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Innovative Application of Automatic Test Equipment in the Control Board Testing of Household Appliances

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Abstract: This article introduces the composition and working principle of home appliance control board automation testing equipment, elaborates on the importance of key technical indicators, explains the integrated design of functional modules, signal processing modules, and data analysis modules, and covers aspects such as the application of machine learning algorithms and the establishment of fault waveform databases. Finally, it looks forward to the development of intelligent testing systems and emphasizes the importance of building a standardized testing system.

Keywords: Home appliance control board; Automated test; Test standard

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1. Introduction

With the advancement of intelligent manufacturing, the home appliance industry is facing new opportunities and challenges. The “Made in China 2025” plan, released in 2015, emphasized the importance of intelligent manufacturing and provided a clear direction for the upgrading of the home appliance industry. Against this backdrop, automated testing equipment for home appliance control boards has become increasingly crucial. Comprising sensors, actuators, and control systems, these devices work in concert to test the control boards. Key metrics such as testing frequency, precision, and response time play a vital role in verifying product performance. Functional modules, signal processing, and data analysis can be integrated into the design. Moreover, technologies like machine learning algorithms, big data analytics, and fuzzy logic have been applied in the testing and diagnosis of home appliance control boards, driving the test systems towards greater intelligence and integration. The establishment of a comprehensive testing standard system has become a safeguard for the high-quality development of the industry.

2. Basic technology of the automatic test of the home appliance control board

2.1. Working principle of automated test equipment

Typically, automated testing equipment for home appliance control boards consists of sensors, actuators, and a control system, all of which work together to effectively test the control boards. Sensors are responsible for collecting various parameter information from the control boards during operation, such as temperature, voltage, and current [1], and then transmitting this information to the control system. Actuators, on the other hand, perform corresponding operations on the control boards based on instructions from the control system, such as simulating user button presses or adjusting the load. The control system serves as the core of the entire testing device. It receives information from the sensors, processes and analyzes it, and then sends control commands to the actuators. Additionally, it can monitor and record the testing process, which facilitates subsequent analysis and evaluation of the test results. Through the coordinated efforts of the sensors, actuators, and control system, the automated testing equipment is able to efficiently and accurately complete the testing tasks for home appliance control boards.

2.2. Core test technical indicators

Testing frequency, precision, and response time are key technical indicators for the automated testing of home appliance control boards, and they have a significant impact on the verification of the performance of home appliances. Testing frequency reflects how often the testing is conducted. An appropriate testing frequency can ensure a comprehensive examination of all the functions of the control board and help identify potential issues in a timely manner [2]. Precision is related to the accuracy of the test results. High-precision testing can accurately determine whether the control board meets the design requirements and avoid misjudgments caused by errors. Response time is an indicator that measures how quickly the control board reacts to commands. A shorter response time means better user experience and product performance. In actual testing, these indicators need to be considered comprehensively to fully and accurately assess the quality of the home appliance control boards and ensure the performance and reliability of the home appliances.

3. Test system architecture design method

3.1. Modular system architecture

The functional testing module, signal processing module, and data analysis module can be designed in an integrated manner. The functional testing module is responsible for inspecting the various functions of the home appliance control board to ensure they meet the design requirements [3]. The signal processing module handles the signals acquired during the testing process, including operations such as signal acquisition, amplification, and filtering, to enhance the quality and accuracy of the signals. The data analysis module analyzes the processed signals, extracting key information to provide a basis for judging the test results.

Through rational interface design and data transmission protocols, efficient collaboration between the three modules can be achieved. For example, the functional testing module passes the testing requirements to the signal processing module, which then transmits the processed signal data to the data analysis module. This kind of integrated design can improve the overall performance and efficiency of the testing system while reducing its complexity and cost.

3.2. Adaptive test algorithm

The dynamic adjustment algorithm for test parameters based on machine learning has significant applications in the compatibility testing of home appliance control boards. By learning and analyzing a large amount of test data, this algorithm can adaptively adjust the test parameters to enhance the accuracy and efficiency of testing. Utilizing supervised or unsupervised learning methods in machine learning algorithms, it models and predicts various performance metrics of the control boards [4]. Continuously updating the model parameters enables it to better adapt to the characteristics of different control board models. In practical applications, the algorithm can dynamically adjust parameters such as test voltage, current, and frequency based on real-time feedback from the control board, thereby achieving a comprehensive and accurate compatibility test. This not only reduces the need for human intervention but also increases the level of automation and reliability of the testing process.

4. Innovative applications in intelligent manufacturing scenarios

4.1. Intelligent diagnostic technology

4.1.1. Fault feature library construction method

To establish a fault waveform feature database using big data analysis, a multi-faceted approach is required. First and foremost, a vast amount of fault waveform data needs to be collected. These data are sourced from a wide range of origins, including waveform records of malfunctions occurring in various models of home appliance control boards during actual operation. The collected data should then undergo preprocessing to eliminate noise and other interfering factors, thereby enhancing the quality of the data [5]. Subsequently, data analysis techniques are employed to extract key features that can accurately reflect the essential characteristics of the faults. By analyzing the features of a large number of samples, a mapping relationship between fault waveform features and specific fault types can be established. Finally, these mapping relationships are integrated into the database to form a comprehensive fault waveform feature database, which provides data support for subsequent intelligent diagnostics.

4.1.2. Real-time diagnostic algorithm optimization

In the context of intelligent manufacturing, the optimization of real-time diagnostic algorithms is of great significance in intelligent diagnostic technologies. The application of fuzzy logic in the rapid fault-location technology of home appliance control boards under complex working conditions is an important research direction. By employing fuzzy logic, various uncertainties under complex conditions can be effectively dealt with [6]. It can simulate the human-like fuzzy thinking process to conduct a comprehensive evaluation of the control board's operating status. When a fault occurs, the fuzzy logic system can quickly identify the potential fault-prone areas based on preset rules and fuzzy reasoning algorithms. This technology overcomes the limitations of traditional diagnostic methods when facing complex working conditions, enhancing the accuracy and efficiency of fault diagnosis and providing an innovative solution for the intelligent diagnosis of home appliance control boards.

4.2. Flexible testing technology

4.2.1. Reconfigurable test platform design

In the design of reconfigurable test platforms under the intelligent manufacturing scenario, the modular rapid changeover mechanism of flexible testing technology plays a significant role in the testing of home appliance products. This mechanism can adapt to the diverse testing requirements of various home appliances and achieve rapid switching between different product tests through flexible module replacement. This not only improves testing efficiency but also reduces testing costs. For example, for different models of home appliance control boards, accurate testing can be conducted simply by replacing the corresponding test modules, without the need to rebuild the entire testing system. This modular design endows the test platform with better scalability and compatibility, enabling it to promptly respond to the updating and upgrading of home appliance products and providing strong support for the intelligent production in the home appliance manufacturing industry [7].

4.2.2. Multi-protocol compatibility solution

In the context of intelligent manufacturing, the design of a universal test interface for products with different communication protocols is crucial. With the development of the Internet of Things (IoT), home appliance control boards have adopted a variety of communication protocols. To achieve multi-protocol compatibility in flexible testing technology, a universal test interface needs to be designed. This interface should be capable of recognizing and adapting to multiple protocols, such as ZigBee, Bluetooth, and Wi-Fi [8]. By analyzing different protocols and extracting their commonalities and key features, a universal test framework can be constructed based on these foundations. This framework can flexibly switch between different protocols to ensure the accuracy and efficiency of testing. At the same time, the compatibility and scalability of the interface should be considered to accommodate the emergence of new protocols in the future. Such a universal test interface design will enhance the applicability and flexibility of testing equipment, meeting the diverse testing needs under the intelligent manufacturing scenario.

5. Analysis of typical application cases

5.1. Air conditioning control board test

5.1.1. Temperature control accuracy verification scheme

The PID control algorithm plays a significant role in verifying the temperature control accuracy of air conditioner control boards. The implementation process of its automated testing begins with determining the control parameters, including the proportional coefficient, integral time, and derivative time. The rational setting of these parameters is crucial for temperature control accuracy [9]. Subsequently, the automated testing equipment simulates various ambient temperature conditions and inputs them into the air conditioner control board. The control board then regulates the temperature according to the preset PID algorithm. In terms of effect evaluation, the main measurement is the deviation between the actual temperature and the set temperature. By conducting multiple tests, the deviation data under different ambient temperatures are obtained. These data are analyzed to assess the effectiveness of the PID control algorithm and whether the temperature control accuracy of the air conditioner control board meets the requirements [9].

5.1.2. Power stability test

In the power stability testing of air conditioner control boards, adaptive load testing has shown innovative applications. This test can simulate a variety of abnormal voltage conditions, providing a precise assessment of the stability of the air conditioner control board in complex power environments [10]. It can automatically adjust the load size according to the preset different voltage parameters, simulating abnormal situations that may occur in actual use, such as voltage surges, drops, and fluctuations. This helps to detect the performance of key parts in the control board, such as the power management module and protection circuits, under abnormal voltage conditions. By analyzing a large amount of test data, the working stability of the control board within different voltage deviation ranges can be determined. This provides a strong basis for optimizing the control board design and improving product quality, ensuring that the air conditioner can operate stably under various power conditions.

5.2. Washing machine drive board test

5.2.1. Multi-mode switching logic verification

In the verification of multi-mode switching logic in washing machine drive board testing, fuzz testing has significant applications. For the validation of the abnormal handling mechanism in complex washing programs, fuzz testing can trigger potential anomalies by inputting a large amount of random, invalid, or unexpected data into the system. In this way, it can simulate various input combinations that may occur in actual use but are hard to predict, and check whether the response of the washing machine drive board to abnormal inputs meets the design expectations. For example, by simulating user misoperations that set unreasonable washing mode parameters, one can observe whether the drive board can correctly identify them and give reasonable feedback, such as displaying error messages or automatically adjusting to a default reasonable mode. This helps to identify vulnerabilities and deficiencies in the program logic and enhances the stability and reliability of the washing machine drive board in complex usage scenarios.

Furthermore, the introduction of mutation injection coupled with three dimensions of time, temperature, and voltage can increase the probability of triggering anomalies by 40%. It can also automatically generate reproduction scripts to achieve rapid defect localization and regression

5.2.2. Automatic detection of waterproof performance

In home appliance manufacturing, the waterproof performance of washing machine drive boards is crucial. An automated inspection solution based on machine vision has proven to be highly effective in this area. This solution uses high-precision cameras to capture images of the drive boards and employs image analysis algorithms to detect defects such as gaps in the seals. Its advantages are significant. The inspection speed is fast, allowing a large number of drive boards to be inspected in a short period of time, which enhances production efficiency. At the same time, the high detection accuracy enables the precise identification of minor sealing issues, avoiding the release of defective products due to human inspection errors. In practical applications, this automated inspection method has greatly reduced the complaint rate of washing machine failures caused by poor waterproof performance. It has improved product quality and brand reputation, bringing considerable economic benefits to the enterprise.

The system can also record a defect distribution heatmap online and automatically upload it to the cloud to train the model, enabling continuous optimization of the algorithm. It is compatible with multiple models and can switch flexibly, reducing the line-change time to less than 3 minutes. This further reduces production costs and enhances the intelligence level of the production line.

5.3. Smart kitchen appliance control test

5.3.1. Multi-sensor fusion test

In the multi-sensor fusion testing of intelligent kitchen appliance control, the simulation of ambient parameters is crucial. Using high-precision temperature and humidity control chambers, programmable smoke generators, and light-intensity regulation systems, extreme kitchen scenarios are dynamically simulated, including temperature ranges from -10°C to 60°C, relative humidity from 20% to 90% RH, smoke concentration from 0 to 5,000 ppm, and illuminance from 0 to 100 kLux. At the same time, composite interferences such as VOC, CO, and PM2.5 are introduced to verify the robustness of multi-source data fusion algorithms for MEMS temperature and humidity sensors, optical smoke sensors, infrared human-body sensors, and gas-sensor arrays under drift, cross-sensitivity, and hysteresis effects.

The test platform can set gradient or abrupt-change curves, record sensor response times, linkage delays, and false-alarm rates, and automatically generate a three-dimensional evaluation matrix of environment–event–action. This provides closed-loop data for cloud-based OTA strategies, edge-AI threshold adaptation, and failure-prediction models. Ultimately, it ensures that kitchen appliances achieve millisecond-level precise coordination in real-world high-risk situations such as stir-frying, dry-burning, and gas leaks, significantly enhancing user safety and experience retention.

5.3.2. Voice interaction function verification

To verify the voice-interaction function of intelligent kitchen appliances, it is necessary to construct high-fidelity acoustic scenarios. The background noise library covers a wide range of sound levels from 20 to 80 dB, including sizzling sounds from frying and stir-frying, popping sounds from deep-frying, exhaust fan noises, and multi-source interferences such as living room TV sounds and baby crying. The dialect speech dataset includes 12 accents such as Cantonese, Sichuanese, and Hokkien, with 8,000 variant commands, and introduces continuous speech flow, inverted sentence structures, ellipsis, and colloquial expressions.

During testing, a movable artificial head and an 8-microphone circular array are used to repeatedly trigger compound semantics such as “turn the left burner to low heat” and “turn off the fire in 3 minutes” at distances of 1–5 meters and azimuths of 0–90 degrees. The wake-up rate, false wake-up rate, command delay, and rejection rate are recorded in real time. Meanwhile, a signal-to-noise ratio gradient from -5 dB to +20 dB is injected to verify the noise reduction algorithm and the directionality of Beamforming. A scenario performance heatmap is generated to drive continuous model iteration, ensuring zero false triggers and a highly robust interaction experience in noisy kitchen environments.

6. Conclusion

Automated testing equipment has shown significant advantages in the testing of home appliance control boards. By accurately simulating various working conditions, it can efficiently detect the performance of control boards, greatly enhancing the quality of home appliances. At the same time, it provides rapid feedback on test results, effectively shortening the R&D cycle and accelerating the product’s time to market.

Looking ahead to the AIoT era, intelligent testing systems will evolve towards greater intelligence and integration. By leveraging IoT technology to achieve interconnectivity among devices and utilizing AI algorithms to enhance testing accuracy and efficiency, these systems will continue to advance.

To better promote the development of the industry, it is essential to establish a comprehensive testing standard system. This system should cover various aspects such as testing methods, indicators, and procedures, ensuring the accuracy and comparability of test results. In this way, it can provide a solid guarantee for the high-quality development of the home appliance industry.

Disclosure statement

The author declares no conflict of interest.

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