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Retraction

Retracted: Application of Boiler Optimization Monitoring System Based on Embedded Internet of Things

Mathematical Problems in Engineering

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] H. Zhang, M. Qiu, X. Yu, Y. Wu, and Y. Ma, "Application of Boiler Optimization Monitoring System Based on Embedded Internet of Things," *Mathematical Problems in Engineering*, vol. 2022, Article ID 9974393, 12 pages, 2022.

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Research Article

Application of Boiler Optimization Monitoring System Based on Embedded Internet of Things

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In order to study the deficiency of tuning PID controller in traditional boiler combustion air system, this paper proposes an embedded Internet of things monitoring system and puts forward a method of fuzzy PID controller with the help of nonlinear optimization algorithm to reasonably set the initial value of control parameters. Through the simulation comparison with the traditional engineering tuning PID controller, it is found that when the simulation process is $t = 2000$ s, the step disturbance with amplitude of 0.1 is added to the system input, and there will be slight disturbance in the combustion process. Through fuzzy PID and strong robustness support, the modeling error of the monitoring system model can be controlled between 10%~25%, which proves that the nonlinear optimized PID has strong anti-interference and can meet the process requirements of the system.

1. Introduction

Boiler is the most common heating equipment and the most widely used heating device in human production and life [1]. However, if the combustion process of boiler is not effectively controlled, it will inevitably lead to the decline of boiler combustion efficiency, which will not only produce large economic losses, but also discharge fuel gas with high carbon content, causing varying degrees of damage to the ecological environment. If the boiler combustion process is not reasonably controlled, even danger will occur [2]. At present, most of the boiler combustion control systems used are basically engineering adjusted PID controllers, which have great shortcomings. Based on this problem, this research proposes a fuzzy PID controller based on the nonlinear optimization method and further optimizes the boiler monitoring system with the help of embedded Internet of Things monitoring system.

2. Literature Review

The most common problem encountered in video surveillance is the recognition of surveillance targets, also known as motion detection. The current research methods are mainly divided into static scene and dynamic scene. In recent years, morphological filtering has been gradually applied to the analysis of video images. For static analysis, there are two kinds of analysis methods: background difference and streamer field [3]. At present, the research on the background difference method has been very mature, and its principle is relatively easy to understand. Therefore, the research results for it are relatively rich. The background subtraction method of Gaussian mixture model was proposed by foreign scholars; these research results are based on the background subtraction method. It can be seen that this method is universal. Similarly, some researchers have also studied the results of using background feature modeling [4]. Some scholars proposed a deep understanding of the background subtraction method and a sequential kernel density approximation method. When using the background difference method, it can not only form its own theory, but also be combined with other methods, such as the new concept of double threshold adopted by the W4 system; in the knight intelligent monitoring system, the combination of the Gaussian mixture model and gradient detection is used to improve the target acquisition; SAKBOT system can effectively analyze various shadows in the monitoring image.

In traditional control problems, people hope to optimize the control effect by improving the accuracy of the system dynamic model. However, in the actual production and life, the problems that people want to solve are becoming more and more complex [5]. The simple and accurate system model is too ideal and has no practical application value. It is difficult to describe the dynamics of complex systems correctly. With the development of modern science, scientists and engineers try to simplify the system to achieve the purpose of control, but the effect is not ideal. In short, traditional control methods have strong control ability for simple and clear systems. However, for complex or difficult to accurately describe the system, it cannot achieve a good control effect, and even cannot meet the requirements of the process. Therefore, in the face of such control problems, the idea of fuzzy mathematics came into being [6].

The research on Fuzzy Mathematics in China began in the early stage of reform and opening up. In the following decades, fuzzy mathematics has made a lot of achievements in theory and application [7]. In 1988, a university professor and his scientific research team successfully developed the fuzzy inference engine, that is, the prototype of discrete component machine, and used it to carry out the inverted pendulum control experiment [8]. The controller shows good results for all kinds of controlled objects with different shapes and even soft objects, and has the advantages of fast and real-time. Its operation speed can reach 1.5 million times/s. Such a high operation speed indicates that China has made great progress in fuzzy information processing.

3. Design of Monitoring System for Embedded Internet of Things

3.1. System Architecture. According to the environmental requirements of the site, the system uses ARM9 series microprocessor as the hardware core, embedded Linux as the operating system, and constructs an embedded system as the server to manage the webcam, collect the image data of the webcam, and provide users with the functions of real-time viewing, monitoring, and historical playback through the built-in Apache Web server [9]. The whole system is of B/S structure, and the system composition is shown in Figure 1.

The main hardware modules of the system include ARM920T series processor based on ARMv4T architecture, FLASH, SDRAM, power module, Ethernet controller, and RS232C. The specific hardware structure is shown in Figure 2.

S3C2410 processor is a 32 bit RISC microcontroller with ARM920T processor core and 0.18 um manufacturing process. It is a low-power and highly integrated microprocessor specially designed for embedded devices. It supports thumb and arm instruction sets, has MMU and Cache, and integrates rich peripherals in the chip, which greatly reduces the cost of the whole system. Its instruction execution efficiency has been greatly improved [10]. The processor has AMBA BUS and Harvard cache architecture. LCD controller supporting TFT, starting from nandflash, with 4 DMA with external request pins, 3 UART, 2 SPI, etc. The operating frequency of S3C2410 processor can reach 203MHz. This running frequency can run embedded Linux and other systems well. The microprocessor divides the storage space into eight blocks, each with a size of 128 MB and a capacity of 1 G. The memory controller supports the storage formats of Big Endian and Little Endian. Bank0 is 16/32 bit addressing, others are 8/16/32 bit addressing, and Bank0 to Bank5 are used for ROM and SRAM. Bank6 and Bank7 are used for ROM, SRAM, or SDRAM. The starting address of Bank6 is fixed and the starting address of Bank7 is changed [11].

3.2. Software Design of the System. The embedded network monitoring system adopts B/S structure, constructs the embedded system as the server, and uses the web browser as the user interface of the system. The system adopts the idea of component design, applies object technology to system design, and further abstracts the implementation process of object-oriented programming. The functions of the system can be expanded through continuous functional components to meet the growing and changing needs of users [12]. Therefore, the system has strong scalability and the ability of secondary development and continuous development. The overall architecture of the system is shown in Figure 3.

The components of embedded monitoring system belong to interprocess communication and data acquisition through files. Because the communication modes between components are different, the interprocess communication is provided by each component to hide the communication mode. The specific software communication interface is shown in Table 1.

The main processing part of the webcam management module includes initialization processing at startup, end processing at the end of the process, and sending/receiving processing of external API messages. See Figure 4 for details.

Initialization processing during process startup includes application and initialization of shared memory, application and initialization of FIFO, application and initialization of semaphore, application and initialization of socket, updating shared memory according to configuration file, opening FIFO for management, initializing shared memory allocated for the latest image, and generating network camera monitoring thread [13]. The initialized resources need to be released at the end of the process; otherwise, it will cause memory leakage or system crash (because the end processing in case of power failure cannot be executed, and the end processing of the process will not be executed). See Figure 5 for details.

Message processing process of webcam management process: when receiving a message sent by an external API, judge the type of received message, make corresponding processing according to the message type, and then return data to the corresponding external. The specific types and processing of messages sent from external APIs are shown in Table 2.

The main work of this chapter is to provide a feasible implementation scheme, which combines embedded technology, network communication technology, and intelligent monitoring technology to build a practical, low-cost,

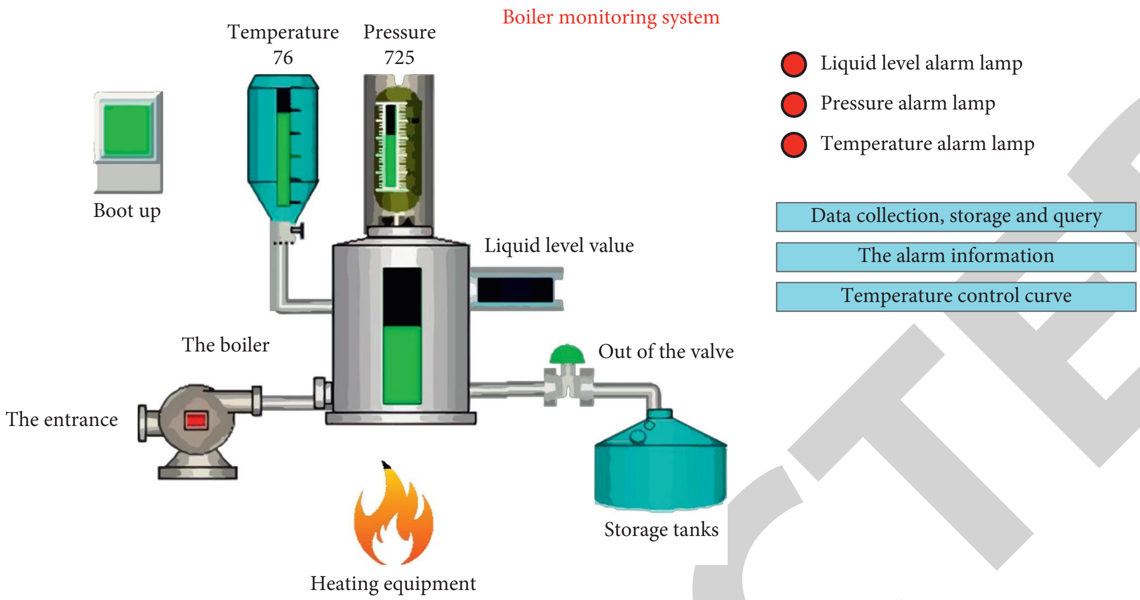

FIGURE 1: System composition.

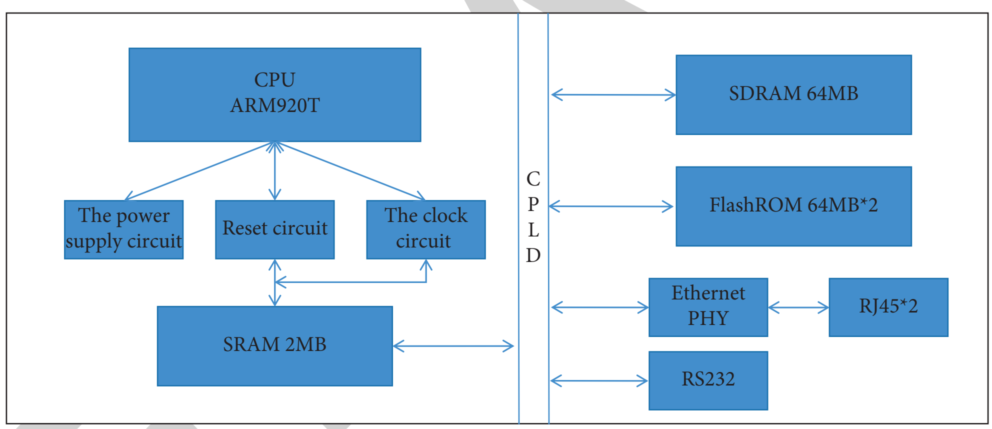

FIGURE 2: Physical structure of hardware.

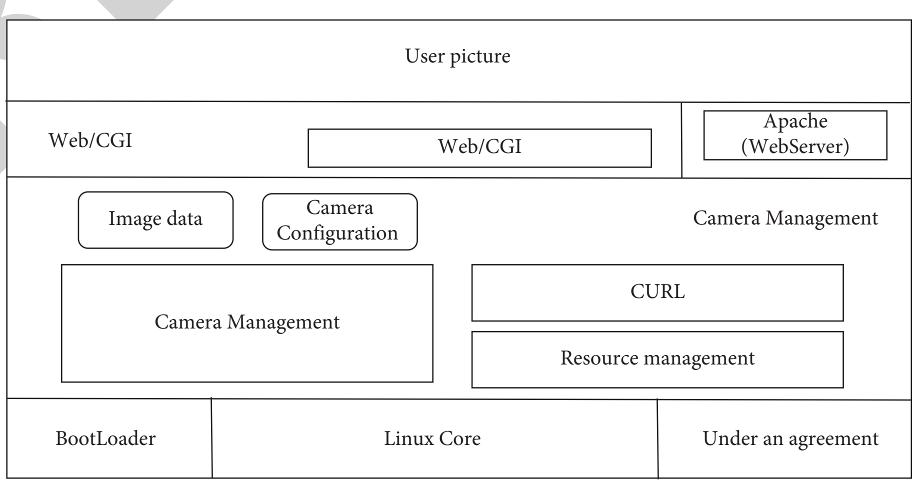

FIGURE 3: Software structure.

Table 1: List of communication modes between components.

Serial number	Communication mode between components	Explanation
1	FIFO	The interface is provided in the form of dynamic library, which is mainly used for interprocess message passing.
2	Socket	The interface is provided in the form of dynamic library, which is mainly used for communication with network camera.
3	Shared memory	The interface is provided in the form of dynamic library, which is mainly used for communication with CG I.
4	File	The interface is basically provided in the form of dynamic library. When the dynamic library cannot be used, it can be accessed directly.

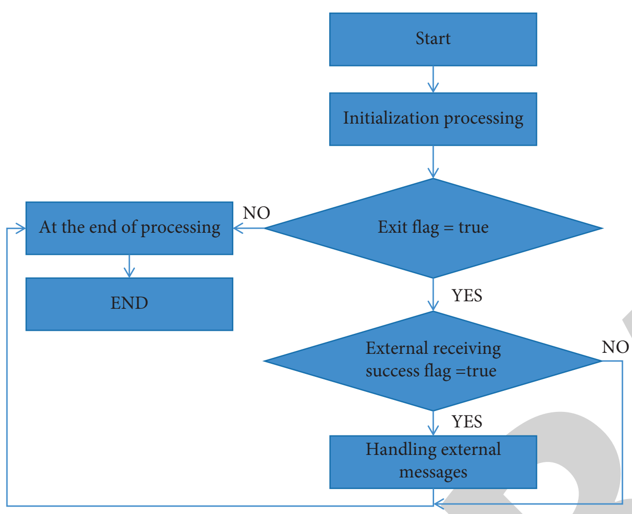

Figure 4: Main processing of network camera management.

scalable, flexible, and efficient embedded network monitoring system [14]. This paper systematically analyzes the current situation of video surveillance and puts forward a video surveillance scheme based on S3C2410 according to the specific requirements of the application of video surveillance in the family field. The network camera image acquisition, network transmission, and local storage are realized. In the process of image acquisition and data transmission, most of the technologies of interprocess communication such as pipeline and socket are used. At the same time, multithread technology is used to manage the network camera, which improves the execution efficiency of the system [15]. The whole system adopts modular design to ensure the balance between closure and openness and efficiency. Through the selection and combination of modules, it can meet the customized needs of different users and is also conducive to the reuse and upgrading of the system.

4. Design of Combustion Process Monitoring Scheme for Coal-Fired Chain Boiler

4.1. Composition of Boiler Combustion Control System. Fuel combustion is a chemical reaction with oxygen in the air at a certain temperature, in which chemical energy will be released. Taking standard coal combustion as an example, the reaction equation is

$$C + O_2 = CO_2 + 97.65\,\frac{\text{kcal}}{\text{mol}}. \quad (1)$$

In order to ensure that the heat released in the combustion process reaches the theoretical value, the fuel and air must maintain a certain proportion in order to achieve full combustion and improve combustion efficiency. The control system mainly controls the coal feed, furnace negative pressure, and air supply volume to achieve the best combustion effect. The control system includes two loop controls, namely, coal feeding control and furnace negative skin control, as well as a proportional control system and "air supply coal feeding" ratio control system. For the hot water boiler, the coal feeding quantity control is to detect the water supply temperature, calculate the deviation from the set value, and adjust the grate motor speed to change the coal feeding quantity, and then realize the water temperature control [16]. For the steam boiler, the coal feeding amount is adjusted by detecting the steam pressure of the output pipeline so as to realize the control of the boiling effect of the heat energy generated by combustion on the water in the boiler and then realize the control of the steam pressure. The air supply volume is controlled in proportion to the coal supply according to the reactant ratio of the combustion reaction equation. Table 3 lists each measurement variable, its measurement device, and its role in the control system.

The controlled variables and control equipment of boiler combustion process are given in Table 4.

4.2. Boiler Combustion System Control Scheme

4.2.1. Coal Feeding Control System. The structure diagram of coal feeding control system is shown in Figure 6. That is, a simple feedback control system compares the water temperature at the outlet of the boiler with the set value by detecting the water temperature and transmits the deviation to the PID controller [17]. In this project, the PID controller is realized by the lower computer PLC. The controller will output 4–20 mA current and control the motor driving the grate to rotate.

The lower computer PID control program is a part of the lower computer PLC control program, which is skillfully developed in the configuration software. When programming PLC control program, it is necessary to con figure and variable configuration in the software first. The program flowchart of PID part is shown in Figure 7.

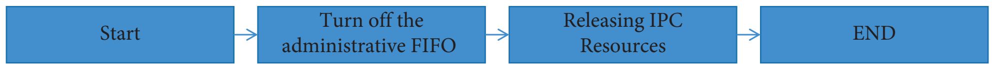

Figure 5: End processing of webcam.

Table 2: Message types and processing.

Classification	Message type	Message code	Processing summary	Return data
Real time image request	GET	OXO1	(1) Check the range of webcam ID value. (2) Obtain the real-time image of the webcam, store it in the common memory and return it to the CGI caller.	Real-time image
Webcam action notification	GET	OXO2	(1) Find the ID of the webcam in the configuration information according to the IP address of the webcam. (2) Generate the action processing thread of the webcam with the corresponding ID	OK

Table 3: Boiler combustion process detection transformer and its detection equipment.

Controlled variable	Testing equipment	Control function
Boiler outlet supply/return water temperature	Supply/return water temperature measuring instrument	Reaction boiler load
Steam pressure at drum outlet	Steam pressure detector	Output steam pressure of reaction boiler
Furnace negative pressure	Furnace pressure sensor	Negative pressure of reaction furnace and flue gas emission

Table 4: Controlled variables and their actuators in boiler combustion process.

Controlled variable	Executing agency	Control function
Coal feed	Grate motor	Adjust coal feed
Air supply volume	Blower	Adjust the air supply volume
Induced air volume	Induced draft fan	Adjust furnace negative pressure

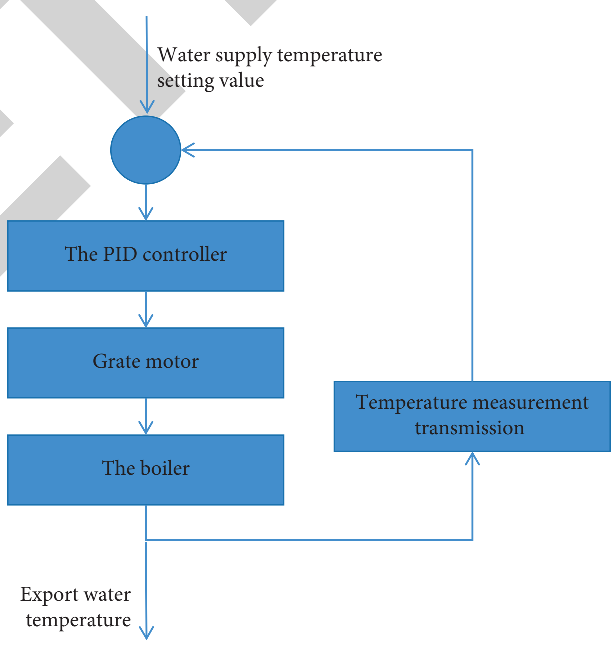

Figure 6: Block diagram of coal feeding control system.

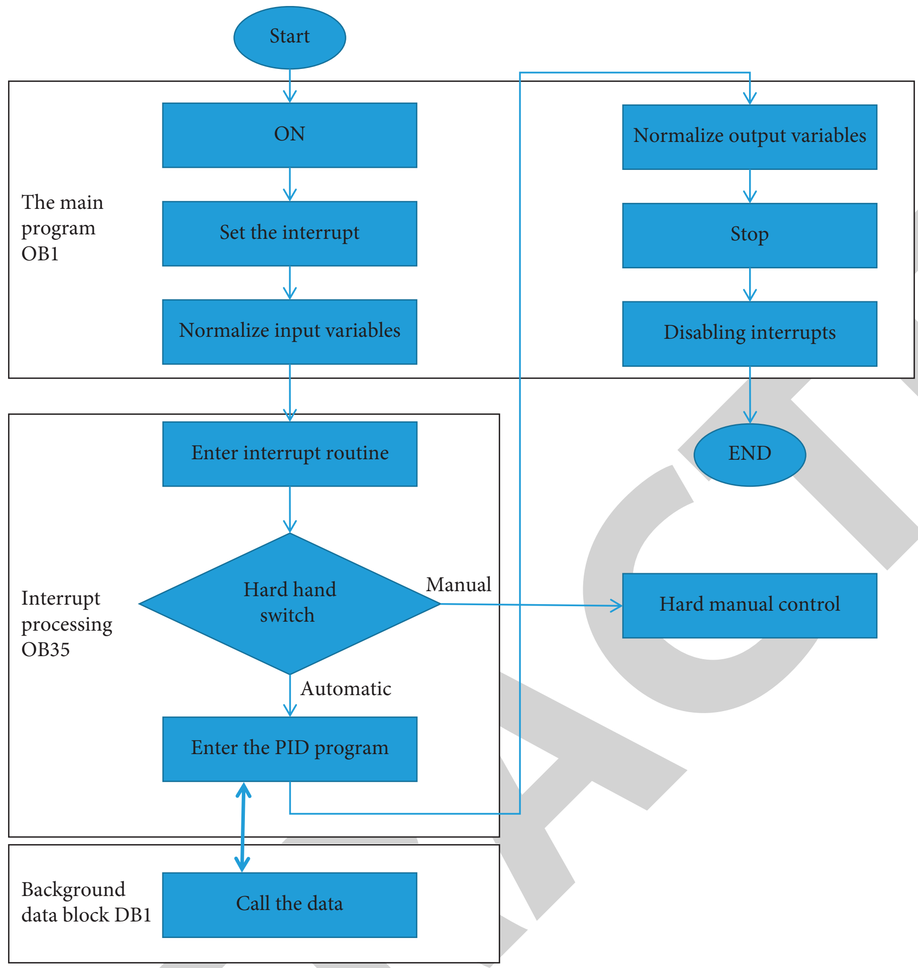

Figure 7: Calling part of PID module control program.

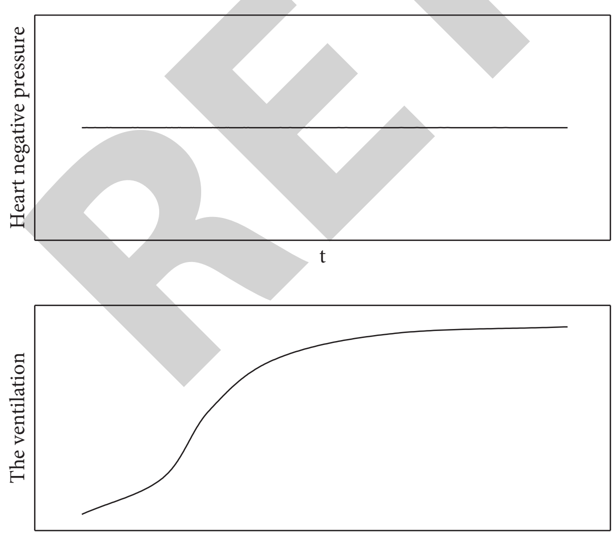

Figure 8: Step response curve of furnace negative pressure to induced air volume.

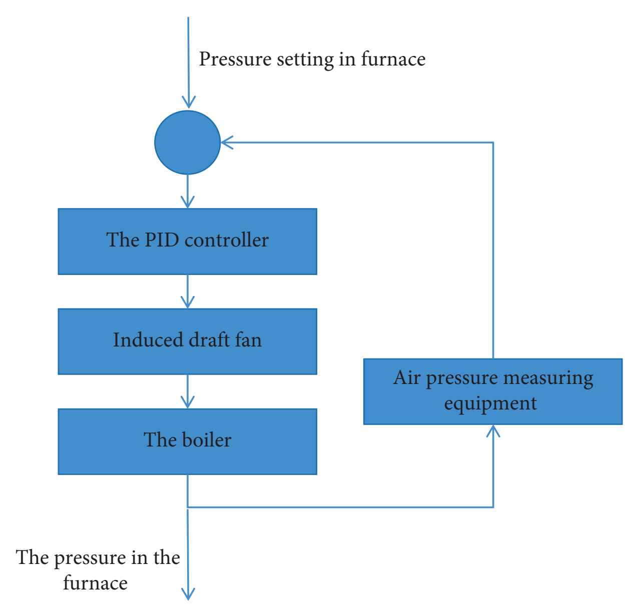

Figure 9: Structure diagram of furnace negative pressure control system.

For the "soft manual" control of the upper computer, its priority is lower than the "hard manual" control on-site. When the "hard manual" switch is set to "1," the system is in manual control state, and the upper computer cannot switch to manual control mode. This part of logic is realized in the upper computer [18].

4.2.2. Induced Air Volume Control System. Controlling the furnace cavity in a micronegative pressure state is an important condition to ensure the safety of on-site staff and the on-site equipment from damage. Furnace negative pressure is mainly controlled by adjusting the air pressure in the furnace through induced draft fan. Of course, factors such as forced draft fan and furnace air leakage will also affect the control of furnace negative pressure. The characteristic curve of the step change of furnace negative pressure with induced air volume is given in Figure 8. It can be seen from the curve that the negative pressure of the furnace reacts quickly to the induced air volume, the delay is small, and it is easy to control [17].

The structure diagram of furnace negative pressure control system is shown in Figure 9. It is the same as the implicit principle of coal feed control. It is also a single loop feedback control system. The negative pressure of the furnace is greatly affected by the air supply volume, so the control system needs to have good robustness. The optimization of the control system will be described in detail below [19].

4.3. Development of Monitoring System

4.3.1. Design Ideas. Before developing the boiler group combustion process monitoring operating system, the framework of the monitoring system needs to be structured in combination with the functions and advantages of WINCC.

(1) Type of project. The project types provided by WINCC include single user, multiuser and client. The project type selected by the boiler group combustion process monitoring operating system is single user [20].

(2) Definition of variables. Before creating the project, count the variables to be controlled, monitored, and collected variables and alarm variables in combination with the PLC control program of the lower computer. WINCC provides users with two types of variables: internal variables and process variables. The use of internal variables can make the development W and application of the monitoring system more flexible. It is created for some operation and display status of the monitoring system without connecting the variable address of PLC program. The process variable needs to be connected with the variable address in the PLC program. Through the process variable, it can not only operate the field equipment but also collect the field real-time data in time. The number of process variables allowed by WINCC is directly related to the purchased WINCC authorization.

(3) The use of scripts. WINCC's script function is divided into global script and action script. It supports ANSI-C and VBS editing languages. The action script can also be directly connected.

4.3.2. Monitoring System Architecture. The most important principle of developing the monitoring system is to be able to monitor the working state of the site in real time and inform the operators of the problems on the site at the first time. Therefore, on the premise that the monitoring screen can reflect the status of field equipment, we must strive to be concise, give the operator the most intuitive feeling, and facilitate its operation. The startup interface of the monitoring system is "boiler group monitoring main interface." In the main interface, you can see the operation status of each boiler of the boiler group and provide some public parameter data and status ideas. Through the main interface, you can enter the monitoring subsystem of each boiler, and the monitoring system interface of each boiler is basically similar [21]. Taking the monitoring screen of boiler No. as an example, the picture structure of boiler monitoring system is shown in Figure 10.

4.3.3. Monitoring Process Variable Record. The configuration process variables are archived in the "WinCC Explorer" interface. Select "variable record" to open the variable record editor. The variable record editor can set the sampling period timer of W data and add *w* record to the data for archiving. The system automatically provides five timers: 500 ms, 1s, 1 min, 1 H, and 1 day to trigger the archiving of variables in the system. You can also customize the new archiving cycle. You only need to create a new timer in "variable record" and set it. The archiving of system variables can be created according to the "archiving Wizard" provided by WinCC software. After that, select the variable to be recorded and configure its properties. The variables to be archived in this project are given in Table 5.

4.3.4. Alarm Record. In the combustion process control system of boiler group, in order to avoid the wrong operation or negligence of on-site personnel, resulting in dangerous shade or affecting the operation of heating pipe network. In the design of the monitoring system, the alarm information is recorded and displayed, and W timely reminds the operator to deal with it.

(1) For alarm record configuration, select "alarm record" under the directory in the "WinCC Explorer" interface, and select "system Wizard" in "alarm Wizard." Follow the prompts to configure various information and display attributes required. After setting the display properties of the alarm record, add the alarm signal. Double click the position of "1" under the window to open the variable window, select "NO.1dig"⟶"NO1_GLCSpress_L" under the

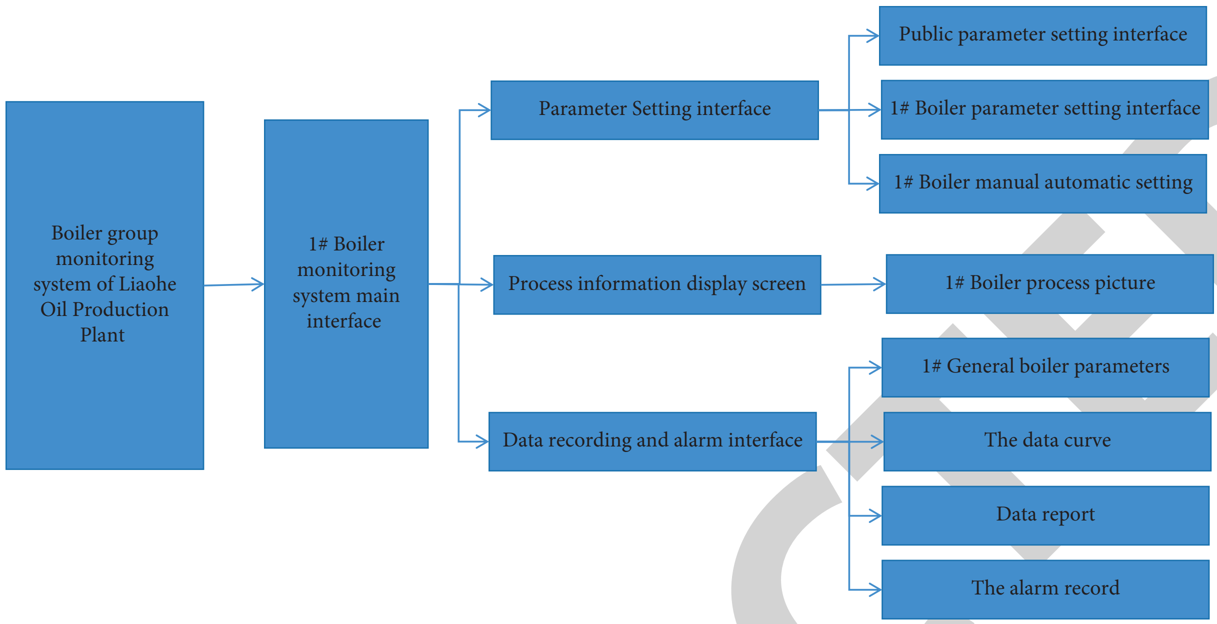

Figure 10: Picture structure of boiler monitoring system.

Table 5: Partial archive variables.

Variable name	Variable type	Acquisition cycle	Archive/display cycle
Water supply header pressure	Analog quantity	1 second	1 second
Return header pressure	Analog quantity	1 second	1 second
Outlet water temperature of 1# boiler	Analog quantity	1 second	1 second
1# boiler blast speed	Analog quantity	1 second	1 second
1# boiler grate speed	Analog quantity	1 second	1 second
1# boiler house negative pressure	Analog quantity	1 second	1 second
1# boiler induced draft speed	Analog quantity	1 second	1 second

internal variable directory, fill in "boiler outlet pressure is too low" under "message text," and enter "1 boiler" at "error point" to complete the alarm record setting caused by the signal of too low pressure at the boiler outlet. Set other alarm signals in the same way [22].

(2) Display alarm record, create a new graphical interface, and name it "alarm record." Add a control named "WinCC Alarm Control" using the method described earlier. Set control ownership. In the message list tab, add text message and error point to display the contents of text message and error point.

4.4. Research on Optimization Algorithm of Boiler Combustion Control System

4.4.1. Nonlinear Optimization Method with Constraints. The general nonlinear programming problem has the following form:

Binding issues:

$$\min f(x). \tag{2}$$

With constraints:

$$G_i = 0 \quad i = 1, \ldots, m_e, \tag{3}$$

$$G_i \leq 0 \quad i = m_e + 1, \ldots, m, \tag{4}$$

$$x = [x_1, x_2, \ldots, x_n], \tag{5}$$

$$G_x = [g_1(x), g_2(x), \ldots, g_m(x)]. \tag{6}$$

Formula (5) is the design parameter vector and formula (6) is the function vector. Where $f(x)$ is the objective function, m_e is the boundary value of equality or inequality constraints, and $f(x)$ and $g(x)$ can be nonlinear functions at the same time.

SQP algorithm is a sequential optimization method for solving general nonlinear programming problems. Firstly, the following Lagrange functions are approximately quadratic;

$$L(x, \lambda) = f(x) + \sum_{i=1}^{m} \lambda_i g_i(x), \tag{7}$$

where λ is the Lagrange factor, and then the QP subproblem is solved. After linearizing the nonlinear constraints, the following problems can be obtained:

Its objective function is

$$\min \frac{1}{2} d^T H_k d + \nabla f(x_k)^T d. \quad (8)$$

The constraints are

$$\begin{gathered} \nabla g_i(x)^T d + g_i(x) = 0, i = 1, \ldots, m_e \\ \nabla g_i(x)^T d + g_i(x) \leq 0, i = m_e + 1, \ldots, m, \end{gathered} \quad (9)$$

where d is the search direction of all variables, ∇ is the gradient, and matrix H is the positive definite quasi-Newton approximation of Hessian matrix of Lagrange function.

In the problem of PID parameter tuning, some performance criteria can be used as the optimization objective function and some performance indexes of expected output can be used as constraints. In the programming simulation, the constraints composed of the system simulation output and performance indexes are taken as the input variables of the optimization process.

These constraints can be regarded as piecewise linear boundary, and a segment n linear boundary y_{bnd} can be expressed as

$$y_{bnd}(t) = \begin{cases} y_1(t) & t_1 \leq t \leq t_2 \\ y_2(t) & t_2 \leq t \leq t_3 \\ \cdots & \cdots \\ y_n(t) & t_n \leq t \leq t_{n+1}. \end{cases} \quad (10)$$

Then, the distance between the simulation output and the boundary is calculated. For the lower boundary, this signed distance value can be expressed as

$$c = \begin{cases} \max\limits_{t_1 \leq t \leq t_2} & y_{bnd} - y_{sim} \\ \max\limits_{t_2 \leq t \leq t_3} & y_{bnd} - y_{sim} \\ \cdots & \cdots \\ \max\limits_{t_n \leq t \leq t_{n+1}} & y_{bnd} - y_{sim} \end{cases}, \quad (11)$$

where y_{sim} is the simulation output, that is, the function with the parameters to be optimized as variables. For the upper boundary, the distance value can be expressed as

$$c = \begin{cases} \max\limits_{t_1 \leq t \leq t_2} & y_{sim} - y_{bnd} \\ \max\limits_{t_2 \leq t \leq t_3} & y_{sim} - y_{bnd} \\ \cdots & \cdots \\ \max\limits_{t_n \leq t \leq t_{n+1}} & y_{sim} - y_{bnd}. \end{cases} \quad (12)$$

The nonlinear programming problem with constraints can be solved by using fmincon function in MATLAB. Fmincon function requires the nonlinear constraint inequality to have the following form:

$$C(x) \leq 0. \quad (13)$$

Transfer the simulation output and the boundary value of each segment to fmincon function. By constantly calling fmincon function to optimize the three control parameters of PID to meet the output performance index, the problem of initial value setting of PID parameters can be solved [23].

4.4.2. Design of Fuzzy PID Controller. In fuzzy control, the real range of input and output signals is defined as the basic domain. In this paper, the input variables are temperature deviation e and deviation change rate ec. According to the characteristics of boiler combustion system, the basic domain of e is [−80,80], and the basic domain of ec is [−10,10]. Let the universe of deviation 6 fuzzy set be

$$X = \{-n, -n+1, \ldots, 0, 1, \ldots, n-1, n\}. \quad (14)$$

The fuzzy set domain of deviation change rate ec is

$$Y = \{-m, -m+1, \ldots, 0, 1, \ldots, m-1, m\}. \quad (15)$$

For quantization factors K_e and K_{ec}:

$$\begin{gathered} K_e = \frac{n}{e} \\ K_{ec} = \frac{m}{ec}. \end{gathered} \quad (16)$$

If $n = m = 6$ is selected in this paper, there are

$$X = Y = \{-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6\}. \quad (17)$$

That is, the fuzzy universe of input variables E and EC, so it is concluded that

$$\begin{gathered} K_e = \frac{n}{e} = \frac{6}{80} = 0.075 \\ K_{ec} = \frac{m}{ec} = \frac{6}{10} = 0.6. \end{gathered} \quad (18)$$

According to the concept of quantization factor of input variable fuzzification, the scale factor of antifuzzification of input variable is defined as

$$G_u = \frac{u}{l}, \quad (19)$$

where u is the basic universe of control quantity and l is the number of quantization files of the basic universe of control quantity. Similarly, the scale factor $G_P = 0.13, G_I = 0.02, G_D = 1$ is obtained.

After designing the fuzzification and defuzzification part of the fuzzy controller, it is necessary to establish the fuzzy control rule base. For the boiler combustion process, it is mainly to control the heat output of the combustion system by adjusting the grate speed, air supply, and other variables to make the outlet water temperature meet the control requirements. In this paper, the output $\Delta K_P, \Delta K_I, \Delta K_D$ of fuzzy controller is the increment of PID control parameter K_P, K_I, K_D.

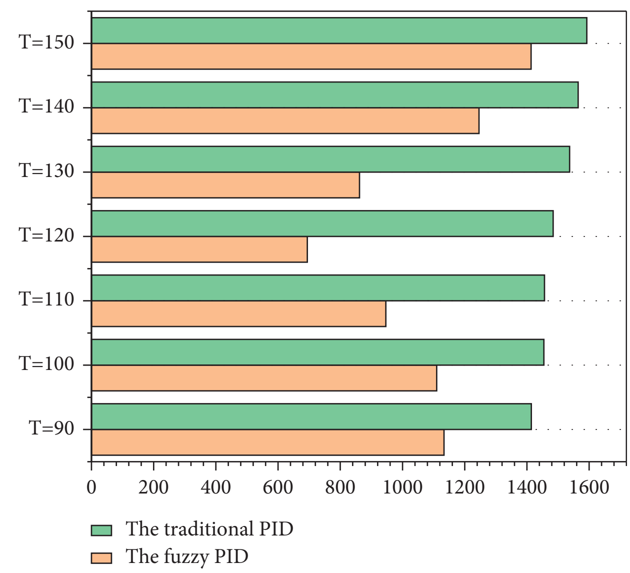

Figure 11: Histogram of adjustment time comparison.

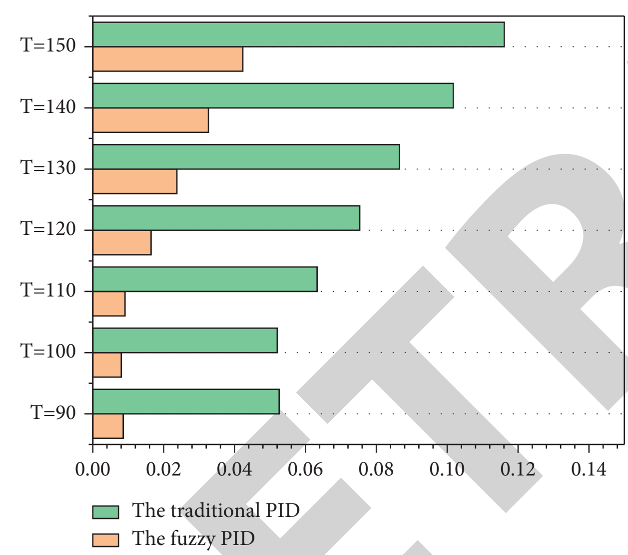

Figure 12: Comparison histogram of relative percentage overshoot.

4.4.3. Algorithm Simulation Research. As the control group, the traditional PID adopts the parameter setting method based on IST^2E criterion, that is the time square error square integral criterion. This paper makes a simulation analysis when the expected performance index of the system is Rise Time $t_r \leq 600s\,(90\%)$, adjustment time $t_s \leq 1000s\,(2\%)$, and percentage overshoot $\sigma\% \leq 5\%$. In order to explore the influence of nonlinear optimization fuzzy PID controller on system robustness, a comparative analysis is made when the inertia time τ of the controlled object model changes by $-25\%{-}+25\%$ and the delay time τ changes by $-17\%{-}+17\%$. The simulation results show that when the inertia time constant of the controlled object changes to -25%, the nonlinear optimization fuzzy PID is less affected, and the overall performance is better than the traditional PID. Moreover, the cost of fuzzy PID control is also less than that

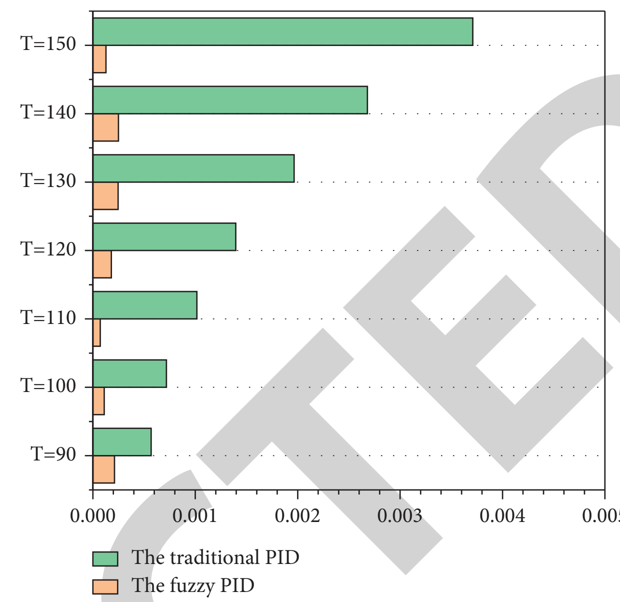

Figure 13: Comparison histogram of steady state error.

of traditional PID. Next, the simulation experiment is carried out when the inertia time coefficient increases by 25%. It can be seen that when the inertia time constant increases to 25%, the traditional PID control system has a large overshoot, needs a long time to converge, and there is a certain steady-state error.

For some specific performance indicators, such as adjustment time, relative percentage overshoot quantization, and steady-state error, fuzzy PID shows good robustness and control effect. This paper uses the data of several main performance indexes of the two kinds of PID to make a histogram for analysis and comparison, as shown in Figures 11, 12, and 13.

Through the histogram, we can clearly see that the nonlinear optimized fuzzy PID can still meet the process requirements to a certain extent when the model parameters of the controlled object change to a certain extent, so that the system has a certain robustness and maintains a good control effect.

Through the above experiments, it can be concluded that the nonlinear optimization fuzzy PID has better adaptability to the change of model and improves the robustness of the system compared with the traditional PID. Fuzzy PID has short response time, small relative overshoot, small steady-state error, and its ability to suppress interference is also stronger than traditional PID. Therefore, nonlinear optimization fuzzy PID has strong practical significance in the boiler combustion process with nonlinearity, time variability, and frequent interference. Its strong robustness can ignore about 10% to 25% of the modeling error of the controlled model. Moreover, it can also play a good control effect on the dynamic change of the model in the combustion process. Under the disturbance of boiler system heat supply network load or the disturbance caused by the change of external environment, the anti-interference of nonlinear optimization fuzzy PID can still make the system meet the process requirements.

In this chapter, the nonlinear fuzzy PID is expounded and analyzed from theory to practice. Firstly, the nonlinear programming theory and its application in tuning the initial value of PID control parameters are described. Then, the fuzzy control theory and the working principle of fuzzy controller are introduced. On this basis, a fuzzy PID controller based on nonlinear programming method to adjust the initial value of control parameters is proposed. MATLAB software is used to simulate and compare the nonlinear optimization fuzzy PID and traditional PID. It is concluded that the nonlinear optimization fuzzy PID still has a good control effect when the model parameters of the controlled object change to a certain extent, can still meet the process requirements in a certain range of parameter changes, improves the robustness of the system, and has a strong suppression effect on interference. It shows that it has strong practical value in boiler control system.

5. Conclusion

After understanding the process flow, equipment, functions, and control requirements of the boiler combustion control system, this study gives the general control scheme of the boiler combustion process control system. This set of distributed control system for combustion process of boiler group with redundant function is developed. Firstly, this paper introduces the hardware configuration and network configuration of the control level lower computer of the control system, as well as the development process of the monitoring interface of the monitoring level upper computer, and designs the functions of data recording, alarm recording, and historical curve. Then, this paper studies the application of advanced control method in boiler combustion process. Based on the previous use of fuzzy PID controller for water temperature control of hot water boiler, air pressure control of steam boiler, and furnace negative pressure control, a method based on nonlinear programming algorithm to optimize the initial value of fuzzy PID is proposed to make the controller have better control effect. The simulation experiment is carried out in the Simulink environment of MATLAB software. It is roughly estimated that the mathematical model of combustion process is a first-order large inertia and large time delay model. Through the comparative analysis of inertia time constant change, delay time change, and step disturbance experiment, it is verified that the fuzzy PID controller based on nonlinear optimization proposed in this paper has better robustness and anti-interference than the traditional PID controller based on error integral criterion. Therefore, in the project implementation, the approximate parameters of the model can be obtained by means of system identification or manual rough identification, and the initial value of the optimized control parameters can be obtained by calculus in the Simulink environment. The implementation of the algorithm can be completed by using the PLC program of the lower computer to realize the function of the fuzzy p-melon controller. Through the simulation comparison experiment with the traditional engineering tuning PID controller, it is found that when the simulation process is $= 2000$ s, the step disturbance with amplitude of 0.1 is added to the system input, and there will be slight disturbance in the combustion process. Through the support of fuzzy PID and strong robustness, the modeling error of the monitoring system model can be controlled between 10%~25%, which proves that the nonlinear optimized PID has strong anti-interference and can meet the process requirements of the system.

As the project is in the implementation stage, there will be some problems in the process of on-site commissioning in the future. This needs to be a control system with high safety and economy. Our designers and constructors should treat each step and process carefully to prevent accidents and accidents.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest..

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