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2025 Volume 3, Issue 11
Educational Innovation Research
ISSN: 3029-1852 (Online)
ISSN: 3029-1844 (Print)

Research on Defect Identification and Detection of Electronic Components Based on Intelligent Algorithms and Its Applications

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Abstract: The rapid iteration of intelligent algorithms provides a core foundation for advancing electronic component defect detection technology, effectively addressing industry challenges such as low accuracy, poor efficiency, and limited adaptability associated with traditional detection methods. Focusing on electronic component defect identification and detection, this paper analyzes the fundamental principles of integrating intelligent algorithms with defect detection, identifies key optimization directions for industrial applications, explores algorithmic applications across various defect types, and outlines practical implementation pathways. The study aims to offer theoretical insights for establishing an efficient and precise intelligent defect detection system and promote the widespread adoption of intelligent algorithms in electronic manufacturing quality control.

Keywords: Intelligent algorithms; Electronic components; Defect identification; Detection applications

Online publication: Dcecmber 20, 2025

1. Introduction

As the core components of electronic devices, electronic components directly determine the operational stability and service life of complete systems. Defect identification and inspection constitute a critical phase in quality control throughout the entire electronic manufacturing process. Traditional manual visual inspection and semi-automatic detection methods, constrained by subjective judgment and equipment limitations, suffer from high rates of missed minor defects, low batch inspection efficiency, and weak resistance to interference in complex scenarios, making them inadequate for meeting the intelligent and efficient production demands of Industry 4.0. Intelligent algorithms, with their robust feature extraction capabilities, high-speed data processing, and adaptive classification abilities, have emerged as the key solution to overcome technical bottlenecks in defect detection. This paper systematically investigates the adaptation principles and application methods of intelligent algorithms for defect identification and inspection, based on the defect morphology of electronic components and characteristics of industrial inspection scenarios, providing practical support for advancing the intelligent transformation of detection technologies.

2. The core principle of intelligent algorithm adaptation for electronic component defect detection

2.1. Principle of feature extraction and defect recognition adaptation in intelligent algorithms

The feature extraction capability of intelligent algorithms is highly aligned with the core requirements of electronic component defect identification. By employing a multi-layer network architecture, these algorithms autonomously learn and deeply analyze fundamental features such as grayscale, texture, and contours in component images, enabling precise detection of minute defects that are difficult for humans to identify and achieving accurate differentiation between defective and normal areas. Unlike traditional inspection methods that rely on manual feature selection, intelligent algorithms can adaptively extract critical defect features based on the material and structural characteristics of different components, effectively addressing the issue of poor recognition adaptability caused by variations in component types.

Defects in electronic components exhibit diverse morphologies and concealed characteristics. Intelligent algorithms employ techniques such as convolutional operations and feature fusion to integrate and enhance scattered defect features, transforming them into quantifiable feature vectors that provide precise data support for subsequent defect classification and identification. This feature extraction approach overcomes the limitations of traditional detection methods, enabling efficient recognition of various defect types, including scratches, cracks, and material deficiencies, further ensuring that the algorithm's identification logic closely aligns with the inherent patterns of component defect characteristics [1].

2.2. High-speed computing and batch detection adaptation principle of intelligent algorithms

The high-speed parallel computing capability of intelligent algorithms aligns perfectly with the industrial demands of mass component inspection. Leveraging multi-core processors and an optimized computational framework, these algorithms can detect defects in individual component images within milliseconds, significantly enhancing inspection efficiency and meeting the fast-paced requirements of electronic manufacturing assembly lines. Traditional inspection methods are time-consuming for single-image analysis and struggle to meet mass production demands, whereas intelligent algorithms enable continuous, high-speed processing of large volumes of component images. Their efficiency remains unaffected by production batch sizes, ensuring uninterrupted workflow continuity.

During the mass production of electronic components, comprehensive inspection of each product is essential for quality control. By developing lightweight computational models, intelligent algorithms enhance processing speed while maintaining detection accuracy, while also supporting multi-channel synchronous inspection to achieve seamless integration between inspection workflows and production lines. This high-speed computational capability enables the algorithms to adapt to batch inspection scenarios of varying scales, satisfying both the inspection requirements for small-to-medium batch customized production and the full-inspection demands of large-scale standardized manufacturing, thereby synergistically improving both inspection and production efficiency.

2.3. Model optimization of intelligent algorithms and principles for complex defect adaptation

The adaptive optimization capability of the intelligent algorithm model is highly aligned with the detection requirements for complex defects in electronic components. Through techniques such as transfer learning and fine-tuning, the algorithm model can autonomously optimize itself based on the characteristic patterns of different types of complex defects, enhancing its ability to identify composite and latent defects and addressing the low accuracy issue in traditional defect detection. Complex defects in electronic components often manifest as multiple defects superimposed with their features blending into the background; the intelligent algorithm continuously learns from samples to optimize model parameters, thereby strengthening its feature recognition capability for complex defects.

Optimization strategies such as regularization and dropout in intelligent algorithms effectively enhance the model's generalization capability, prevent overfitting caused by sample bias, and enable the optimized model to adapt to diverse production environments and the complex defect detection requirements of different batches of components. Additionally, the algorithm model can undergo dynamic optimization based on defect data feedback during the detection process, continuously improving its accuracy in identifying novel complex defects and achieving dynamic adaptation between the detection model and defect types. This allows intelligent detection technology to keep pace with advancements in electronic component manufacturing processes and evolving defect patterns.

3. Optimization directions for intelligent algorithms in defect identification and inspection of electronic components

3.1. Optimization directions for enhancing algorithmic accuracy in addressing minor defects

To enhance the accuracy of algorithms for detecting minute defects in electronic components, the primary optimization focus lies in strengthening the underlying feature extraction capabilities. This involves increasing the number of convolutional layers in the algorithm network and optimizing the convolution kernel size, enabling the algorithm to capture micron-scale defect features. Additionally, the introduction of an attention mechanism directs detection efforts to critical regions where components are prone to developing minute defects, thereby improving the specificity and precision of feature extraction. To address the issue of weak defect feature signals, feature enhancement algorithms are employed to amplify the extracted defect features, enhancing their distinguishability from the background.

Another optimization direction focuses on refining the algorithm's loss function and training strategy. A loss function tailored for micro-sample detection is employed to mitigate detection bias caused by sample imbalance, while a difficult-sample mining strategy enhances the training weight of micro-defect samples, enabling the algorithm model to more comprehensively learn the characteristic patterns of these defects. Additionally, by incorporating super-resolution reconstruction technology for preprocessing component inspection images, image clarity is improved, providing high-quality visual data support for accurate defect identification and thereby enhancing detection accuracy at the source [2].

3.2. Optimization directions for algorithm classification capability targeting multiple types of defects

The optimization of algorithm classification capabilities for detecting various types of defects in electronic components focuses on constructing multi-label classification network architectures. This approach overcomes the limitations of traditional single-label classification methods, enabling algorithms to simultaneously identify multiple defect types on component surfaces, achieve concurrent detection and classification of multiple defects, and enhance the handling of composite defects. Through mixed-training with samples representing different defect types, the algorithm models learn the distinctive feature differences and correlation patterns among defects, thereby improving classification accuracy and discrimination capability.

The algorithm simultaneously optimizes feature fusion and classifier design by employing multi-scale feature fusion technology to integrate defect features across different scales, thereby fully extracting the inherent characteristics of various defect types and preventing classification errors caused by similar defect appearances. Tailored classifier modules are designed according to the distinctive features of each defect type, enhancing classification accuracy for similar defects. Furthermore, by introducing metric learning, the algorithm increases the distance between feature vectors of different defect types while reducing variations among feature vectors of the same defect type, thereby further strengthening its classification capabilities and meeting the precision detection requirements for multiple defect types.

3.3. Optimization directions for algorithm interference resistance in industrial scenarios

To enhance the interference resistance of algorithms for industrial inspection scenarios, the primary focus is improving their adaptability to complex environments. Addressing interference factors such as uneven lighting, image noise, and component position deviations in industrial production, image preprocessing algorithms are employed, utilizing techniques like grayscale correction, noise reduction filtering, and image registration, to mitigate the impact of environmental disturbances on inspection images and provide high-quality input data for the algorithms. Concurrently, the robustness of the algorithm models is optimized by incorporating interference-containing sample data during training, enabling the algorithms to learn the distinction between interference features and defect features and thereby enhancing their interference resistance.

Another optimization direction involves developing lightweight algorithm models tailored to the operational environment of industrial hardware. By employing techniques such as model pruning, quantization, and knowledge distillation, the algorithm network architecture is simplified while maintaining detection accuracy, thereby reducing its computational resource requirements. This enables the optimized algorithm to run efficiently on embedded devices and edge computing systems in industrial settings, avoiding detection delays caused by hardware performance limitations. Additionally, a dynamic adaptive detection strategy is designed to allow the algorithm to adjust detection parameters in real-time according to environmental changes, achieving a dynamic balance between detection accuracy and interference resistance [3].

4. Application dimensions of intelligent algorithms in electronic component defect detection

4.1. Application dimensions of intelligent algorithms in surface defect detection of components

The primary application of intelligent algorithms in surface defect inspection of electronic components focuses on detecting surface defects in planar components such as resistors, capacitors, and chips. These algorithms rapidly identify and classify defects, including scratches, stains, material deficiencies, and pinholes, enabling high-speed, comprehensive inspection akin to an assembly line process. By performing pixel-by-pixel analysis of component surface images, the algorithms precisely locate defect positions, identify defect types, and measure defect dimensions, providing accurate data for quality grading. This approach replaces traditional manual visual inspection, significantly enhancing both detection efficiency and accuracy.

Another application area is surface defect inspection for irregular-shaped components such as connectors and plugs. These components feature complex surface structures where defects often hide in corners and gaps. By constructing a three-dimensional inspection model and analyzing the component's 3D point cloud data, intelligent algorithms enable comprehensive, blind-spot-free detection of irregular surface defects. Through multi-angle image acquisition and feature fusion, the algorithm captures defect characteristics from various perspectives, overcoming the limitations of traditional inspection methods that provide incomplete coverage, thereby achieving full-spectrum defect detection across all types of components.

4.2. Application dimensions of intelligent algorithms in internal defect detection of components

The primary application of intelligent algorithms in internal defect detection of electronic components focuses on identifying defects within semiconductor devices such as chips and transistors. By integrating X-ray imaging technology, these algorithms analyze X-ray images to accurately detect hidden defects, including voids, cracks, delamination, and poor solder joints, that cannot be detected through surface inspection. Such defects significantly impact a component's electrical performance and service life. The advanced feature extraction capabilities of intelligent algorithms enable precise identification and localization of internal defects.

Another application area involves internal defect detection in packaged components. For electronic components with plastic or ceramic packaging, intelligent algorithms integrate non-destructive testing techniques such as ultrasonic and infrared detection to perform intelligent analysis and processing of detection signals, extracting characteristic signals of internal defects and enabling non-destructive inspection. The algorithms effectively distinguish defect features from noise signals, enhancing detection accuracy while automating data analysis and result generation, replacing traditional manual signal analysis and improving both efficiency and objectivity in internal defect detection.

4.3. Application dimensions of intelligent algorithms in component solder joint defect detection

The primary application of intelligent algorithms in electronic component solder joint defect detection focuses on printed circuit board (PCB) solder joint inspection. For surface-mount and through-hole solder joints on PCBs, these algorithms analyze image features to accurately identify defects such as poor soldering, false soldering, missed soldering, bridging, and oversized/under-sized solder joints, enabling high-speed batch inspection of PCB solder joints. By evaluating characteristics like joint shape, grayscale, and contour, the algorithms assess soldering quality while supporting adaptive detection for various specifications and types of solder joints, meeting diverse PCB inspection requirements.

Another application area involves the detection of micro-solder joint defects in precision components. For micro-solder joints in components such as miniature connectors and microchips, the joint dimensions are extremely small and defect characteristics are concealed. By combining intelligent algorithms with high-magnification microscopic imaging technology, ultra-fine analysis of micro-solder joint images enables accurate identification of minute defects. Through optimized algorithmic feature extraction and classification capabilities, normal joint characteristics can be effectively distinguished from minor defect features, addressing the challenges of traditional inspection methods, such as difficulty in defect detection and high false-negative rates, further ensuring the welding quality of precision electronic components.

5. Implementation path of intelligent algorithm-driven defect detection for electronic components

5.1. Digital acquisition and modeling path for component defect characteristics

The digital acquisition of component defect characteristics requires establishing a standardized collection system. First, unified image acquisition and data annotation standards should be developed based on the structural characteristics and defect types of different electronic components. High-resolution industrial cameras and 3D scanners should be employed to conduct comprehensive, multi-angle image and data acquisition of both normal and defective samples, ensuring the completeness and standardization of the collected data. Simultaneously, a defect sample database should be established to classify, annotate, and store the acquired sample data, providing high-quality sample support for algorithm model training.

Building upon this foundation, we conduct digital modeling of defect characteristics. Through in-depth analysis of data from the sample database, we identify the distinctive patterns of various defect types and construct digital models that transform abstract defect features into quantifiable and identifiable numerical attributes. To meet the requirements of different inspection scenarios, we develop defect feature models combining general-purpose and specialized approaches: the general model is designed for basic defect detection across various components, while the specialized model is optimized for specific component and defect detection needs. This ensures precise alignment between defect feature models and inspection requirements, establishing a robust data foundation for algorithm training and practical detection applications.

5.2. Debugging and implementation path of intelligent algorithms in testing scenarios

The debugging of intelligent algorithms in detection scenarios should follow the sequence of “laboratory debugging–field testing–optimization iteration”. First, in a laboratory environment, the algorithm model is trained and fine-tuned using a defect sample database to optimize model parameters, thereby enhancing its detection accuracy and efficiency under ideal conditions and establishing the initial model framework. Subsequently, the debugged algorithm model is deployed to industrial detection equipment for field testing, where data and issues encountered during the detection process are collected, and the impact of interference factors in industrial settings on the algorithm’s performance is analyzed.

To address issues identified during field testing, the algorithm model underwent targeted optimization and iteration. For instance, its anti-interference capabilities were enhanced by accounting for on-site factors such as lighting conditions and equipment vibrations; its feature extraction and classification strategies were refined based on the manufacturing characteristics of field components, enabling the model to adapt to real-world industrial detection environments.

Additionally, the algorithm's operational efficiency was optimized to ensure efficient and stable performance on field hardware, facilitating seamless deployment from laboratory to industrial settings and ensuring the practicality and reliability of the detection technology.

5.3. Integration and routine application pathway of the intelligent detection system

The integration of the intelligent inspection system requires deep integration of algorithms, hardware, and software. Centered around the optimized intelligent algorithms, it incorporates hardware components such as industrial cameras, image acquisition cards, inspection platforms, and edge computing devices, while developing corresponding inspection software systems to achieve full-process automation for image acquisition, data processing, defect identification, result output, and data storage. Additionally, a user-friendly human-machine interface is implemented to facilitate on-site operators in parameter configuration, result viewing, and equipment maintenance, enhancing system usability. Furthermore, the system is integrated with the enterprise production management system to enable real-time transmission and sharing of inspection data.

Upon completion of system integration, efforts should be made to promote the routine application of intelligent detection technology. First, provide professional technical training to on-site operators to ensure they master the system's operational procedures and maintenance techniques, thereby guaranteeing its stable operation. Second, establish a regular operation, maintenance, and optimization mechanism by assigning technical experts to perform periodic system maintenance and fault diagnosis. Concurrently, continuously optimize algorithm models and detection systems in response to upgrades in production processes and component types, ensuring the intelligent detection system remains aligned with the enterprise's production requirements. Additionally, leverage big data analytics to conduct in-depth mining of detection data, providing data-driven support for optimizing production processes and enhancing quality control, thereby maximizing the value of intelligent detection technology.

6. Epilogue

The research on intelligent algorithm-based defect identification and detection for electronic components represents a pivotal technological advancement driving the electronics manufacturing industry toward smarter, higher-quality development, effectively addressing the limitations of traditional inspection methods. This study establishes a comprehensive research framework that deeply integrates intelligent algorithms with component defect detection across four dimensions: adaptation principles, optimization strategies, application dimensions, and implementation pathways, clarifying the core logic and practical methodologies for technological deployment. The enhanced adaptability and multi-dimensional applications of intelligent algorithms have achieved triple improvements in detection accuracy, efficiency, and compatibility, while standardized implementation protocols ensure successful industrial adoption. As intelligent algorithms and industrial inspection technologies continue to evolve, the intelligent defect detection system will further mature, providing core technological momentum for quality control and industrial upgrading in electronics manufacturing, thereby propelling the sector toward higher quality and greater operational efficiency.

Funding

2023 University-Level Research Project of Hainan Vocational University of Science and Technology, Project Title: Research on Defect Identification and Detection of Electronic Components Based on Intelligent Algorithms and Its Applications (Project No.: HKKY2023-21)

Disclosure statement

The author declares no conflict of interest.

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