structure, the primary factors to take into account are the actual load conditions and the specific requirements imposed by the complex boring and milling machining center's operation. The beam bears the external load, which includes the weight of components like guide rails and electrical equipment, in addition to its own gravitational forces. Furthermore, the beam also supports the center of gravity of milling components such as headstock and sliding table. It is important to note that the center of gravity of these components and the gantry milling system structure may not always align perfectly, leading to eccentric forces that result in torsion of the beam. This, in turn, causes the left and right columns to experience complex external forces. To address the influence of milling force, a translation calculation method for the maximum operational conditions is employed, taking into account the cutting forces detailed in the "Metal Cutting Manual" for end milling of a place [3]:

$$F_c = 6 \times 10^4 \times \frac{P_c}{v_c}$$

In milling, the cutting force in rough milling is much greater than that in fine milling, so the structure of gantry milling system under rough milling is analyzed. According to the machining center manual, the milling power can be obtained as 22.356 kW, and the vertical milling component force can be obtained as $F_{fN} = 801.12\ N$ by inserting the above formula. Longitudinal milling force is $F_f = 312.5\ N$; Transverse milling force is $F_c = 467.21\ N$. The cutting force will cause bending and torsional deformation of gantry milling system structure, thus affecting the machining accuracy.

In the finite element analysis, the beam can be regarded as a whole, the left and right columns as a whole, the gantry milling system structure is divided into three parts respectively.

3.2. Modal and static analysis of gantry milling system structure

The working stroke of the beam is 1000 mm, then it can be divided into 7 working conditions in the transverse: 830 mm, 1,030 mm, 1,230 mm, 1,330 mm, 1,430 mm, 1,630 mm, 1,830 mm. The longitudinal working stroke of the headstock is 1,000 mm, which can be divided into 5 working conditions in the longitudinal direction: 330 mm, 580 mm, 830 mm, 1,080 mm, 1,330 mm. Therefore, the orthogonal analysis of gantry milling system structure can be carried out.

Only the maximum deformation of the x and z axes is considered first. According to the analysis results, the deformation under 1,330 mm / 330 mm is the most serious, so the optimization design under the constraint conditions can meet the stiffness requirements under other working conditions.

To facilitate grid division work, finite element models for the original beam and the left and right columns were established based on their respective dimensions. It was crucial to ensure that these models retained the essential features required for the assembly of beams and columns while simplifying unnecessary elements. For instance, extraneous features such as round holes, chamfers, small bosses, sags, and similar details were omitted [4]. Additionally, material properties were assigned to the gantry milling system structure, and hexahedral mesh division was applied, along with the incorporation of boundary conditions and other necessary adjustments. The displacement contour plots for the original beam and columns can be observed in **Figures 2(A)** and **2(B)**. The first-order natural frequency modes of the original beam and the left and right columns are illustrated in **Figure 3(A)** and **3(B)**.

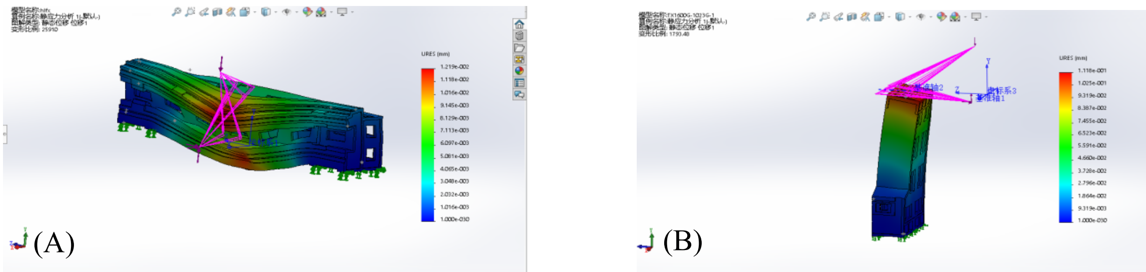


Figure 2. Static analysis cloud image of (A) the original beam and (B) the original column

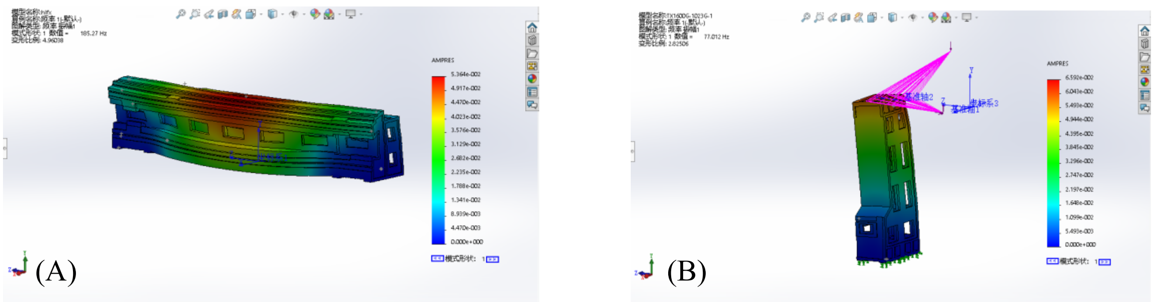


Figure 3. First order modal analysis cloud image of (A) the original beam and (B) the original column

The maximum comprehensive deformation of the original beam is 0.0122 mm. The first natural frequency of the original beam is 185.270 Hz. The maximum comprehensive deformation of the original left column is 0.1118 mm; The first natural frequency of the original left column is 77.012 Hz. The above data were inserted into the mathematical model to prepare for the next step of multi-objective topology optimization.

4. Structural topology optimization of gantry milling system

This paper employs a combination of the compromise programming method and the efficiency function method to enhance the stiffness and first natural frequency of the gantry milling system within the TX-1600G complex boring and milling machining center. To achieve this, the strain energy and the first-order natural frequency of the original beam and left column were processed to standardize their performance parameters. These processed values, namely the strain energy and the first-order natural frequency, were designated as the design variables for the comprehensive objective function, facilitating the topology optimization of the gantry milling system [5].

For each individual objective, the ideal value was substituted into the mathematical model, and the objective function aimed to minimize this mathematical model. Modal analysis of the model post-optimization revealed a ω-weight ratio of 0.44 for the beam and 0.45 for the left column, both subject to a specific volume fraction constraint.

Following 80 iterations for the beam, the model reached an optimal value of 0.03, and the corresponding density cloud map was generated (**Figure 4A**). Similarly, after 57 iterations for the left column, an optimal model value of 0.41 was achieved, accompanied by the generation of a density cloud map (**Figure 4B**).

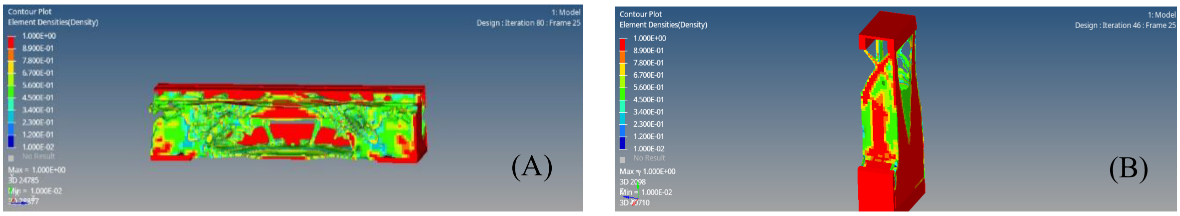


Figure 4. Spectacular topology optimized density cloud image of (A) the beam and (B) the column

5. New structural modeling of gantry milling system

In the process of re-modeling the gantry milling system structure, two guiding principles are adhered to, taking into account the distribution of the density contour for both the beam and the left column: (1) Maintain the original assembly relationship between the new model and other components, while modifying the distribution of reinforcement plates and the internal cavity's shape within the structure; (2) Align the distribution structure of stiffened plates within the design area as closely as possible to the corresponding density contours obtained from the structure's topology optimization. This alignment ensures that the performance parameters of the newly designed structure are in sync with the ideal values and guarantees the quality of the new structure [6-8]. Following several iterations of modeling improvements, static analysis, and modal analysis, the new beam structure for the gantry milling system of the TX-1600G complex boring and milling machining center, as designed in this paper, is shown in **Figure 5(A)**, and the new column structure is shown in **Figure 5(B)**.

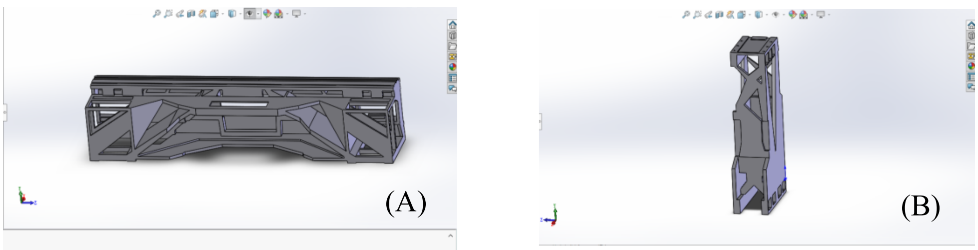


Figure 5. Structure drawing of (A) the new beam and (B) the new column

6. Performance comparison before and after structure of gantry milling system

The displacement contour plots from static analysis for the newly optimized and reconstructed gantry milling system structure can be observed in **Figure 6(A)** and **(B)**. Meanwhile, the first-order natural frequency mode illustrations are provided in **Figure 7(A)** and **(B)**. Additionally, **Table 1** presents the structural performance parameters of the gantry milling system.

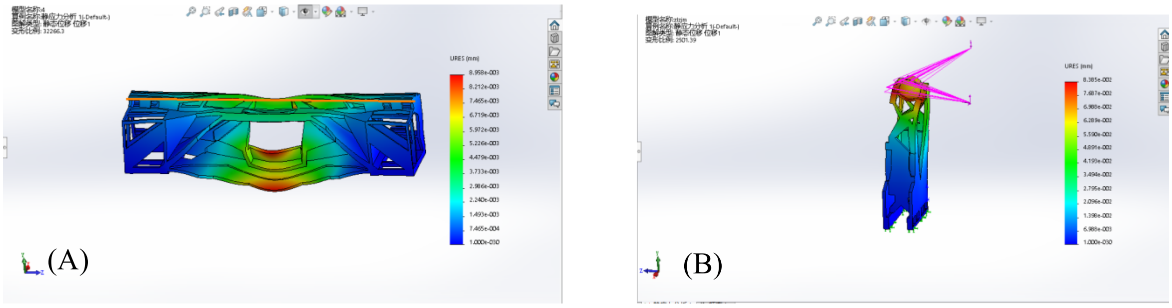


Figure 6. Static analysis cloud image of (A) the new beam and (B) the new column

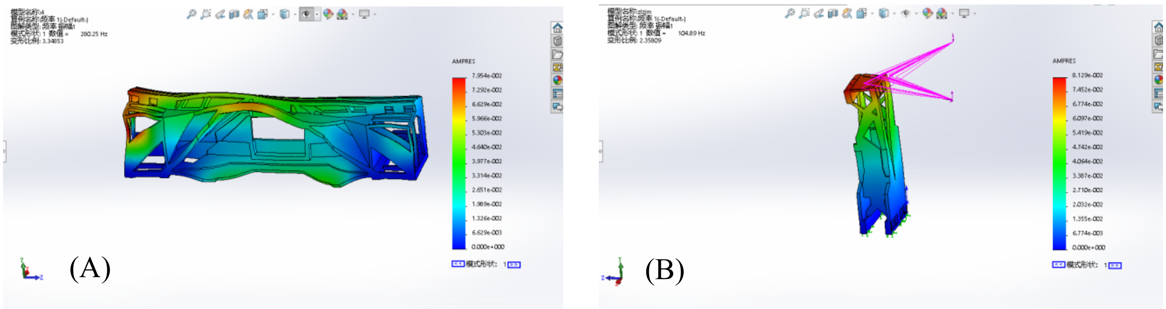


Figure 7. Cloud image of first-order modal analysis of (A) the new beam and (B) the new column

Table 1. Comparison of structure and performance parameters of gantry milling system

Structure component	Before and after optimization	Maximum deformation (mm)	First natural frequency (Hz)	Quality
Beam	Before optimization	0.01219	185	2838kg
	After optimization	0.008958	280	2366kg
	Degree of improvement	-25.13%	34%	-16%
Post	Before optimization	0.1118	77	2110kg
	After optimization	0.08385	105	1809
	Degree of improvement	-25%	27%	-14%

Table 1 provides conclusive evidence of the improved mechanical characteristics of both the beam and the column within the gantry milling system structure. Specifically, the beam exhibits significantly reduced deformation, even under the most demanding operational conditions when the headstock is positioned at the beam's midpoint. Moreover, there is a substantial increase in the first-order natural frequency for each component. As these performance parameters are improved, the overall weight of the gantry milling system structure is significantly reduced, resulting in lowered manufacturing costs. These improvements collectively contribute to the smoother operation of the compound boring and milling machining center and lead to heightened machining precision within the machining center.

7. Conclusion

In this paper, a novel gantry milling system structure is designed using the topology optimization method, which incorporates both the compromise programming method and the efficiency function method. The resulting structure exhibits superior performance parameters while maintaining reduced overall weight. This not only leads to cost savings but also enhances the machining accuracy of the complex boring and milling machining center by improving the dynamic and static characteristics of the gantry milling system structure. Furthermore, this paper underscores the advantages of multi-objective topology optimization technology in structural design, showcasing its potential for various optimization projects. The findings here can serve as a valuable reference for the topology optimization design of different components and structures.

Disclosure statement

The authors declare no conflict of interest.

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Application of EDA Technology in Intelligent Communication Electronic Circuit

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Abstract: Electronic design automation (EDA) technology is the product of the computer age and finds its foundation in CAD, CAM, CAT, and CAE. EDA is a kind of auxiliary tool in the design process, which requires the designer to carry out the file design work using hardware language as the foundation. Subsequently, the computer system automatically compiles and integrates the file to achieve simulation goals, and can complete the programming download of the target chip. At present, this technology is widely used in the communication of electronic circuits. This paper summarizes EDA technology and analyzes its specific application in communication electronic circuits, aiming at promoting the application of CDA technology and promoting the further development of the communication field.

Keywords: EDA technology; Intelligent communication; Electronic circuit

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1. Introduction

In the 21st century, human beings have entered the computer age, and the development of any field is inseparable from computer technology, among which electronic design automation (EDA) technology is a typical representative of advanced computer technology, which is mainly used in the design of communication electronic circuits. The communication industry is the fundamental element of social and economic development, and the stability of communication electronic circuits will have an important impact on the development of other fields, so it is necessary to conduct in-depth research on the application of EDA technology in communication electronic circuits.

2. EDA technology overview

EDA technology operates on computer platforms and continually evolves in tandem with advancements in computer technology. Its most distinctive feature lies in the design process, which contrasts with the traditional electronic design process. EDA employs a top-down approach, commencing with the overarching concept, planning the interrelations among various components, rectifying design errors through simulation, and ultimately reducing the error rate. When describing high-level language logic, EDA serves as a critical support, allowing designers to delineate the hardware functionalities of the system according to their design needs, thereby facilitating electronic circuit design. In summary, the application of this technology in electronic circuit design enhances design efficiency, mitigates the occurrence of design errors, and plays a pivotal role in the development of the communication field [1].

3. The specific application of EDA technology in communication electronic circuits

3.1. Application to radio frequency electronic circuit design

The design of a radio frequency (RF) electronic circuit requires the support of EDA technology, with a toolkit that comprises three types of software: programmable chip design software, chip-assisted design software, and system design software. These software tools collectively enable the preparation of the design files with the use of very high-speed integrated circuit hardware description language (VHDL), which is a hardware description language. Upon the completion of logical compilation tasks, the system automatically segments and simplifies the compilation outcomes. Subsequently, several key tasks are essential for the target chip: firstly the accomplishment of logic mapping; secondly, the execution of adaptation compilation; and thirdly, the successful programming download.

EDA technology also contains two types of important software packages: the synthesizer and the adapter, which the latter needs the support of the former to form a file configuration. These files are placed in the target device after the generation of downloaded files such as JED. When selecting the target device, the adaptability of the adapter as well as the relationship between the adapter and the synthesizer need to be considered. The synthesizer must first comprehend the hardware structure parameters, convert the high-level language in the circuit into a low-level description, and then carry out a series of compilation and conversion works before it starts working [2].

When this technology is applied to RF electronic design, each unit circuit and the total circuit need to be simulated and verified, which requires the electronic simulation component model to provide support. Under normal circumstances, these component models have typical characteristics, the component parameters show obvious discreteness, and the distribution of all electronic circuits needs to follow certain laws. To begin with, the schematic circuit is designed using tools such as Menter and Protel, and the design file can be generated. The circuit performance of the design also requires testing. Simulation software is used for detecting the wrong connection modes in the circuit and giving reminder contents that the designer can modify accordingly and generate a correct and perfect design drawing. The printed circuit board (PCB) is then generated according to the design. It is worth noting that EDA technology has higher requirements for PCB size and large device density, and must be routed following the prescribed rules. PCB design poses a greater level of complexity, but with the assistance of these auxiliary software tools, it becomes possible to streamline the design process, effectively manage circuit signals, and ultimately generate a comprehensive PCB layout. This finalized layout serves as the foundation for production in the factory.

3.2. Applications in radio frequency electronic circuit design

EDA technology leverages computers as tools, empowering designers to utilize the EDA software platform alongside the hardware description language VHDL for the creation of design files. Thereafter, the computer automatically undertakes tasks encompassing logic compilation, simplification, segmentation, synthesis, optimization, layout, wiring, and simulation. This comprehensive process leads to the eventual adaptation compilation, logic mapping, and programming download for the specific target chip.

In terms of its development trajectory, EDA technology has experienced three distinct stages. The initial stage involved EDA's application in electronic circuit CAD, employing simulation software like Eesolf and Protel, which served as essential tools for domestic circuit design developers over many years [3]. During this stage, the primary objective was to harness the computer's program editing capabilities to formulate circuit theoretical algorithms and related empirical formulas, gradually transitioning toward more sophisticated functions such as auxiliary analysis and PCB production. While the early adoption of EDA software alleviated the labor burden and enhanced efficiency, it was characterized by relatively low levels of intelligence due to its nascent stage.

The second stage of EDA development witnessed the introduction of automatic layout and circuit-level simulation and analysis capabilities, driven by competition among EDA companies in developed nations. During this stage, EDA technology demonstrated improved intelligence. Since then, EDA technology continued to evolve, reaching its pinnacle in the late 1990s when it transitioned from a rudimentary software with limited functionality to a sophisticated simulation system capable of replacing much of the manual effort. In the mature stage, EDA technology proved exceptionally valuable, particularly in the realm of radio frequency electronic circuit design.

Currently, the most widely employed EDA software in the field of RF technology includes Agilent's ADS software, Ansoft's HFSS designer software, and CST software. In addition, circuit design software like AWR and Serenade are also widely used. Among China's universities and numerous research institutes, ADS software stands out as the most extensively utilized, as it is a comprehensive electronic design software offering capabilities for circuit design analysis, device analysis, electromagnetic (EM) compatibility analysis, and more. On the other hand, HFSS software excels in solving enclosed domain problems and conducting radiator calculations. AWR or Serenade software shines in swiftly calculating parameters. For designing microwave components like filters, the filter design guide software comes into play. The initial design can be created using this software, followed by constructing a model through ADS EM simulation or HFSS software. Subsequently, the simulation design can be optimized using the method of moments (MOM) or finite element method (FEM), significantly enhancing design efficiency and accuracy.

For instance, the microstrip filter is designed using AWR and ADS software, and its technical specifications call for a frequency range of 4.25–5.55 GHz with a band interpolation loss of 1 dB. The design process begins with the AWR software's filter synthesis wizard, which facilitates rapid filter fitting calculations. In this case, a 5th-order half-wavelength wide-side coupled resonant microstrip filter is selected as the design task [4]. Parameters like band interpolation loss (set to 0.2 dB), bandwidth (chosen as 3.85–5.95 GHz), and dielectric substrate properties ($\varepsilon = 9.6$, 25 mil thickness) are configured. These settings yield a calculation model for a 5-order half-wavelength wide-edge thickened microstrip filter. After adding excitation, S-parameter curves are obtained. To enhance the accuracy of the design results and account for transmission line discontinuities and edge capacitance, electromagnetic values need to be calculated. Here, the powerful capabilities of ADS software come to the forefront, where the process begins with correcting each transmission coupling line segment involved in the filter, followed by moment method analysis in the EM mode. The moment method accurately simulates and optimizes the filter within the semi-open domain of planar circuits.

The calculated microstrip line impedance and corrected sizes of each segment are embedded within ADS. The model is then established in EM simulation mode. Ultimately, the sub-bandpass filter's 3 dB bandwidth, simulated using ADS software, falls within the range of 4.05–5.98 GHz, with a band interpolation loss below 0.36 dB, meeting the relevant requirements. However, when an actual filter is fabricated and tested, the 3 dB bandwidth is measured as 4.41–5.39 GHz, with a somewhat deteriorated band interpolation loss. This degradation can be attributed to inherent losses in the microstrip line and incomplete port connections.

Nevertheless, the passband center remains generally stable.

3.3. Application to the frequency divider design

Frequency dividers constitute a fundamental component of electronic circuits, and their selection varies based on different communication electronics. When designing these circuits, there are generally two options for frequency division: half-integer frequency division or integer digital frequency division. In some cases, multiple electronic circuits may necessitate various forms of frequency division. The choice depends on the specific design requirements.

With the advent of EDA technology, the design of frequency dividers has undergone significant changes. This paper primarily discusses designing reference signal integer frequency dividers. When the electronic system receives a signal, it is assumed to be a clock signal, and its period and frequency are predetermined before processing. This signal is treated as a sensitive input and undergoes processing to generate four corresponding output signals. Meanwhile, an alarm bit signal needs to be configured within the relevant system, along with the corresponding counter, enabling the conversion of message numbers to achieve the design objective. The specific design process can be broken down into six steps:

(1) Launch the program and open an existing project, specifying the design type and specific requirements. Select an appropriate storage path, create a new folder if needed, and assign a name to the design folder, followed by loading the necessary file.

(2) Examine the model of the target chip and select the corresponding FPGA chip. Configure all parameters accordingly and invoke the relevant EDA tools based on the selected chip type.

(3) Construct hardware descriptors using auxiliary software. Navigate to the File menu, locate the New icon in the dialog box, input the corresponding language program, save the file, and assign a suitable filename based on its content. Proceed to compile by clicking the toolbar, and if any errors arise, they should be reviewed and corrected by the designer.

(4) After creating the document, generate a simulation waveform diagram. Follow similar steps as before, but when selecting the waveform file in the New menu, move the mouse icon to the blank area below and double-click to enter the emulation port selection.

(5) Simulate the selected simulation port by setting the simulation time, typically around 20 microseconds. In the clock dialog box, establish the start and run times, then select the high or low-level range. After these settings, exercise caution to protect against unintended changes and maintain consistency between names and files.

(6) Proceed with compilation settings to complete the waveform diagram compilation. Obtain the quadrature waveform with an equal duty cycle from the output port and adjust the technical state of the counter to achieve a variety of frequency divisions within the design.

3.4. Application of communication electronic circuit teaching experiment

The course of communication electronic circuits is a fundamental component of electronic information engineering, communication engineering, and related majors. Its primary objective is to delve into the analysis of essential functional elements commonly found in communication circuits. It aims to provide learners with an understanding of the operational principles and implementation of these circuits. Moreover, it introduces the principles and techniques involved in the linear and nonlinear applications of electronic circuits within analog signal processing systems. This comprehensive approach ensures that students acquire a solid foundation in communication theory, gain a systematic grasp of the working principles and analytical design of various functional units within communication systems, and establish a fundamental framework for theoretical engineering in communication and signal processing.

Traditionally, in the simulation of communication electronic circuits, physical circuits or experiment setups are often employed, accompanied by various instruments for testing, analysis, and calculation. Nonetheless, this method relies on experimental equipment with a certain level of precision, and the accuracy of instruments and equipment significantly influences the experimental results. In addition, circuit connection issues may also impact experimental accuracy. The use of simulation software for experimental teaching effectively mitigates these challenges. This paper centers on the discussion of Multisim2001 software, which proves highly beneficial for communication sub-circuit simulation experiments. Utilizing Multisim2001 software not only addresses the issue of experimental equipment accuracy affecting results but also expands the range of experiments in high-frequency circuits. This software enables precise control over amplitude, frequency, and phase values of input signals, substantially enhancing experiment accuracy and efficiency. Consequently, it plays a pivotal role in ensuring the reliability of experimental outcomes and significantly enhances the teaching environment in communication electronic circuit experiments. The application of simulation software, such as Multisim2001, can be employed in confirmatory experiments, comprehensive experiments, and development experiments [5].

A common step in the analysis and design of communication electronic circuits involves waveform and spectrum analysis of input and output signals. Multisim2001 proves to be exceptionally valuable for simulation analysis and testing in this regard. An example of the double-sideband modulation within communication electronic circuits is given here. This circuit is a critical component of transmitters in communication equipment, and its teaching holds significant importance. Due to the inherent complexities, including high calculation difficulty, intricate waveforms, and challenging observation of specific points, students often encounter difficulties in comprehending this topic during the teaching process. The use of Muhisim2001 simulation software alleviates these challenges. Its intuitive interface, user-friendly features, and powerful capabilities enable students to visually observe and analyze the input and output signals of the circuit, thereby gaining a deeper understanding of waveform and amplitude change.

4. Conclusion

The innovation of computer technology has provided technical support for the further development of the communication and electronics fields and has made important contributions to social and economic development. The application of EDA technology in communication electronic circuit design is a typical example, which optimizes the circuit design process, effectively improves the design efficiency, and reduces the failure rate in practical application, which is of great significance for the healthy development of the communication field.

Disclosure statement

The author declares no conflict of interest.

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Development of Medical Informatization in the Era of Big Data

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Abstract: The purpose of this paper is to discuss the development of medical informatization in the era of big data. Through literature review and theoretical analysis, the development of medical informatization in the era of big data is deeply discussed. The results show that medical informatization has developed rapidly in the era of big data, and its role in clinical decision-making, scientific research, teaching, and management has become increasingly prominent. The development of medical informatization in the era of big data has important purposes and methods, which can produce important results and conclusions and provide strong support for the development of the medical field.

Keywords: Electronic medical record system; Digitization of medical images; Clinical decision support system

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1. Introduction

With the rapid development of science and technology, human society has entered the era of big data. In this era, the collection, processing, and analysis of data provide an unprecedented perspective and opportunity to understand various complex phenomena [1,2]. The medical field is no exception. The application of big data technology is promoting the development of medical informatization, which has a far-reaching impact on medical research, diagnosis, and treatment.

2. Challenges faced by the development of medical informatization under the background of the big data era

2.1. Data security and privacy protection

Medical data involves patients' privacy and confidential information. Ensuring the security and privacy protection of these data is vital [3], as any data leakage or unauthorized access may lead to serious consequences, including identity theft and insurance fraud.

2.2. Data quality and reliability

Medical data often involves a variety of sources, including medical records, laboratory tests, image inspection, and so on. The quality and reliability of these data have an important impact on the accuracy of analysis and decision-making [4]. However, there may be errors in the process of data collection and processing, hence it is essential to ensure the quality and reliability of data.

2.3. Data processing and analysis capabilities

Medical data usually involves a large number of data, including structured data (such as electronic medical records) and unstructured data (such as images and pathological images) [5]. Strong data processing and analysis capabilities are required to effectively process and analyze these different types of data and extract valuable information from them.

2.4. Legal and ethical issues

In the development of medical informatization, a series of legal and moral issues are involved, including patient privacy protection, data sharing and use, medical responsibilities, and obligations. Navigating the complex landscape of adhering to pertinent laws, regulations, and ethical standards to ensure legal compliance poses a formidable challenge.

2.5. Technology development and update

The development of medical informatization needs to constantly track and adapt to the latest technological developments, including big data technology, artificial intelligence, cloud computing, and so on. Meeting the challenge of staying abreast of rapid technological progress and harnessing new technologies to enhance support for medical research and healthcare services is paramount.

3. The development of medical informatization under the background of the big data era

3.1. The popularity of electronic medical records

An electronic medical record is a computer-based medical record system for patients, which can record information such as diagnosis, treatment, and nursing of patients.

(1) The popularity of electronic medical records has greatly changed the storage mode of medical information. Traditional paper medical records not only occupy space but also are not conducive to preservation and search [6]. The electronic medical record system can store the patient's medical information electronically, which is convenient for doctors to view and edit anytime and anywhere. At the same time, electronic medical records can also share medical information across institutions and regions, which makes it convenient for doctors to make comprehensive diagnoses and treatments of patients.

(2) The electronic medical record system has powerful medical record retrieval and statistical analysis functions. Through keyword or condition screening, doctors can quickly find the needed patient information [7]. At the same time, the system can also carry out statistics and analysis on a large number of patient data, help doctors understand the disease distribution and epidemic trends of patients, and provide data support for clinical decision-making.

(3) Electronic medical record systems can collect patients' medical information in real-time, including physical sign data, diagnosis results, medication, etc. [8]. Based on these data, the system can monitor and warn the health status of patients in real-time, find the abnormal situation of patients in time, and provide timely intervention and treatment for doctors.

(4) Electronic medical records contain a lot of patient information, including genetic information, living habits, and so on. Through the application of big data technology, we can analyze these data, find out the occurrence and development law of diseases, and provide patients with more accurate personalized treatment programs. At the same time, electronic medical records can also record the doctor's treatment process and effect, and provide valuable data for clinical research and teaching effect evaluation.
(5) The electronic medical record system has accumulated a large number of patient data, which is of great significance for disease prevention and control. Through data mining technology, we can extract valuable information from electronic medical records for epidemiological research, understand the distribution and spread of diseases, and provide the scientific basis for disease prevention and control.
(6) Electronic medical records contain important private information of patients, such as illness and personal information. Protecting patients' privacy and data security is an important prerequisite for the popularization of electronic medical records. The electronic medical record system needs to take strict security measures, including data encryption, access control, audit tracking, etc., to ensure that patient information is not leaked or abused.
(7) The popularization of electronic medical records can improve the efficiency and quality of medical coordination. Doctors can view patients' information on the same platform for diagnosis and treatment. At the same time, the standardization of electronic medical records can reduce unnecessary medical accidents and disputes caused by writing errors or misunderstandings. Through the quality control and supervision mechanism of electronic medical records, the standardization and quality of medical services can be improved.

3.2. Digitization of medical images

Medical imaging is an important diagnostic method, and the pathological changes in patients can be observed intuitively through image data. With the popularization of digital medical images, doctors can easily obtain and share image data, which improves the accuracy and efficiency of diagnosis.

(1) Digitization of image acquisition refers to obtaining medical images through digital equipment. These devices include X-ray machines, computed tomography (CT) machines, magnetic resonance imaging (MRI) machines, ultrasound machines, and so on [9]. These devices can convert the original physiological signals into digital signals and generate various types of medical images, such as X-ray films, CT scans, MRI scans, and ultrasound images. Digital equipment can provide high-definition and high-resolution images, which significantly improves the accuracy of diagnosis.
(2) Digitization of image storage refers to storing medical images in digital form in a computer system. Compared with traditional paper images, digital images have the advantages of easy storage, retrieval, and transmission [10]. Digital images can be saved in different file formats, such as TIFF, JPEG, DICOM, etc. Among them, the DICOM format is the standard format of medical images, which can contain a lot of image information and related metadata. Digital images are stored in a database or cloud, which can be preserved for a long time and shared across institutions.
(3) Digital image transmission refers to the digital transmission of medical images to needed places, such as doctors' offices, diagnosis rooms, and wards [11]. Digital transmission can greatly shorten the time of image acquisition and diagnosis and improve the efficiency of diagnosis. Digital transmission can be realized through local area networks, the Internet, wireless networks, and other ways. In addition, telemedicine and mobile medicine are also applications of digital transmission in the field of medical

imaging.

(4) Digitization of image printing refers to printing digital images into paper images by a printer. The printed paper images can be used for diagnosis, treatment, and consultation. Compared with traditional film printing, digital printing has a higher resolution and lower cost. Digital printers can choose different paper and ink to get different print results with different quality and resolution.

(5) Digitization of image processing refers to the use of computer software to process medical images to improve image quality and extract useful information. Image processing includes contrast adjustment, brightness adjustment, edge enhancement, and noise reduction. Digital image processing can improve the clarity and readability of the image and help doctors diagnose the disease better.

(6) Digitization of image analysis refers to the analysis of medical images by computer software to extract useful diagnostic information. For example, by analyzing X-rays, we can judge whether the lungs are abnormal; By analyzing MRI scans, we can judge whether there are brain lesions. Digital image analysis can improve the accuracy and efficiency of diagnosis and reduce human error.

(7) Digitization of image interpretation refers to the automatic interpretation and diagnosis of medical images by computer software. This technology combines artificial intelligence and deep learning technology, which can identify the abnormal performance in the image and give corresponding diagnosis suggestions. Digital image interpretation can improve the speed and accuracy of diagnosis, but in some complex cases, doctors still need to participate and judge.

3.3. Clinical decision support system

(1) Diagnostic decision support is one of the important functions of a clinical decision support system. The system can provide diagnosis suggestions and relevant evidence by analyzing the patient's medical history, signs, and laboratory tests, and help doctors diagnose diseases more quickly and accurately. Diagnostic decision support can also provide risk assessment and prognosis prediction of diseases, and provide reference for doctors to formulate personalized treatment plans.

(2) Treatment decision support is one of the core functions of the clinical decision support system. According to the patient's condition, physical condition, and treatment history, the system can provide doctors with a variety of treatment proposals, and give detailed information such as the advantages and disadvantages, possible risks, and expected effects of each scheme [12]. According to this information, doctors can choose the most suitable treatment plan for patients, and improve the treatment effect and patient satisfaction.

(3) Drug decision support is one of the important functions of a clinical decision support system. According to the patient's illness, drug allergy history, and medication history, the system can provide doctors with appropriate medication advice, including drug types, dosage, administration methods, and so on. Drug decision support can also provide tips on drug interactions and adverse reactions to help doctors avoid potential risks.

(4) Follow-up decision support is one of the important functions of a clinical decision support system. The system can provide follow-up suggestions for doctors according to the patient's condition and treatment, including follow-up time, follow-up items, and follow-up standards. Follow-up decision support can help doctors find the changes in the disease in time, adjust the treatment plan in time, and improve the treatment effect and the survival rate of patients.

(5) Prevention of complications is one of the important functions of the clinical decision support system. According to the patient's condition and treatment, the system can provide doctors with prevention

suggestions for complications, including preventive measures, monitoring indicators, and early warning standards. Prevention of complications can help doctors reduce the risk of complications during treatment and improve the quality of life and treatment effect of patients.

(6) Clinical guidelines refer to the norms and guidelines formulated and issued by professional institutions to guide clinical practice. The clinical decision support system can convert clinical guidelines into digital form and combine them with doctors' diagnosis and treatment process to remind doctors to follow relevant guidelines in the diagnosis and treatment process. This can help doctors ensure the standardization and consistency of diagnosis and treatment, and improve the treatment effect and patient safety.

(7) Electronic medical record data is an important data source for clinical decision support systems. Clinical decision support systems can use electronic medical record data for data mining and analysis, and extract useful information such as patient's condition, treatment history, and drug allergy history. This information can provide doctors with more comprehensive and accurate diagnosis and treatment suggestions, and improve medical quality and patient satisfaction.

3.4. The development of personalized medical care

Personalized medical treatment is a method to tailor the treatment plan for patients according to individual genes, living habits, and other information [13]. Through the application of big data technology, we can analyze a large number of patient data, find out the occurrence and development law of diseases, and provide patients with more accurate personalized treatment programs.

3.5. Application of telemedicine and intelligent medicine

The application of telemedicine and intelligent medical treatment enables doctors to remotely obtain the medical information of patients and provide timely telemedicine services for patients [14]. The application of these technologies improves the coverage and efficiency of medical services and reduces the cost of patient medical treatment.

3.6. Application of medical research and data mining

The application of big data technology enables medical research to analyze the occurrence and development mechanism of diseases, explore new drug treatment methods, and evaluate treatment effects based on a large number of patient data [15-17]. The application of data mining technology can help doctors find valuable information from a large number of medical data and provide support for clinical decision-making.

4. The development significance of medical informatization under the background of the big data era

4.1. Serving residents

Residents' health guidance services provide precise medical care and personalized health care guidance so that residents can maintain continuity in hospital, community, and online services. Miao Health provides a professional team of doctors who can help users solve various diseases online and give health guidance. Residents can also buy daily medicines in their pocket pharmacies, which is convenient and fast.

4.2. Serving doctors

Medical health big data can provide doctors with more comprehensive and accurate patient information, and help doctors better understand the patient's medical history, disease development law, treatment effect, and other aspects, thus improving the doctor's treatment accuracy. For example, using medical health big data can quickly identify abnormal points in multi-dimensional data such as biochemical indicators and imaging, predict the development trend of diseases in advance, and carry out corresponding intervention treatment.

4.3. Service scientific research

Service scientific research including disease diagnosis and prediction, improving statistical tools and algorithms for clinical trial design, analysis and processing of clinical trial data, such as identifying disease susceptibility genes and extreme expression groups for major diseases, and establishing personal health medical records. The establishment of personal health medical records can share personal medical information, let doctors know the patient's past medical history directly and quickly, avoid the phenomenon of repeated consultation, and enable patients to receive treatment in time and effectively.

4.4. Acceleration of drug research and development

Medical health big data can effectively improve the efficiency and success rate of drug research and development. By analyzing a large number of clinical trials and drug research and development data, we can fully understand the efficacy, safety, and other characteristics of different drugs, and provide a valuable reference for the development of new drugs. Using medical health big data, we can also screen drugs for different groups of people and different diseases, especially in dealing with massive medical literature data and screening effective drug components, to determine the dosage and usage of drugs, thus shortening the cycle of drug research and development quickly and efficiently. Compared with the traditional manual method, it has obvious advantages and greatly saves the cost of drug research and development. For example, Atomwise Company in the United States used supercomputers to carry out drug research and development and completed the analysis and testing of more than 7,000 drugs within 24 hours when developing drugs to treat the Ebola virus. However, if traditional methods are used, it will take at least several months or even years to complete the testing process.

4.5. Auxiliary diagnosis and treatment services

Big data technology has been widely used in medical image recognition, medical data analysis, comparative effect research, precision surgery, and other aspects, effectively improving the efficiency and quality of disease diagnosis and treatment. For example, Watson, developed by IBM, collects professional knowledge and clinical experience in the clinical diagnosis and treatment of rare tumors and applies these data to personalized treatment and imaging diagnosis after processing and calculation. The Medical College of the University of North Carolina in the United States tested its learning ability through 1,000 cases of cancer patients. As a result, 99% of the treatment schemes provided by Watson were consistent with those suggested by oncologists, and many auxiliary suggestions were put forward on its own initiative, 30% of which were unexpected by doctors.

4.6. Promotion of the genetic medical research progress

Genetic medical products and technologies such as gene sequencing are evolving from laboratory research to clinical application research, in which big data plays a key role. In particular, technologies such as cognitive computing can achieve large-scale workloads and completion accuracy that conventional manpower cannot operate. At present, the focus of genetic medicine research is to study individual genetic variation and susceptibility to specific diseases by analyzing genome data, to determine who is susceptible to certain diseases and provide timely early diagnosis and personalized treatment for patients. The United States launched the Precision Medical Program in 2015 and is committed to promoting individualized genomics research and formulating personalized precision medical programs through technologies such as big data and artificial intelligence.

4.7. Realization of smart medical care

Medical health big data is a necessary condition to realize smart medical care. The collection, integration, analysis, and application of medical and health big data can achieve the goals of clinical diagnosis and treatment decision support, life-cycle health management of patients, improvement of medical service delivery efficiency, control of medical expenses, and improvement of public health literacy. Smart medical care can comprehensively improve the quality of medical services and optimize the allocation of medical resources, to better meet the medical needs of the people.

4.8. Service management organization

Service management organization includes normative drug use evaluation, evaluation of preventive interventions and measures for epidemics and acute diseases, as well as public health monitoring, optimization of clinical pathways, etc.

4.9. Public health services

Public health services include monitoring and early warning of health-threatening factors, network platforms, community service, and so on. Miao Health relies on Miao+, the largest health data platform in China, to provide customers with a series of services such as health management through data collection, risk assessment, and health intervention.

5. Suggestions on the development of medical informatization under the background of the big data era

5.1. Acceleration of the establishment and improvement of the standard system of healthcare big data

Since 2016, our Committee, together with the Central Network Information Office and the National Development and Reform Commission, has continued to promote the construction of the standard system of health care big data, compiled the National Measures for the Management of Health Care Big Data Standards, Security and Services (Trial), the Information Security Technology Health Care Data Security Guide and other documents, and effectively promoted the construction of the standard system of health care big data.

5.2. Optimization of China's healthcare big data security control and personal privacy protection

It is suggested to promote the construction of big data security norms and regulations for health care, clarify the responsibility for network information and data security, and continuously improve the security protection capability. It is also crucial to strictly implement the network security law enforcement inspection, and carry out special actions for network security inspection, important data, and personal information protection in the whole industry.

5.3. Establishment of a socialized healthcare information exchange mechanism

To comprehensively standardize and promote the application and development of healthcare data, and constantly improve the functions of the national health information platform, we will further strengthen the research on public health and social management relying on healthcare big data on the basis of improving the databases of residents' electronic health records, electronic medical records, and the total population, and further promote the sharing and opening of health care big data.

5.4. Promotion of the application of big data in healthcare

The deepening of the application of health care big data in industry governance and public health should be continued. During the epidemic prevention and control period, the epidemic prevention and control group of the State Council joint prevention and control mechanism set up a special group on big data analysis to gather multi-source data and use digital technologies such as big data and artificial intelligence to strengthen epidemic monitoring and trend judgment, which strongly supported accurate epidemic prevention and control.

5.5. Promotion of the development of the healthcare big data industry

It is imperative to promote the national pilot project for the construction of healthcare big data centers and industrial parks, promote the deep integration of healthcare business and big data technology, and strengthen the exploration and application of healthcare big data in clinical scientific research, the transformation of research results, and the research and development data sharing mechanism. There should be an active exploration of healthcare big data as a market factor, with initial emphasis on data collection, consolidation, resource integration, open sharing, data mining and application, security protection, etc. By establishing and improving the socialized health care big data information sharing mechanism, we will further accelerate the cross-departmental, cross-industry, and cross-level interconnection of health care big data, promote the deep integration of health care and pension, tourism, Internet, food, and other fields, actively build a health care big data industrial chain, and continuously improve the development level of health care big data application.

5.6. Formulation of laws and regulations on medical big data

It is suggested that we should always adhere to the "people-centered" development idea, formulate and improve the laws and regulations on information development under medical big data as soon as possible, fully respond to the needs of the people in the digital age, promote the rule of law, institutionalization, standardization, proceduralization, and science and technology in the use of big data, establish and improve a comprehensive supervision system with mutual cooperation and collaborative supervision among various departments, implement fair policies and payment methods for online and offline medical services, further improve the use efficiency of big data and protect patients.

5.7. Usage of big data technology to completely solve the problem of insurance fraud

At present, various emerging biometric technologies are becoming more and more mature, and the application scenarios are constantly expanding. It is suggested to gradually build a cross-platform, open, extensible, and national unified multi-modal big data patient identity authentication system. By flexibly combining various biometric technologies such as fingerprint, face, iris, finger vein, voiceprint, gait, etc., according to different application requirements and scenarios, the appropriate combination method is chosen to cover more application scenarios and improve the safety, accuracy, stability, and authentication efficiency of patient identity authentication and identification in various scenarios.

5.8. Adoption of intelligent supervision of big data to effectively improve the level of supervision

It is suggested that a cross-platform, intelligent, and real-time audit system should be constructed by using emerging technologies such as big data, artificial intelligence, and blockchain, and the data of diagnosis, treatment, prescription, drug use, and service facilities of designated medical institutions in the region should be collected, sorted and classified to form systematic supervision rules and reasoning rules, and the whole process of patients' use can be reminded and monitored in real-time intelligently. By learning algorithms, the potential and undisclosed regular trend characteristics of medical biological information can be automatically mined, and the rule language can be applied.

6. Conclusion

In summary, the era of big data has brought great opportunities for the development of medical informatization. By making full use of big data technology, we can realize the informatization of medical data, promote the development of medical research and precision medical care, and improve the efficiency and quality of medical services. At the same time, it is also necessary to meet the challenges brought by big data, ensure patient privacy and data security, and ensure the healthy and sustainable development of medical informatization. It is believed that in the process of continuous exploration and improvement, medical informatization will make greater breakthroughs and development under the impetus of the era of big data.

Disclosure statement

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Practical Analysis of Mechanical Automation Technology in Automobile Manufacturing

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Abstract: In today's rapidly developing modern society, automobiles, as an important part of transportation and industrial fields, play a pivotal role. With the improvement of people's living standards and the increase in traffic demand, the automobile manufacturing industry has been continuously developing and growing globally. However, to cope with increasingly fierce market competition and ever-changing consumer demands, the automobile manufacturing industry is also facing the challenges of improving production efficiency, reducing costs, and improving product quality. In this context, automation technology has gradually become a major trend in the automobile manufacturing industry. As an important support of modern industry, automation technology has shown great application potential in many fields. From industrial production to daily life, automation technology can be seen everywhere. In the field of manufacturing, especially in automobile manufacturing, the application of automation technology is getting more and more attention. Automated production lines, intelligent robots, and automated warehousing systems have all changed the face of automobile manufacturing to varying degrees, bringing companies higher efficiency, more stable quality, and greater competitive advantages. The application trend of this automation technology in various fields not only meets the needs of modern industry for efficient, precise, and sustainable development but also provides new ideas and paths for the future development of the automobile manufacturing industry.

Keywords: Mechanical automation technology; Automobile manufacturing; Practical analysis; Production efficiency

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1. Introduction

This article will deeply discuss the practical application of mechanical automation technology in automobile manufacturing, and analyze its role in improving production efficiency, optimizing resource allocation, and improving product quality. Through the analysis of actual cases and application scenarios, it aims to reveal the importance of automation technology in the automobile manufacturing industry and the prospects for future development.

2. Overview of mechanical automation technology

In today's fast-growing industrial field, mechanical automation technology has become the focus of attention from all walks of life with its remarkable achievements and wide application. As the core of the modern manufacturing industry, automation technology aims to reduce manual intervention, improve production efficiency, and integrate a series of technologies and methods to ensure product quality. As an important part of automation technology, mechanical automation plays a pivotal role in the industrial field [1].

The definition and scope of automation technology is broad. It represents a series of highly developed and complex technologies, aiming at the automatic execution of physical operations and production tasks in industrial processes through the introduction of computer control systems, sensors, actuators, and other devices. This technological approach not only greatly reduces human intervention, but also significantly improves productivity, accuracy, and consistency.

However, the application of automation technology is not limited to this. As technology advances, more and more industrial processes and production tasks are being automated [2]. This has led to the emergence of more complex automation systems, such as in smart factories. The smart factory system integrates various automation technologies, such as robots, automatic navigation vehicles, automatic storage systems, etc., to achieve a high degree of intelligence and autonomy in the entire production process. In the smart factory system, the application range of automation technology becomes more extensive and in-depth. It not only covers the tasks on the production line but also includes the formulation of production plans, material management, product quality control, and other aspects. These systems can optimize and adjust the production process in real-time through real-time data analysis and feedback mechanisms, so as to more flexibly adapt to market demands and changes.

Mechanical automation technology plays a pivotal role in the modern industrial field, and its importance is reflected in many aspects. Firstly, automation technology is widely seen as a powerful tool for increasing productivity. By introducing automation systems, enterprises can achieve precise control of the production process without long-term manual operations, thereby reducing production cycles and waste of resources. This not only speeds up production but also reduces energy and raw material consumption, enabling efficient use of resources.

Secondly, the high consistency and stability brought about by automation technology have a significant impact on the improvement of product quality. Manual operations are easily affected by factors such as emotions, physical strength, and the environment, which may lead to product instability and quality fluctuations. Automated systems, on the other hand, can perform tasks with extreme precision and consistency, thereby ensuring high quality and consistency of products, reducing defect rates, and establishing a good reputation for the company.

In addition, the implementation of mechanical automation technology enables the continuous operation of the production line 24/7. In contrast, traditional manual operations need to consider employees' working hours and rest periods, which may lead to stagnation of the production line and reduction of production efficiency. Automated systems, on the other hand, are not limited by time and can run continuously without human intervention, maximizing production capacity and output [3].

3. Application of mechanical automation technology in automobile manufacturing

3.1. Production line automation

The application of mechanical automation technology in the field of automobile manufacturing is extensive and far-reaching, of which the automation of the production line is a significant part. This automation approach covers several key areas in automotive manufacturing, including assembly processes and component machining and handling.

3.2. Assembly process automation

In automobile manufacturing, the assembly process is a complex and critical link. Mechanical automation technology has achieved a high degree of automation in the assembly process by introducing industrial robots and automation devices. Industrial robots can assemble components with precise paths and speeds, ensuring accuracy and consistency at each step [4]. The application of sensors and vision systems enables the robot to perceive the environment and the position of parts, thereby achieving highly precise operations. This not only improves assembly efficiency but also reduces the risk of human error and ensures assembly quality.

3.3. Parts processing and handling automation

In the automobile manufacturing process, the processing and handling of various parts are essential steps. Machine automation technology plays an important role in this. Through the introduction of computer numerical control (CNC) machine tools and automated processing equipment, the processing of parts can be automated and precisely controlled. Automated processing not only improves processing efficiency but also ensures the dimensional accuracy and surface quality of parts. In addition, for processes involving painting, cleaning, and heat treatment, the automation system can consistently perform tasks, ensuring the stability and reliability of the treatment effect.

The application of mechanical automation technology enables the automotive production line to achieve a high degree of process optimization and resource utilization. The automation system can realize unattended continuous production without time constraints, thus maximizing production efficiency. In addition, they can also monitor and optimize the production process through data collection and analysis, providing decision support and improvement directions for manufacturers. In the field of automobile manufacturing, the practice of production line automation not only improves manufacturing efficiency and product quality but also creates a more flexible and intelligent production environment for enterprises, laying a solid foundation for the sustainable development of the industry. With the continuous advancement of technology, production line automation will continue to evolve, bringing more innovations and breakthroughs to the automotive manufacturing industry.

4. Application of intelligent robot technology in mechanical automation

With the development of intelligent robot technology, it has gradually become an indispensable part of mechanical automation technology and has been widely used in the field of automobile self-manufacturing.

4.1. Robot application in the production process

Intelligent robots play a key role in the production process of automobile manufacturing and can perform various tasks on the assembly line, such as handling parts, assembling, and welding. Based on intelligent robots, through precise trajectory planning and motion control, they can efficiently complete complex assembly tasks, ensuring the accuracy and consistency of each step. Moreover, the autonomy of robots enables them to adapt to different products and production needs, so as to realize the flexible adjustment and optimization of the production line and effectively improve the level of automobile manufacturing.

4.2. Quality inspection and quality control

Intelligent robots also play an important role in quality inspection and quality control. They are capable of precise detection and measurement of parts and vehicles through technologies such as vision, touch, and sensors. Compared with traditional manual inspection, robots can complete more inspection tasks in a shorter time and have higher accuracy and stability. This helps to detect and correct potential quality problems in advance, ensuring the pass rate and compliance of the final product. The application of intelligent robots not only improves production efficiency and product quality but also creates a safer working environment. They can take on high-risk, harsh, or heavy tasks, reducing health risks for employees [5]. In addition, robots can work in high-temperature, high-pressure, and toxic environments, allowing manufacturers to better meet stringent safety standards and regulatory requirements.

5. Practical case analysis

In this actual case, an automobile manufacturing company realized the full automation of the automobile production process by introducing an automated production line and achieved significant advantages and effects.

5.1. Advantages and effects of production process automation

The automotive manufacturing company employs an advanced industrial robot system in the assembly shop for the automatic assembly of automotive parts. These robotic systems are characterized by high speed and precision, these robotic systems perform well on a variety of assembly tasks. From engine components to interior parts, robots can quickly and accurately complete the assembly process. This high consistency and accuracy greatly improves the assembly quality of products and significantly reduces the defect rate. In addition, the use of automated production lines has significantly increased assembly speed and effectively increased production capacity.

5.2. Technical problems and solutions

In the process of implementing an automated production line, the company faced some technical difficulties, one of which was how to achieve a high degree of collaborative work of robotic systems to ensure a smooth assembly process. To solve this problem, the company adopted an advanced control system that enables multiple robots to work together on the same assembly line to complete complex assembly tasks. Through precise coordination and synchronization, the robots can work together efficiently to ensure the correct assembly of parts.

In addition, due to the diversity and customization requirements of the automotive market, how to flexibly adapt the robot system to the assembly of different models is also a challenge. To meet this challenge, the company introduced intelligent transformation devices and program controls. These innovative technologies allow the robot system to be quickly switched and adjusted to suit the assembly needs of different vehicle models. This flexibility enables the company to respond more quickly to market needs and provide customized products [6].

To sum up, this practical case shows the experience of an automobile manufacturing company in successfully applying an automated production line. By overcoming technical difficulties and adopting innovative measures, they have achieved significant improvements in production efficiency and product quality, laying a solid foundation for meeting ever-changing market demands [7].

6. Challenges and solutions in practice

6.1. Technical challenges and innovations

Automobile parts usually have complex structures and shapes, requiring highly precise processing and assembly. However, mechanical automation systems may have difficulty handling these complex components, resulting in inaccurate or damaged assemblies. To overcome this challenge, manufacturing companies employ innovative sensing technologies and advanced vision systems. Using 3D scanning, image recognition, and precision sensors, the system can accurately detect and position components to ensure their precise fit during assembly [8].

6.2. Diversity and customization requirements

In today's market, there is an increasing demand for car diversity and customization, and manufacturing companies need to produce cars with different models and configurations. This requires the mechanical automation system to be flexible and able to adapt to different production requirements. To address this challenge, manufacturers employ programmable controls and intelligent algorithms. The mechanical automation system can be quickly adjusted and set up according to different production tasks and product specifications, so as to meet customized needs while maintaining high efficiency and accuracy.

By overcoming these technical challenges, mechanical automation technology has made remarkable progress in automobile manufacturing. Innovative solutions not only improve production efficiency and product quality but also enable manufacturing companies to better adapt to market changes and customer needs. In the future, with the further development of technology, mechanical automation technology will continue to play an important role in the automobile manufacturing industry and continue to meet new challenges [9].

6.3. Human-machine collaboration and training

In the practice of introducing mechanical automation technology into the automobile manufacturing industry, human-machine collaboration has become a key issue. Although mechanical automation systems play an important role in the production process, the role of humans is still crucial. However, there are challenges in achieving effective human-robot collaboration and ensuring that workers adapt to the automation environment, and training and upskilling are particularly important.

6.4. Human adaptation to the challenges of an automated environment

When introducing mechanical automation systems, employees may face adaptation issues due to changes in the way they work. Moving from previously manual operations to working with robots may require employees to adapt to new workflows and ways of operating. This can lead to feelings of uneasiness, uncertainty, and even resistance among employees. At the same time, employees may feel unfamiliar with the use and operation of new technologies, thereby affecting productivity [10].

6.5. Importance of training and skills improvement

To meet the challenges of human adaptation to an automated environment, training and upskilling becomes critical. Manufacturing companies need to invest time and resources in training employees to familiarize them with new workflows, operating machinery, and working with robots. Training can help employees fully understand how automated systems work, reducing anxiety and uncertainty. In addition, training can help employees master maintenance and troubleshooting skills, improving the stability and reliability of the production line.

7. Conclusion

Through a practical case study of an automobile manufacturing company, we gain an in-depth understanding of the significant impact of mechanical automation technology in modern automobile manufacturing. The company successfully applied automated production lines, which greatly improved production efficiency and product quality. Mechanical automation technology not only speeds up the assembly process but also reduces human error and improves the accuracy of component assembly. Although it faced technical challenges in practice, such as the machining of complex components and the variety of requirements, the company overcame these obstacles with innovative solutions. In addition, human-robot collaboration and employee training play a key role in ensuring the successful adoption of the technology. In short, the practice of mechanical automation technology in automobile manufacturing has proved that it is a powerful tool for improving production efficiency and quality, and provides exciting prospects for the future development of the industry.

Disclosure statement

The author declares no conflict of interest.

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Application of Multivariate Reinforcement Learning Engine in Optimizing the Power Generation Process of Domestic Waste Incineration

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Abstract: Garbage incineration is an ideal method for the harmless and resource-oriented treatment of urban domestic waste. However, current domestic waste incineration power plants often face challenges related to maintaining consistent steam production and high operational costs. This article capitalizes on the technical advantages of big data artificial intelligence, optimizing the power generation process of domestic waste incineration as the entry point, and adopts four main engine modules of Alibaba Cloud reinforcement learning algorithm engine, operating parameter prediction engine, anomaly recognition engine, and video visual recognition algorithm engine. The reinforcement learning algorithm extracts the operational parameters of each incinerator to obtain a control benchmark. Through the operating parameter prediction algorithm, prediction models for drum pressure, primary steam flow, NO_x, SO_2, and HCl are constructed to achieve short-term prediction of operational parameters, ultimately improving control performance. The anomaly recognition algorithm develops a thickness identification model for the material layer in the drying section, allowing for rapid and effective assessment of feed material thickness to ensure uniformity control. Meanwhile, the visual recognition algorithm identifies flame images and assesses the combustion status and location of the combustion fire line within the furnace. This real-time understanding of furnace flame combustion conditions guides adjustments to the grate and air volume. Integrating AI technology into the waste incineration sector empowers the environmental protection industry with the potential to leverage big data. This development holds practical significance in optimizing the harmless and resource-oriented treatment of urban domestic waste, reducing operational costs, and increasing efficiency.

Keywords: Multivariable reinforcement learning engine; Waste incineration power generation; Visual recognition algorithm

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1. Introduction

Waste incineration is an ideal method for the eco-friendly and resource-driven treatment of urban domestic waste. However, current domestic waste incineration power plants generally require much more stable steam production and high production costs [1,2]. Research shows that the complex combustion control objects of municipal solid waste have characteristics such as unknown, time-varying, random, and dispersive system parameters, as well as elusive and variable system time lags. These systems exhibited pronounced nonlinearity and interdependencies among their various variables. Additionally, environmental interference introduces unknown, diverse, and random factors into the equation. For the control problem of this uncertain and complex object (or process), traditional control methods based on mathematical models make it difficult for effective control, hence strategies with more effective control must be explored [3].

The algorithms constructed by various control strategies exhibit variations in complexity, robustness, and decoupling performance. Additionally, there are disparities in software and hardware resource costs within the realm of technical implementation. What people seek is a cost-effective control strategy. The available strategies encompass neural network control, fuzzy logic control, expert system control, and artificial intelligence control [4]. The multivariate reinforcement learning algorithm comprises three components: feature input, decision algorithm engine, and decision output [5]. It utilizes operating parameters to characterize waste incineration. The relationship between relevant equipment instructions at each operational point is established based on multidimensional historical data extraction. This approach provides benchmark operating parameters, eliminating the need for numerous test experiments typically required in conventional control. Consequently, it swiftly generates benchmark characteristic data for each furnace. By mining and reconstructing data from waste incineration power plant operations, algorithms are developed to control variables such as steam flow, feeder speed, upper grate cycle times, lower grate cycle times, primary air frequency, secondary air frequency, primary air temperature, and the coordination of each furnace. These algorithms also address control of nitric oxide and nitrogen dioxide (NO_x), sulfur dioxide (SO_2), and hydrochloric acid (HCl) emissions, facilitating automatic control of the waste incinerator’s combustion process in the power plant. The incorporation of AI technology empowers the environmental protection industry with the potential to harness big data. This development carries practical significance by reducing costs and enhancing efficiency in the optimization of eco-friendly and resource-driven urban domestic waste treatment [6].

2. Multivariate reinforcement learning algorithm

Reinforcement learning is an end-to-end method that combines perceptual decision-making with continuous iterative optimization through trial and error and has strong autonomous learning capabilities [7-10]. In recent years, inspired by biological groups and artificial intelligence, reinforcement learning algorithms have evolved from solving individual decision-making problems to optimizing collaboration problems in clusters, injecting new momentum into enhancing the convergence and emergence of cluster intelligence [11]. The multivariable reinforcement learning algorithm includes feature input, decision algorithm engine, and decision output. The algorithm principle in waste incineration process optimization is to select steam flow, primary air volume, pressure of each air chamber, central steam pressure, furnace smoke temperature, and push. Main operating parameters such as feeder stroke and stroke are used as indicators of waste incineration conditions. The corresponding relationships of relevant equipment instructions under each working condition point are summarized through multi-dimensional historical data extraction, and benchmark operating parameter guidance values are given.

By extracting features from historical data, the corresponding relationship between changes in primary steam flow rate and feeder speed instructions, grate cycle times, and primary and secondary air frequency instructions can be obtained to form a benchmark for control instructions. It avoids using many test experiments to obtain benchmark data in conventional control and quickly obtains the benchmark characteristic data of each furnace.

3. Execution of the parameter prediction algorithm

Waste incineration boilers have large fluctuations in waste calorific value and substantial delay and inertia characteristics. It is difficult for traditional industrial controllers to solve the control lag problem caused by considerable delay and large inertia. In addition, the waste calorific value fluctuates wildly and is uncertain, further increasing the difficulty of control. Making use of data-driven advantages and combining the principles of industrial processes, we develop an industrial prediction engine. Based on the prediction results and combined with recommended algorithms, we guide the control system or operators to take early actions to alleviate the poor control performance caused by considerable delays, large inertia, and model uncertainty, as well as the problem of large fluctuations in operating parameters.

3.1. Alibaba Cloud prediction engine

The industrial prediction engine needs to analyze the relationship between input and output based on the principle of the production process and historical operation data, construct characteristic variables, and combine different system characteristics; characteristic variables (original characteristics + structural characteristics) and target variables are the parameters to be predicted. The industrial forecasting engine is the core of the algorithm. It is constructed through machine learning and deep learning algorithms. The industrial forecasting engine will regularly train and update the model according to the operation of the forecast results to maintain the model with high forecasting accuracy.

The Alibaba Cloud prediction engine involves parameters such as central steam temperature and main steam flow forecast. Based on the prediction model, each control parameter is optimized to improve the boiler stability further. The steam flow prediction relies on the Alibaba Cloud Industrial Brain deep learning platform algorithm. It uses historical operating data (pushing stroke, pushing action, primary air volume, primary air pressure, secondary air volume, furnace temperature, flue gas content (oxygen, feed water flow, drum level, central steam pressure, and other dozens of operating parameters) have established a steam volume prediction model, which can accurately predict the steam volume after 180 seconds in the future, and provide predictions and predictions for subsequent steam volume trends. The time decision provides a practical basis, which alleviates the impact of large fluctuations in steam volume caused by the uncertainty of the calorific value of waste, which is difficult to control effectively.

3.2. Prediction of drum pressure

Applying Alibaba Cloud's big data analysis technology and combining it with the operating mechanism of the unit, a correlation analysis was conducted on historical data encompassing steam drum pressure. This analysis also encompassed determinants such as feed rate, primary air volume, primary air temperature, TX1 temperature, TX2 flue inlet temperature, and flue gas content, including oxygen content. These parameters were identified as key indicators affecting drum pressure. Leveraging the Alibaba Cloud prediction engine and employing a residual modeling method, the study aimed to find the influence characteristics of the drum pressure generation when the aforementioned characteristic parameters change, and as a result, a drum pressure prediction model after 5 minutes was finally established. The prediction model is shown in **Figure 1** below:

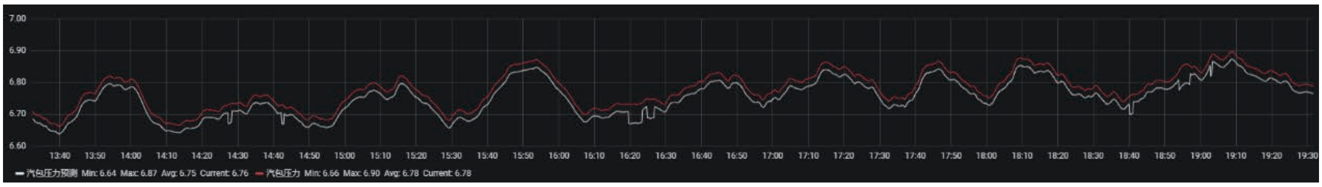

Figure 1. Real-time effect curve of steam drum pressure prediction

It can be seen from the drum pressure prediction curve that the overall fluctuation of the drum pressure predicted value is consistent with the actual value. However, the overall trend phase is about 2 minutes ahead of the actual drum pressure value, which can better predict the future drum pressure. This predictive capability has the practical advantage of anticipating changes in the boiler steam load through prediction, enabling the adjustments of air volume based on the prediction results, which then facilitates proactive steam load adjustments.

3.3. NO_x content prediction

Utilizing Alibaba Cloud‘s big data analysis technology, coupled with an understanding of the unit’s operational intricacies, a comprehensive correlation analysis of historical NO_x data was conducted. This analysis considered variables such as feed rate, flue gas oxygen content, primary and secondary air volumes, primary air temperature, TX 1 temperature, TX2 flue inlet temperature, ammonia (NH_3) flow rate, dilution water flow rate, and other parameters identified as characteristic indicators of NO_x content. By harnessing the predictive capabilities of the Alibaba Cloud prediction engine and employing a residual modeling approach, the study aimed to ascertain the impact characteristics on NO_x generation resulting from changes in the aforementioned characteristic parameters. Consequently, a NO_x content prediction model was successfully developed to forecast NO_x content level two minutes in the future. The prediction model is shown in **Figure 2** below:

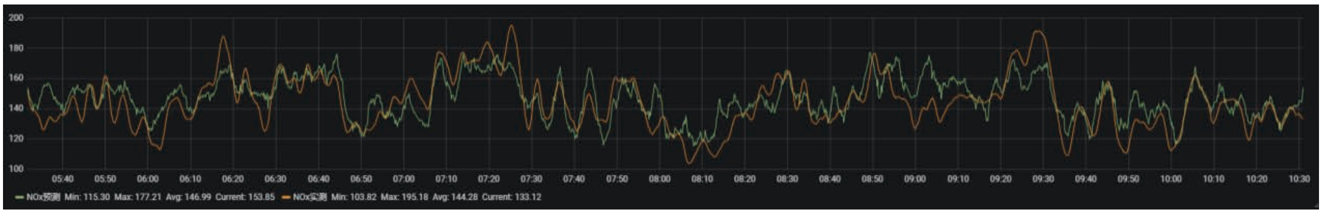

Figure 2. NO_x prediction effect curve

In **Figure 2**, the green curve represents the predicted NO_x content values, while the yellow curve represents the actual NO_x content values. The predicted values closely align with the overall fluctuation of the actual values. Notably, there exists a consistent phase difference of approximately 2 minutes, with the predicted values showing trends ahead of the actual NO_x content values. This advanced prediction capability significantly enhances the capacity to anticipate forthcoming fluctuations in NO_x content trends and it holds practical advantages by enabling the proactive sensing of changes in boiler steam load through prediction. Subsequently, it allows for the implementation of control instructions, such as NH_3 water flow and secondary air volume adjustments, based on prediction results. This proactive approach facilitates advanced NO_x control adjustments.

3.4. SO_2 content prediction

Similarly, Alibaba Cloud’s big data analysis technology is used to conduct SO_2 data correlation analysis on the unit's historical data and targeted test adjustment data and determine the parameters based on the feed rate, flue gas oxygen content, and primary and secondary air volumes, primary air temperature, TX1 temperature, TX2 flue inlet temperature, lime volume, dilution water flow, and other parameters that are used as SO_2 content characteristic parameters. Applying the Alibaba Cloud prediction engine and residual modeling method to find the impact characteristics on SO_2 production when the aforementioned characteristic parameters change, a prediction model for SO_2 content after 2 minutes was finally established. The prediction model is shown in **Figure 3** below:

Figure 3. SO_2 prediction effect curve

In **Figure 3**, the green curve is the predicted value of SO_2 content, and the yellow one is the actual value of SO_2. The overall fluctuation of the predicted value is consistent with the actual value, but the overall trend phase is about 2 minutes ahead of the actual value, which can better predict the future fluctuation of the NO_x trend; through prediction, the changing trend of boiler steam load can be perceived in advance, and then according to the prediction result, the lime supply command can be acted in advance to realize the advance adjustment of SO_2.

4. Anomaly identification algorithm engine

The anomaly identification algorithm mainly uses unsupervised learning methods from massive historical data to identify normal and abnormal states under different operating conditions. It then uses big data machine learning algorithms to learn and model the differentiated operating conditions. Through historical data learning, we can identify the thickness deviation of the material layer at a specific primary air volume, identify the abnormal temperature of a particular section of the grate under a specific primary air volume and primary air temperature, and then reflect the garbage humidity. Through abnormal recognition and sensing, it is ensured that the system can make automatic and targeted adjustments, promptly discover problems during operation, and maintain the stability of operating parameters. The primary architecture process of the algorithm is as follows in **Figure 4**:

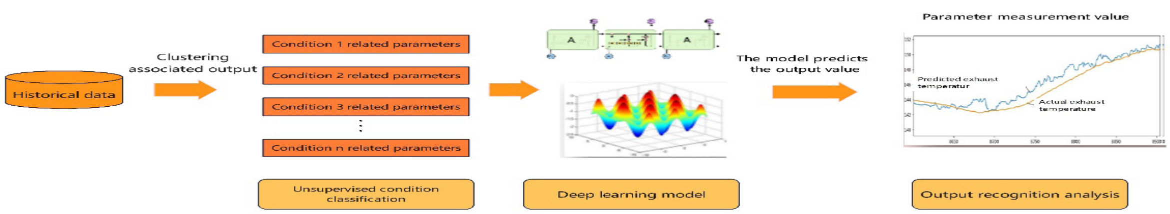

Figure 4. Primary structure of anomaly recognition algorithm

As shown in **Figure 4**, after obtaining the operating history data, the anomaly identification algorithm divides the working conditions through unsupervised clustering algorithms such as K-means and K-MEDOIDS, eliminates the abnormal working condition data, and obtains data within the normal generalized working conditions range. At the same time, the Alibaba Cloud modeling engine is used to model the standard working condition data and obtain the big data black box model of the target variable. The theoretical standard value can be calculated in real-time, and after comparing it with the actual value, it can judge whether the current state deviates from the standard value.

In the power generation process of waste incineration, the consistency in the quantity of waste fed into the furnace is a critical factor that determines the quality of the combustion process. If an excessive amount of waste is introduced into the furnace, it poses the risks of overtemperature, overloading, and exceeding environmental protection standards. Conversely, if insufficient waste is fed into the furnace, it can lead to burnout, causing the furnace temperature to drop rapidly or fall below the range of 8–50°C, which poses environmental protection hazards. However, accurately assessing the quantity of garbage inside the furnace presents challenges due to the complex and changeable nature of waste. Factors such as blockages, slippage, and bridging of garbage can obscure the direct measurement of garbage feeding rates. Additionally, issues such as garbage non-ignition and deflagration can lead to operator misjudgment, resulting in either overfeeding or underfeeding of waste, leading to material buildup or shortages. Accurately and effectively determining the garbage level within the furnace has thus emerged as a key factor in determining the feasibility of implementing automated combustion processes.

In this project, an effective method for gauging the quantity of garbage being introduced into the furnace was devised. It relies on the incinerator's furnace structure, specifically using the wind pressure within the drying section as a key indicator for estimating the garbage level within the furnace. However, it's worth noting that the wind pressure in the drying section is affected by both the primary air volume and the damper settings of the drying section. Yet, the instantaneous value of this parameter cannot directly represent the amount of garbage due to the varying openings of different dampers, including those in the combustion section. To address this challenge, the Alibaba Cloud anomaly identification algorithm engine was introduced. It employs wind pressure as an indicator of garbage feed quantity and conducts extensive big-data modeling of the wind pressure in the drying section. This process involves selecting 3–5 months' worth of historical operational data, utilizing unsupervised learning methods to filter out abnormal operating conditions, and obtaining standardized data for normal working conditions. Within these normal conditions, parameters such as primary wind frequency feedback, primary wind pressure, and the openings of each section's damper are selected as input features for the model. The Alibaba Cloud data modeling engine is then employed to establish a wind pressure model for the drying section. The model leverages the deviation between the predicted wind pressure ($P_{predicted}$) and the actual win pressure (P_{actual}) to ascertain the current amount of waste being fed into the furnace, followed by adjusting the feeder's feeding speed dynamically, ensuring a consistent feed volume. **Figure 5** illustrates the wind pressure model and the feed speed control curve for a drying section of the incinerator.

As shown in **Figure 5**, the upper diagram presents the actual wind pressure values in blue and the predicted wind pressure values in red, while the purple curve represents the difference between the actual value minus the predicted value. The lower diagram shows the corresponding feeder speed value. In the yellow box within the figure, it is evident that the actual wind pressure values significantly exceed the predicted value, resulting in a substantial deviation. This signifies an excessive amount of garbage within the drying section, prompting a reduction in feeder speed and a decrease in the feeding quantity. On the other hand, the red box within the figure reveals instances where both the wind pressure and actual compression values are significantly lower than the predicted value, with a minimal deviation. This indicates an insufficient amount of garbage in the drying section, leading to an increase in feeder speed to swiftly replenish the material. Through the wind pressure prediction model, the condition of garbage within the furnace can be continually monitored and assessed in real-time. Adjustments to the feeding speed can then be made as needed, effectively addressing the challenges associated with assessing furnace garbage levels and ensuring uniform feeding.

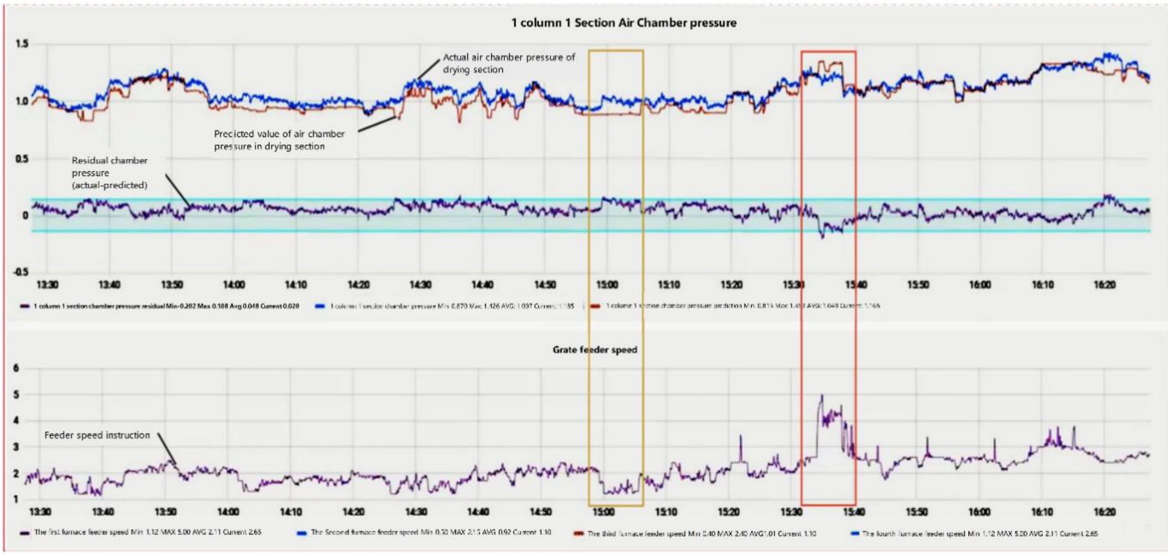

Figure 5. Wind pressure model and feed speed control of a row of drying sections

5. Visual recognition algorithm engine

The primary function of the visual recognition algorithm is to identify flame video images. Through visual recognition, it can promptly detect the burning conditions and burning locations of the garbage within the furnace, and then facilitates quick adjustments to the grates and primary fans of each section to ensure a stable combustion process. Within this project, the visual recognition algorithm primarily employs image classification and image segmentation techniques to analyze various aspects of the flame image, including the fire line, flame area, smoke, and brightness. This information is then subjected to post-processing to enable real-time analysis of the combustion status of the grate flame, which serves as input for subsequent control optimization algorithms. The overall algorithm flow is depicted in **Figure 6** below:

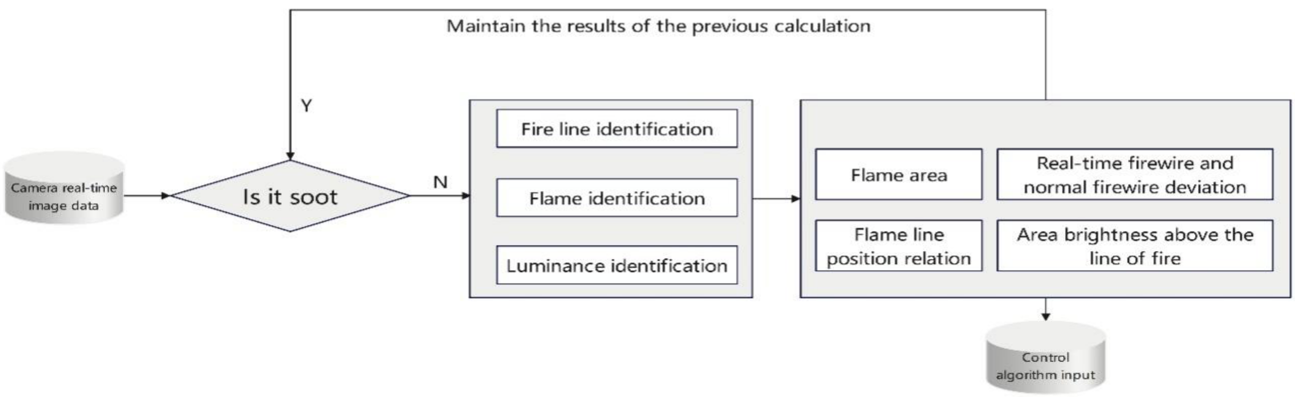

Figure 6. Visual recognition algorithm flow chart

A recognition algorithm is developed utilizing on-site flame image conditions, and the identified flame, fire line area, and corresponding position relationship are divided into images to conduct a more detailed analysis of the flame-burning state, as shown in **Figures 7** and **8**.

Figure 7. Flame image recognition algorithm: left side of the flame in furnace #1

Figure 8. Flame image recognition algorithm: right side of the flame in furnace #2

When the camera is clear, the current combustion situation in the furnaces and the material layer in the combustion section can be evaluated based on the flame width and brightness to make targeted combustion adjustments.

6. Discussion and conclusion

To assess the performance of the AI automation system, an 18-day evaluation test was carried out. During the test, the system was operated in the automatic and manual modes for nine days, respectively, while ensuring the unit remained under consistent operating conditions with similar waste calorific values. Based on the operational data analysis during the test period, the AI control system primarily demonstrated efficiency improvement in four aspects, including optimizing and transforming a total of 45 control loops across the feeding system, wind and smoke system, and exhaust gas treatment system. Moreover, parameter tuning yielded positive outcomes in five aspects: improving the automation level of the unit, improving combustion stability, reducing manual operation intensity, reducing plant power consumption, improving variable load performance, and achieving the expected goals.

6.1. Automatic operation rate of unit

After debugging and optimizing the early modeling prediction algorithm and control algorithm, debugging and optimizing the video image algorithm, switching deployment between the edge and the cloud, and the overall trial operation test, the combustion control algorithm can be put into operation, the automatic operation rate is about 97%, and the specific data of the comparative test are shown in **Table 1**.

Table 1. Automatic operation table of the unit

Furnace number	Operation time (hour)	Total time (hour)	Operation rate (%)
1	205	216	94.9
2	212	216	98.1
3	206	216	95.4
4	209	216	96.8
Total	832	864	96.3

6.2. Furnace header steam flow

It is seen from **Table 2** that during the operation of the combustion optimization automatic control system, it can effectively improve the stability of the steam volume while ensuring that the steam volume is consistent. The average steam volume is the same compared to the manual operation period. The stability of the steam volume of furnaces #1–#4 is increased by 27.48%, 22.12%, 26.12%, and 21.06%, respectively, with an average increase of 24.2 %, indicating a stable combustion optimization control system. It can improve combustion stability while ensuring the overall load.

While the steam volume stability is improved, the header pressure stability is also greatly improved. The overall pressure stability of the #1–#4 furnace headers increased by 4.1%. The stability of the steam pressure effectively improved the stable operation of the steam turbine unit. The specific data are as follows.

In addition, the stability of critical parameters such as furnace temperature and oxygen content has also been improved. The T2X furnace temperature stability increased by 6.0% after operating the system. When the above vital parameters are stable, combustion stability can be improved, pollutants exceeding standards can be reduced, and furnace coking can be reduced, thereby effectively improving unit operation and equipment health.

Table 2. Steam flow in furnace header

	#1 Furnace header		#2 Furnace header		#3 Furnace header		#4 Furnace header	
	Average pressure	Pressure standard deviation	Average pressure	Pressure standard deviation	Average pressure	Pressure standard deviation	Average pressure	Pressure standard deviation
Automatic	6.31	0.038	6.33	0.045	6.34	0.041	6.35	0.041
Manual	6.31	0.041	6.33	0.043	6.35	0.043	6.36	0.045
Increase (%)	0.0%	7.3%	0.0%	-4.7%	0.2%	4.7%	-0.2%	8.9%

6.3. Improvement of manual operation intensity

Table 3 lists system operation numbers before and after implementing the automatic control system. It can be seen from the table that after the combustion optimization, an automatic control system is put into operation; it can control the feeder, each grate, and primary and secondary air in real-time according to the current working conditions. The desuperheated water, SNCR, and other systems are automatically adjusted, requiring only a small amount of manual intervention under abnormal working conditions such as equipment failure, maintenance, garbage not catching fire, and stacking, significantly reducing operators' workload.

Statistics were made on the number of operations of each control quantity of the combustion system during the manual operation period, the number of interventions during the operation of the combustion optimization automatic control system, and the total number of operations was calculated. The statistical results are shown in the figure and table below. During manual operation, the total number of operations of the combustion system in 9 days was 18,080. After the automatic control system was implemented, the total number of operations was 1,295, and the amount of manual operations was reduced by 93%. It significantly reduced the labor intensity of operators and was able to respond to on-site emergencies such as insufficient workforce in the central control room.

Table 3. List of system operation numbers before and after the automatic control system is integrated into the system

#1–#4 Furnaces	Manual	Automatic
Control amount	**Operation amount**	**Operation amount**
Feeder speed	3,016	851
Number of grate cycles	1,114	154
Number of lower grate cycles	1,112	0
Primary fan frequency	1,917	175
Secondary fan frequency	9,862	74
SNCR ammonia water regulating valve opening	361	15
SNCR dilution water regulating valve opening	15	0
Opening degree of the first stage desuperheating water regulating valve	616	26
Opening degree of the secondary desuperheating water regulating valve	67	0
Total	18,080	1,295
Decline (%)	93%	

6.4. Optimization of the environmental reagents dosage and environmental parameters control

With the implementation of the combustion optimization control system, the production and operational conditions exhibited greater stability compared to manual control. Moreover, the system achieved automated control over SCR/SNCR/activated, leading to more consistent control of pollutant parameters, closely aligning them with the predefined set values. As a result, the permissible outlet NO_X and SO_2 values could be moderately increased within the environmental protection assessment requirements, thus effectively reducing the consumption of consumables such as ammonia and activated carbon while still meeting environmental protection standards. **Table 4** shows the average NO_X value and ammonia consumption based on the production operation report during the 18-day experiment. It can be seen from the table that the average NO_X value during automatic operation is the same as that during manual control and is within the environmental protection standards.

Table 4. NO_X average value and ammonia water consumption table during the experiment

	Total garbage disposal volume (t)	Total ammonia consumption (kg)	Ammonia consumption per ton of garbage (kg/t)	Average NO_X value (mg/m^3)
Automatic	26,647	84,570.51	3.17	95.99
Manual	28,516	84,873.12	2.98	95.00
Increase (%)	6.6%	0.36%	-6.63%	-1.03%

Table 5 shows the consumption of activated carbon and slaked lime based on the production operation

report during the 18-day experiment. The average values of SO_2 and HCl are the same between automatic and manual, and ammonia escape is reduced by 11.6%. Slaked lime and the dosage of activated carbon are similar.

Table 5. Activated carbon and slaked lime consumption table during the experiment

	Total activated carbon consumption (kg)	Activated carbon consumption per ton of garbage (kg/t)	Total slaked lime consumption (kg)	Slaked lime consumption per ton of garbage (kg/t)	SO_2 average (mg/m^3)	HCl mean (mg/m^3)	NH_3 escape average value (mg/m^3)
Automatic	11,274	0.4 2	138,830	5.21	1.76	0.57	6.72
Manual	11,438	0.4	138,810	4.87	2.08	0.44	7.6
Increase (%)	1.43%	-5.48%	- 0.01%	-7.02%	15.3%	-29.1%	11.6%

6.5. Energy consumption optimization and gas production indicators per ton

The test showed that during the 18-day experiment, due to more accurate oxygen adjustment and more stable furnace negative pressure, the power consumption of the secondary fan increased by 4.5%, the power consumption of the induced draft fan decreased by 4.7%, and the power consumption of the primary fan decreased by 5.1%; the overall fan power consumption is reduced by 4.1% (**Table 6**), and the average daily power consumption is reduced by 2,620 kWh. Based on this, it is estimated that the annual electricity bill will be saved approximately 620,000 CNY (based on 0.65 CNY per kWh), hence reducing operating costs.

Table 6. Statistics table of fan power consumption

	Primary fan power consumption (kWh)	Secondary fan power consumption (kWh)	Electricity consumption of induced draft fan (kWh)	Total power consumption of the fan (kWh)
Automatic	31,024	44,939	481,038	557,001
Manual	32,697	43,021	504,863	580,581
Increase (%)	5.1%	-4.5%	4.7%	4.1%

During the 18-day experiment, the critical indicators of the boiler's gas production per ton increased by 4.5 %, and the thermal ignition rate decreased by 3.1 % (**Table 7**), which proves that in the fully automatic state, while improving operational stability and reducing production costs, the operation indicator can still be controlled in a stable state.

Table 7. Statistical table of boiler gas production per ton and heat loss rate

	Average gas production per ton of furnace #1–#4	#1–#4 Furnace thermal ignition rate average
Automatic	2.57	2.36
Manual	2.46	2.29
Increase (%)	4.5%	-3.1%

6.6. Conclusion

Intelligent waste incineration control better integrates traditional industrial control and big data artificial intelligence in large-scale grate furnace control. Alibaba Cloud's big data modeling and prediction technology is applied. The operator's operating benchmark parameters are obtained through reinforcement learning algorithms, and the operation control benchmarks for each load section are obtained. Anomaly identification algorithms are used to build an identification model of material layer thickness for the drying section, and the thickness of the feed material is evaluated. Rapid and effective evaluation realizes the feed uniformity control and solves the most fundamental and core feed problem in grate furnace control such as constructing prediction models of steam drum pressure, NO_x, and SO_2 through operation parameter prediction algorithm, and realizes operation parameters. The short-term prediction realizes advanced adjustment and improves the control performance; through a visual recognition algorithm, the flame image recognition is used to obtain the flame-burning status and combustion line position in the furnace, and the flame-burning status in the furnace is understood in real-time. The grate and air volume are then adjusted to optimize the combustion conditions in the furnace, and through comparing the data before and after commissioning, the fluctuations of parameters such as steam volume and turbine pressure have been significantly improved, and the control effect is ideal.

In the future, with the continuous accumulation of operating data after commissioning, the system model will be continuously optimized in combination with the operating process data, and the control effect will be further optimized and improved.

Disclosure statement

The authors declare no conflict of interest.

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Integrated Services Platform of International Scientific Cooperation

Innoscience Research (Malaysia), which is global market oriented, was founded in 2016.Innoscience Research focuses on services based on scientific research. By cooperating with universities and scientific institutes all over the world, it performs medical researches to benefit human beings and promotes the interdisciplinary and international exchanges among researchers.

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