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Systematic Research and Optimization Design of Intelligent Electric Furnace Control System

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Abstract. With the widespread application of smart homes, the study and design of control systems for smart electric stoves, an indispensable part of kitchen life, have garnered significant attention. This research is dedicated to exploring the theoretical foundations and practical applications of smart electric stove control systems, aiming to enhance the user experience of smart stoves while focusing on energy efficiency and environmental impact, thus contributing to the sustainable development of smart kitchens. Various algorithms have been employed for temperature control and energy management to achieve precise control and energy saving. In the design and implementation phases, this research has taken into account multiple factors such as hardware selection, software programming, and system integration, ensuring the reliability and efficiency of the smart electric stove control system. Future research will continue to optimize the control system and explore additional smart features, with the goal of providing users with a more comfortable and convenient kitchen experience while also contributing to environmental protection and energy conservation. This research not only enriches the theoretical study of smart electric stove control systems but also provides valuable references for the design and application of smart electric stoves, holding significant practical significance and long-term research value.

Keywords: Intelligent Electric Stove Control System; Algorithms; Energy Efficiency; Environmental Impact; Market Analysis.

1. Introduction

In the grand tapestry of modern technological advancements, the proliferation of smart home solutions has woven a new thread of convenience and efficiency into the fabric of daily life. The intelligent electric stove, as an indispensable component of contemporary kitchen infrastructure, has taken center stage in the quest for a harmonized balance between user-friendly interfaces and energy-conserving practices. This paper delves into the intricate layers of research and design that underpin the intelligent electric stove control system, an endeavor that is fueled by the pressing need to enhance user experience while remaining cognizant of the urgent demands of energy efficiency and environmental sustainability.

The scope of this research is meticulously crafted to encompass a comprehensive analysis of the control systems that govern the operation of intelligent electric stoves. We aim to construct a user interface design that epitomizes intuitive interaction, thereby elevating user satisfaction to unprecedented heights. The research intricately weaves together considerations regarding hardware selection, software programming, and system integration to ensure the robustness and efficacy of the intelligent electric stove control system. Through rigorous testing and iterative refinement, the resultant research findings illuminate a path toward enhancing energy utilization rates, diminishing energy expenditure, and mitigating environmental pollution.

The impetus for innovation in electric stove control is driven by a confluence of factors, ranging from the evolving expectations of consumers to the inexorable march towards sustainable living. In a world where convenience is often king, the user experience with kitchen appliances can no longer be an afterthought; it must be at the forefront of design and functionality. The intelligent electric stove, with its advanced control systems, holds the promise of revolutionizing the way we cook, offering precision and efficiency that were previously unattainable. However, the pursuit of innovation is not solely for the sake of convenience; it is also a response to the clarion call for environmental responsibility [1]. Energy-efficient appliances are no longer a luxury but a necessity, as the collective consciousness shifts towards reducing carbon footprints and embracing green technology. Thus, the design of intelligent electric stove control systems is not just a technical challenge; it is a societal imperative that demands ingenuity, foresight, and a steadfast commitment to the betterment of our world.

2. Fundamentals of Intelligent Electric Stove Control System

2.1. Working Principles and System Composition of Intelligent Electric Stoves

The inception of an Intelligent Electric Stove Control System is predicated on the necessity to amalgamate convenience in kitchen activities with advancements in technology. The working principle of such a system involves a multifaceted approach, integrating sensors, microcontroller units (MCUs), and user interface components [2]. At the core of the system lies the utilization of temperature sensors, which meticulously monitor the heat levels of the electric stove. These sensors transmit real-time data to the MCU, which is the brain of the system, tasked with interpreting the collected information.

Upon receiving the data, the MCU executes pre-programmed algorithms that are designed to make judicious decisions based on the user's cooking preferences and safety protocols. For instance, it adjusts the power output to the heating elements, ensuring that the temperature is maintained within the desired range. This dynamic regulation is crucial for preventing overheating and conserving energy. Moreover, the system includes a touch screen or a button-based interface that offers users an intuitive method to input their cooking settings, such as temperature, cooking time, and specific cooking modes tailored for various recipes [3].

The composition of an Intelligent Electric Stove Control System is not limited to the aforementioned elements. It also encompasses wireless communication modules, such as Wi-Fi or Bluetooth, enabling the integration with smart home ecosystems. This allows users to control their electric stove remotely via a smartphone application. Additionally, the system may feature a safety mechanism, like an automatic shut-off feature, that activates when the stove is left unattended for an extended period, thereby mitigating potential hazards.

In essence, the architecture of such a system is a harmonious blend of hardware and software components, each meticulously designed to fulfill specific roles. The hardware encompasses the sensors, the heating elements, the interface, and the communication modules [3]. On the other hand, the software is responsible for the logical operations, user interface management, and the communication protocol handling, which together facilitate a seamless cooking experience.

2.2. Methodological Approach

To navigate the multifaceted aspects of this research, a methodological approach that is both systematic and adaptable has been employed. The approach commences with an in-depth analysis of user interactions and experiences with intelligent electric stoves, drawing insights from a rich tapestry of user feedback and ergonomic principles. Subsequently, a diverse array of algorithms was scrutinized and selected based on their aptitude for achieving precise temperature control and energy management. The design and implementation phase were orchestrated with meticulous attention to detail, considering an array of factors from the hardware components to the nuances of software engineering [4]. Each facet of the methodology is interlinked, ensuring that the research is conducted with the utmost rigor and that the findings are robust and actionable.

2.3. Functional Characteristics of Intelligent Electric Stoves

Intelligent Electric Stoves, by virtue of their innovative design, are imbued with a plethora of functional characteristics that distinguish them from their conventional counterparts. A paramount feature is the precision cooking control. The stove's ability to maintain a consistent temperature with minimal fluctuations is indispensable for culinary activities that require exacting standards, such as simmering, melting chocolate, or preparing delicate sauces. This precision is achieved through the continual monitoring of the temperature sensors and the MCU's real-time adjustments.

Another salient characteristic is the energy efficiency of these stoves. By optimizing the power output to the heating elements based on the cooking requirements, Intelligent Electric Stoves consume less energy compared to traditional stoves, leading to reduced utility costs and a smaller carbon footprint. This energy-saving feature is further enhanced by the use of high-quality insulation materials, which prevent heat loss and contribute to the overall efficiency of the system.

Furthermore, the user interface of Intelligent Electric Stoves is a testament to their functionality. It is designed to be user-friendly, with clear visual indicators and responsive controls that make it effortless for users to navigate through the various cooking options. Some models may include voice control capabilities, allowing hands-free operation, which is particularly beneficial when multitasking in the kitchen.

Safety features are also integral to the functional characteristics of these stoves. Advanced models come equipped with child-lock functions, overheat protection, and pan detection technology, which ensures that the stove operates only when a suitable cooking vessel is placed on it. These features provide an added layer of security and peace of mind for users, making Intelligent Electric Stoves a preferred choice for families.

Lastly, the connectivity aspect of Intelligent Electric Stoves cannot be overlooked. The ability to synchronize with other smart home devices and receive firmware updates ensures that the stove remains up-to-date with the latest features and improvements. This connectivity also opens up possibilities for diagnostic checks and troubleshooting, which can be conducted remotely, providing a hassle-free maintenance experience for users.

2.4. Comparison with Traditional Electric Stoves

One of the most striking differences is the level of control and customization that intelligent systems offer. While traditional stoves provide a limited range of temperature settings, Intelligent Electric Stoves allow for granular control over the cooking process, with the ability to make minute adjustments. This precision not only enhances the cooking experience but also contributes to the taste and quality of the prepared dishes.

Energy efficiency is another area where Intelligent Electric Stoves outshine their traditional counterparts. Traditional stoves are typically less efficient, as they do not have the capability to adjust the power output based on real-time cooking requirements. In contrast, intelligent stoves dynamically modulate energy usage, which results in significant energy savings and environmental benefits.

The user interface in traditional electric stoves is often basic, with knobs or switches to control the cooking settings. In comparison, Intelligent Electric Stoves feature advanced interfaces, such as touch screens and digital displays, which provide users with a more intuitive and engaging interaction. Additionally, the smart connectivity features present in intelligent stoves are absent in traditional models, limiting the user's ability to control and monitor the stove remotely.

Safety is another domain where Intelligent Electric Stoves have an edge. Traditional stoves lack sophisticated safety mechanisms, which can lead to accidents if left unattended. Intelligent stoves, however, are equipped with numerous safety features, including automatic shut-off and alerts, which enhance the safety of the cooking environment.

3. Research on Intelligent Electric Stove Control System

3.1. Study on Fuzzy PID Algorithm

3.1.1. Basic PID Algorithms

The pivotal role of Proportional-Integral-Derivative (PID) controllers in the realm of industrial control systems is undeniably significant. The PID algorithm is the cornerstone of many control system applications, owing to its simplicity and effectiveness in various contexts. A PID controller calculates the "error" value as the difference between a measured process variable and a desired setpoint. The controller attempts to minimize the error by adjusting the process control inputs. The proportional component depends on the current error value, the integral component on the accumulation of past errors, and the derivative component on the prediction of future errors.

3.1.2. Fuzzy Logic

However, traditional PID controllers may falter when dealing with complex systems where the model of the system is not well known, or the system is subject to significant external disturbances. Fuzzy logic, introduced by Lotfi A. Zadeh in the 1960s, provides a way to reason about uncertainty and complexity in a manner akin to human thinking and decision-making [5]. Fuzzy logic extends the classical binary set theory with graded membership functions, allowing for intermediate values to represent uncertainty and imprecision. The integration of fuzzy logic into PID controllers results in a Fuzzy PID controller, which adjusts the control strategy based on fuzzy rules, thus handling nonlinearities and uncertainties more effectively.

3.1.3. Fuzzy PID Implementation

The implementation of a Fuzzy PID controller involves the establishment of a rule base, which dictates how the controller will react to various error and change-of-error inputs. A fuzzy inference system interprets the values of error and change in error based on these rules, and a defuzzification process converts the fuzzy control actions into a precise control signal [6]. The Fuzzy PID algorithm, therefore, provides a robust and adaptive approach, particularly suitable for the dynamic environment of an intelligent electric stove, where precise temperature control is crucial for cooking outcomes [7]. The general diagram of the PID system is shown in figure 1.

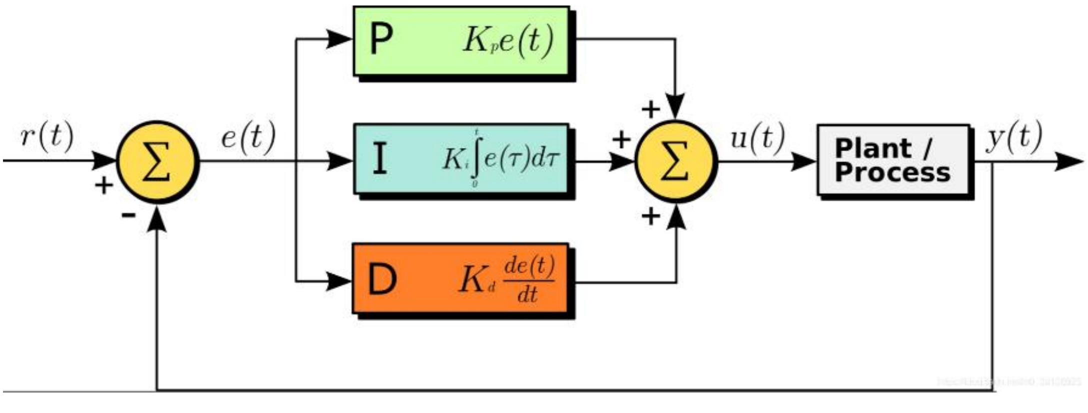

Fig. 1 General diagram of the PID system [6]

3.2. Research on Control Strategies of Intelligent Electric Stoves

3.2.1. User-Centric Control

In the quest to enhance the utility and user-friendliness of intelligent electric stoves, the research delves into user-centric control strategies. These strategies aim to align the stove's operations with the user's cooking habits and preferences. One approach is to incorporate learning algorithms that adapt the stove's behavior based on the frequency and types of dishes cooked. Another aspect is the implementation of voice control and gesture recognition, enabling users to interact with the stove in a more natural and intuitive manner.

3.2.2. Energy Management and Efficiency

Another critical aspect of control strategies for intelligent electric stoves is energy management. The research investigates algorithms that optimize the power consumption of the stove without compromising the cooking performance. By analyzing the usage patterns and predicting the forthcoming power demand, the stove can dynamically adjust its heating elements to optimize energy consumption. These algorithms not only reduce the environmental footprint but also lead to cost savings for the consumer.

3.2.3. Safety Protocols

Moreover, safety is a paramount concern in the design of control strategies for intelligent electric stoves. Advanced sensor technologies are deployed to detect hazardous situations, such as overheating or unattended operations. The control system can then take preventative measures, including shutting down the stove or alerting the user through a mobile device. This proactive approach to safety significantly enhances the reliability and trustworthiness of the intelligent electric stove in the eyes of the end users.

3.3. Adaptability and Efficiency Analyses

3.3.1. Thermal Efficiency Considerations

The study extends into the thermal efficiency of the intelligent electric stove, examining how well the system can convert electrical energy into useful heat under various cooking conditions. The control system is designed to optimize the distribution of heat across the cooking surface, ensuring even cooking and reducing energy waste. The use of high-quality insulation materials and efficient heating elements further contributes to the stove’s overall energy efficiency.

3.3.2. Adaptability to Cooking Methods

Furthermore, the adaptability of the intelligent electric stove to different cooking methods is scrutinized. Whether the user is simmering, boiling, frying, or grilling, the control system can adjust the heating patterns and temperatures to suit the specific cooking technique. This adaptability not only improves the cooking results but also enhances the stove’s versatility, making it an attractive option for a wide range of culinary applications.

3.3.3. Long-term Performance and Sustainability

The long-term performance and sustainability of the intelligent electric stove are also focal points of the analysis. The research evaluates how the control system maintains its efficiency and adaptability over time, accounting for component ware and software updates. Additionally, the study considers the environmental impact of the stove throughout its lifecycle, from production to disposal, underscoring the importance of sustainable materials and recyclability.

In conclusion, the chapter delves into the intricate details of the intelligent electric stove control system, from the foundations of Fuzzy PID algorithms to the intricate control strategies and comprehensive efficiency analyses. The synthesis of advanced algorithms and user-centric features makes the intelligent electric stove not only an epitome of modern kitchen convenience but also a paragon of energy-conscious appliance design. The ongoing research holds the promise of further advancements that will continue to redefine the culinary landscape, offering a harmonious blend of technology, safety, and sustainability.

4. Design and Implementation of Intelligent Electric Stove Control System

4.1. Theoretical Design of Intelligent Electric Stove Control System

In the theoretical framework of the intelligent electric stove control system, it is paramount to consider the intricate amalgamation of user interface design, algorithmic temperature control, and energy management strategies. The purpose of this multi-disciplinary approach is to ensure that the foundation upon which the intelligent electric stove operates is robust, user-centric, and efficient in its energy consumption.

Modeling of temperature models Since it is difficult to establish the heating temperature model of the cooker, we adopt the test modeling method. The heating model is informed by the law of conservation of heat. the heat Q generated by inductive heating of the electric cooker is the sum of the heat Q_1 absorbed by the bottom of the pot and the heat Q_2 distributed by the system $Q = Q_1 + Q_2$, then:

$$Q_1 = C\frac{dT_1}{dt}, Q_2 = KT_1 \tag{1}$$

In the formula, C is the heat capacity of the pot, T is the target set steady-state temperature, t is the heating time, and K is the heat dissipation coefficient. Obtaining the Laplace transform for Q: $Q(s) = CsT_1(s) + KT_1(s)$ After phase shifting arrangement:

$$G_1(s) = \frac{T_1(s)}{Q(s)} = \frac{1}{Cs + K} \tag{2}$$

Analyze the physical mechanism of the model: As the heat transfer process is a complex one, pure time delay processes should be considered. After adding time delay τ, the inertia time constant T should be set, and a scaling coefficient k. So the transfer function should be expressed as:

$$G_1(s) = \frac{ke^{-\tau s}}{Ts + 1} \tag{3}$$

The main circuit of the stove includes rectification and filtering, inverter, and pot load module. Among them, the rectification and filtering stage can be regarded as a proportional stage of pure lag, and the inverter and load modules can be approximated as first-order inertial stages as shown above. Therefore, the power transfer function of the stove power supply is obtained as follows:

$$G(s) = G_1(s)G_2(s)G_3(s) = \frac{k_1k_2k_3e^{-\tau s}}{(1+T_2s)(1+T_3s)} = \frac{Ke^{-\tau s}}{(1+T_2s)(1+T_3s)} \tag{4}$$

This paper study the use of experimental identification method to determine the specific function model parameters of the stove system. When the rated power output of the power supply is 20kW, the effective value of the rectified current is 36.29A. When the output power of the power supply is 10kW, the effective value of the rectified output current is 18.13A. Using the two-point method for K value calculation, it is known that the proportional coefficient K=(20-10)/(36.29-18.13)=0.55. Then, according to the literature, other parameters can be obtained by using the step response curve: r=20s, T2=5s, T3=6s.

Based on the above, the temperature transfer function of the electric stove power supply is:

$$G(s) = \frac{0.55e^{-20s}}{1 + 11s + 30s^2} \tag{5}$$

To simulate the electric cooker system, we first find out that the sampling time of the cooker temperature measurement instrument is usually from 0.01 to 60 seconds, and we choose the sampling time as 1 second. Then through MATLAB, the continuous time transfer function combined with the sampling time is converted into a discrete time transfer function. By Simulink, the structure is drawn as follows in figure 2.

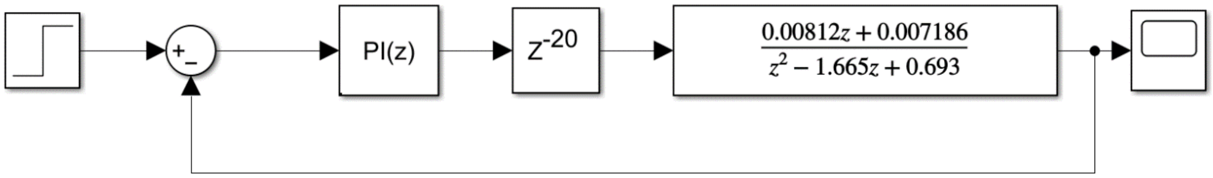

Fig. 2 The structure of the PID controller by Simulink (Photo/Picture credit: Original)

Considering the heat transfer process as a pure time lag process, we therefore added a time delay module, which represents that the response curve in the time domain will be lagged by 20 seconds. Meanwhile, in order to carry out the simulation of the discrete-time system, the solver and the PI controller are set to discrete type.

It can be known that for the proportional link in the PI controller, the larger the proportionality coefficient is, the faster the overall response of the system is, and the shorter the time to reach the steady state. However, too large a proportional coefficient may cause system instability. And for the integral link, the smaller the integral coefficient is, the more stable the system is after reaching the steady state, and the fluctuation can be reduced. However, too small a integral coefficient will also cause system instability. Therefore, through continuous exploration and attempts, we finally determined that the system has a better time domain response when Ki is equal to 0.8 and Kp is equal to 0.049.

If we assume that the user sets the temperature at 150 degrees Celsius, the final time response image is shown below in figure 3.

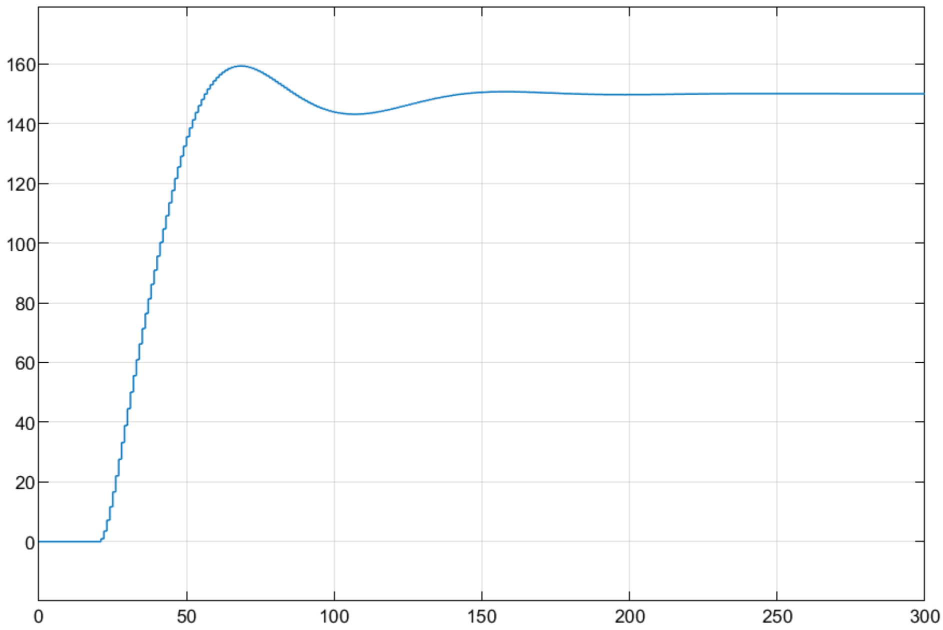

Fig. 3 The final time response image (Photo/Picture credit: Original)

It can be observed that the overshoot is roughly 6.67% and the settling time is about 80 seconds, which has a better response and stability.

Since the high temperature of the electric cooker may cause danger, we set that when the temperature reaches 300 degrees Celsius, the electric cooker will be automatically powered off. Therefore, we set up a judgement module at the negative feedback of the system to ensure that the electric stove operates at less than 300 degrees Celsius. Also, to test the stability of the electric cooker system in the face of interference, we add a negative pulse interference to the system at 200 seconds. The new structure is drawn in Simulink as shown below in figure 4.

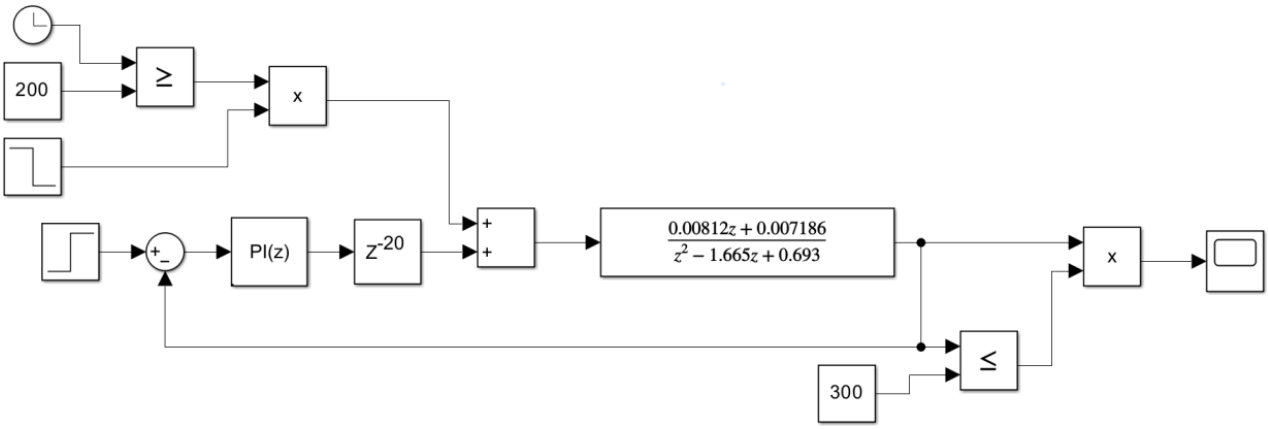

Fig. 4 The new structure of the PID controller by Simulink (Photo/Picture credit: Original)

Simulations are carried out to first test the anti-interference of the system and we obtain the time domain response curve as in figure 5.

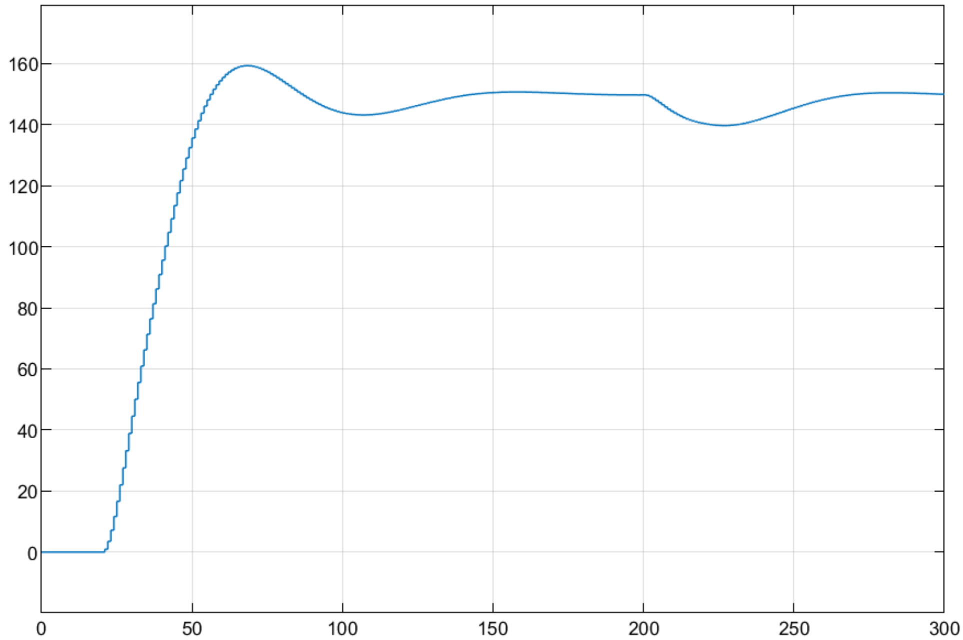

Fig. 5 Time domain response curve (Photo/Picture credit: Original)

It can be seen that the system suffers from the influence of interference at 200 seconds, but it quickly returns to a stable state under the negative feedback regulation, and the system has excellent anti-interference ability.

The safety of the system is then tested, assuming that the temperature exceeds 300 degrees Celsius at the time of the rise is shown in figure 6.

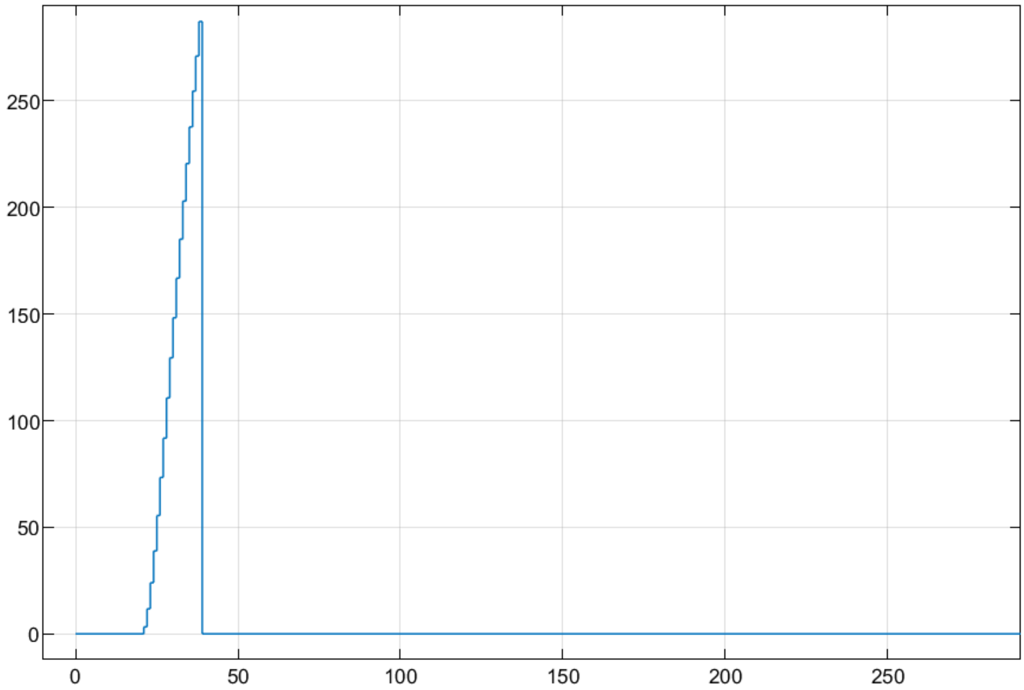

Fig. 6 Time domain response curve when the temperature exceeds 300 degrees (Photo/Picture credit: Original)

It can be seen that once the temperature of the electric cooker reaches 300 degrees Celsius, the system will immediately shut down automatically to prevent the danger from occurring, and the system has well safety.

The intelligent electric cooker control system developed by our group has better performance and functions, but still has some adaptability and scalability problems. Future research can use more excellent control system algorithms such as fuzzy PID control algorithm. This can be better adapted to different user needs and use of the environment [8]. This paper can also further enhance the stability and reliability of the system and improve the response speed of the system. It is hoped that future research can carry out more in-depth study of the above problems, so as to promote the development and improvement of the intelligent electric stove control system.

4.2. Physical Implementation of Intelligent Electric Stove Control Systems

Moving from theory to practice, the physical implementation of the intelligent electric stove control system is a meticulous process involving the selection of appropriate hardware components, software programming, and system integration. The hardware components include a central processing unit (CPU), temperature sensors, heating elements, power supply units, and communication modules, all of which must be carefully chosen to meet the requirements of reliability, durability, and performance [9].

The CPU is selected based on its ability to handle complex computations and manage multiple tasks simultaneously. It serves as the brain of the control system, interpreting input from the temperature sensors and user interface, and sending commands to the heating elements and other components. The temperature sensors are precision devices that provide real-time data on cooking temperatures, allowing the CPU to make informed decisions regarding temperature adjustments.

The heating elements are crafted from high-grade materials that offer rapid heat up times and even heat distribution, which are vital for achieving the desired cooking results. The power supply units are engineered to be energy efficient and to sustain the peak power demands of the heating elements without compromising on safety or performance.

In terms of software programming, the system is equipped with a custom-built operating system that facilitates seamless communication between the hardware components and the user interface. The software includes various modules that handle tasks such as temperature regulation, energy management, and user interaction. It is designed to be upgradeable, allowing for the introduction of new features and improvements over time.

System integration brings all the components together, ensuring they operate harmoniously. This involves rigorous testing to verify that each component functions correctly and that the system as a whole meets the design specifications. Every aspect, from the responsiveness of the touch interface to the accuracy of the temperature control, is scrutinized to guarantee that the intelligent electric stove delivers a superior cooking experience.

4.3. Testing and Validation

The final phase of the design and implementation process is testing and validation, which is critical to ensuring that the intelligent electric stove control system meets all performance and safety standards. This phase is conducted through a series of structured tests that assess the system's functionality, reliability, and user experience [10].

Functional testing involves verifying that each feature of the control system works as intended. For instance, the system's response to temperature adjustments, the accuracy of the cooking timers, and the effectiveness of the standby mode are examined under various scenarios to ensure that they meet the expectations set out in the theoretical design.

Reliability testing evaluates the system's performance over extended periods of use. This includes stress testing the heating elements and power supply units to ensure they can withstand repeated cycles of heating and cooling without failure. Additionally, the system's ability to recover from potential faults, such as power surges or sensor malfunctions, is tested to confirm its robustness.

User experience testing is conducted with a focus group of potential users to gather feedback on the system's interface and overall usability. This feedback is invaluable in identifying any areas that may require refinement to enhance the user's interaction with the stove. The findings from this testing are used to make final adjustments to the software and hardware before the stove is deemed ready for mass production.

5. Conclusion

In conclusion, the research on the intelligent electric stove control system presented in this paper has shown significant potential in improving the energy utilization rate of electric stoves, reducing energy consumption, and lowering environmental pollution. A comprehensive user interface design strategy was developed to create a more intuitive and convenient operation, significantly enhancing user satisfaction. The proposed intelligent control solution incorporated various algorithms for precise temperature regulation and energy management. The design and implementation phase took into account factors such as hardware selection, software programming, and system integration to ensure reliability and efficiency. Discussions on market analysis and business models provided practical strategies for the popularization of intelligent electric stoves, indicating a promising future within the smart home market. Further research will aim to optimize the control system and explore additional intelligent features to provide a more comfortable and convenient kitchen experience while contributing to environmental protection and energy savings. Overall, this study not only enriches the theoretical research on intelligent electric stove control systems but also serves as a valuable reference for the design and application of intelligent stoves, embodying significant practical significance and long-term research value.

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