Proceedings of the 4th International Conference on Software Engineering and Machine Learning
DOI: 10.54254/2755-2721/2026.32539

Machine Vision-Based PCB Defect Detection Method

Zecheng Lin

Maynooth International Engineering College, Fuzhou University, Fuzhou, China
832402113@fzu.edu.cn

Abstract. Printed circuit board (PCB) belongs to the number of crucial components of electronic devices whose flaws may have a dire effect on performance and safety. But PCB can contain either functional defects or cosmetic defects in the production process. Also, as part of the inspection procedure, there can be problems of minor flaws that are not visible, inability to detect the real problems in time, and vulnerability to environmental interference. With the growth of deep learning, a large number of researches are being done on machine vision-based methods of detection. To explore the methods of successful PCB defect detection and assess the usage of machine vision in the given sphere. This paper presents the types of common defects in PCB and difficulty in detecting them, as well as provides the principles underlying machine learning. In this paper, the methodological principles and research applications of PCB defects detection are examined through the perspective of both standard machine learning and deep learning, but with a specific focus on the summary of the accomplishment of the Convolutional Neural Network (CNN) algorithms in the context of defects identification. In the light of the contemporary situation, the future development trends in this project are analysed.

Keywords: PCB, Defect Detection, Machine Vision, Deep Learning, CNN

1. Introduction

The reason is that PCB is one of the most important and fundamental components in the electronics industry that has found its applications in several electronic devices, which are highly integrated, substantially stable, and less expensive to manufacture. As the informatization and intelligence increase at a rapid pace, the PCB requires are on the rise and their design and construction are increasingly slimming towards miniaturization, precision and high performance. Nevertheless, PCB defects, including short circuits, open circuits, solder cracks, copper diffusion, and via blockages are easy to get with factors like electrostatic interferences, chemical reactions, and temperature change in heavy production environments. What would happen in case of not finding and fixing these defects in time? They will not just decrease the dependability and life of the electronic tools in that instance, but also amplify the likelihood of a breakdown. Nevertheless, they can also cause significant safety risks, further costing the electronics producing business a lot of money.

To solve this problem, effective and accurate PCB defect detection has already become a burning issue to the electronics production business. The common methods of traditional inspections are visual inspection that is mostly manual, and simple image processing. They are ineffective methods

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/2026.32539

which do not give the ability to vary, easily hidden defects will be ignored and this will result in a false positive which are not suitable in the fast-paced and high-volume production of the modern electronic industries. As the field of machine learning and artificial intelligence technologies advanced, the approaches to machine vision-based inspection started gaining traction in the research and practicum environment. Specifically, automated feature extraction and power of representation in deep learning allow detecting smaller and more complicated defects with greater accuracy, which greatly improves the accuracy and strength of the inspection method.

Regarding the developmental approach, machine vision of PCB defects has advanced through the traditional machine learning to the deep learning. Defect detection is introduced with the help of the traditional machine learning algorithms, such as classifiers and feature extraction, which have demonstrated certain efficiency gains. Nevertheless, they have a manual feature design and little generalization. This bottleneck has been overcome with successful development of deep learning. Lately, models, such as CNN, Residual Network (ResNet) and You Only Look Once (YOLO), have extensively been used to detect defects in PCBs and have shown brilliant results in their applications, such as small object detection and segmentation recognition in the presence of complex background interference. With the introduction of lightweight networks, in particular, high-precision detection is capable of keeping up with the real-time needs of industrial production.

Overall, this technology that detects defects of PCBs directly affects quality control and financial efficiency used in the electronics sector, as well as has a direct effect on functionality and safety of electronic units. This paper seeks to present an overview and discussion of machine vision methods to detect PCB defects and the development of their methods of detection since the traditional machine learning model to the deep learning model. It will be dedicated to analysis of the uses and benefits of the existing mainstream algorithms and the predictions of the possible directions of their development in the future due to this analysis. The paper initially defines the main category of PCB defects and difficulties of detecting them. It then examines the principles and limitations of the conventional inspection methods. Lastly, the paper is aimed at discussing the development of research in the sphere of PCB defect detection using conventional machine learning and deep learning, summarizing the contents of the research and suggesting the perspective of development in the future. It will act as a basis of reference and guide to other studies in future.

2. PCB defect detection problems and major principles of machine learning

2.1. Introduction to the key varieties of PCB defects

During the production of PCB, the defects could occur as a result of poor production methods or mistakes in the soldering process. Two classes of PCB defects are: functional defects and cosmetic defects [1]. Where they have functional flaws that directly affect the PCB capability, their product will malfunction. Normal PCB functional fault are short circuits, open circuit, impedance defect, poor copper plating of the hole wall and cold solder joints. PCB cosmetic flaws Use PCB cosmetic flaws are apparent physical defects on the PCB screen or framework that could eventually impact the functionality of the PCB. Ordinary cosmetic flaws consist of scratches on the surface, warping, deformation, and misfit of holes.

2.2. PCB defect detection problems

These are the key challenges to PCB faults detection. To begin with, PCB malfunction has many different shapes and sizes; micro-short circuits, micro-cracks on the fine lines, and a tiny

DOI: 10.54254/2755-2721/2026.32539

misalignment of holes can be considered as a PCB defect. Detection systems are usually incapable of obtaining a high enough resolution and a high enough precision. Secondly, the little information on PCB faults, and the lack of correlation between the training and real-world features complicate the detection systems to work in the real industrial situation. And finally, it is difficult to detect in real-time. The inspection of high-speed productions needs to be real time but it has been noted that high-precision algorithms consume a lot of computational power. Delays can easily be caused by the need to correctly determine types of defects.

2.3. Principles of machine learning

The machine learning process may be summed as creating a model, training the algorithm model using information, and executing tasks using the trained algorithm. Based on the various learning methods, supervised, unsupervised, semi-supervised as well as reinforcement learning are the four main types of machine learning. In supervised learning, a model is trained on labelled data and the trained model used to give predictions on previously unseen data. Unsupervised learning is the learning based on the data on whose categories we have no information and the system finds the intrinsic patterns or structures of the raw data. Semi-supervised learning conceptually falls in-between supervised and unsupervised learning whereby training is performed on large amount of unlabelled data and a small amount of labelled data. Reinforcement learning is described as a machine learning parameter that maximises behavioural plans by getting a reward or punishment after its actions.

3. Principles of PCB defect detection in machine learning based on PCB defects detection

3.1. Principles of PCB defect detection on traditional machine learning

The main method of standard machine learning in PCB flaw detection consists of matching the differences between standard boards and test boards and using machine learning algorithms to determine whether the differences are defects or not. Some of the common machine learning algorithms are Support Vector Machines (SVM), K-Nearest Neighbors (KNN), and Naive Bayes among others. Even basic idea of SVM is to locate optimal hyperplane in the high-dimensional space to accomplish classification of data. KNN classifies the data according to the distance of the various data points. Naive Bayes is a probability statistics-based classification methodology. These types of inspection techniques are still common in PCB defect inspection, but are prone to being heavily dependent on manually designed characteristics and uniqueness of image re-registering. As the level of deep learning algorithms were developed, the network models have become more complex, e.g., CNN, to detect PCB defects.

3.2. Principles of deep learning-based PCB defect detection

Deep learning, which is a new technology as opposed to the traditional machine learning develops on the basis of multi-layered neural networks that then allow features of a hierarchical nature to be learnt with the help of large datasets thus performing the classification tasks. The most significant property of the deep learning technology is its ability to automatically extract features. Deep features have better representational power and robustness as compared to manually designed features. Its major process is divided into two steps: defect detection and classification and model training.

DOI: 10.54254/2755-2721/2026.32539

Figure 1 shows the training of PCB defect identification model. The trained deep learning model is very accurate and robust, and can be directly adapted to infer new and unseen PCB images.

Common deep learning detection networks are CNN, ResNet, the YOLO, and so on. Convolutional layers are able to automatically extract image features layer by layer in the CNN model. As an example, the back layers acquire an idiosyncratic knowledge of the characteristics that are highly specific to PCBs on the one hand, whereas the front layers acquire a more general knowledge, which includes lines and edges, on the other. The ResNet model allows stronger and deeper feature extraction, so it can be used in PCB defect detection of minute, low-contrast ones. Also, PCB defect detection can be treated as one regression problem, which makes the YOLO model a viable single-stage object detector, one that can identify all targets during a single forward pass. It is real-time and amazingly accurate.

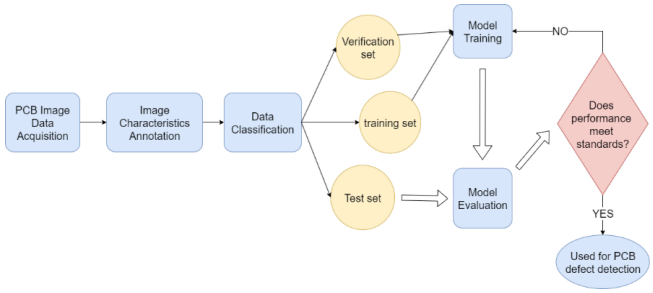

Figure 1. Training of PCB defect detection model (picture credit: original)

4. PCB defect detection methods using machine learning

4.1. PCB defect detection methods that rely on conventional machine learning

The basic technique that Baygin suggests uses feature extraction and feature matching, which make use of the Otsu thresholding and Hough transform in the course of feature extraction [2]. Wang et al. developed and implemented an Automated Optical Inspection (AOI) machine vision system to locate holes in PCB. The environment used to develop the image processing was the Microsoft Visual Studio (C#). The software has the ability of automatically gauging the diverse diameters of the holes [3]. Lu et al. designed two individual models by deriving the Local Binary Pattern (LBP) and directional gradient histogram features of each PCB image and they inserted them into separate SVM. These two models were then fused to classify the faults based on the Bayesian fusion theory with a PCB dataset having both defective and non-defective samples. The results of this model were excellent as far as PCB flaw detection is concerned with regard to efficiency and accuracy [4]. Yuk et al. used machine learning method to detect different categories of defects. It is a mode of learning fault with subsequent computation of probability and the initial step involves extraction of features using the Speed-Up Robust Feature (SURF) technique. It is then done by developing a probability weighted Weighted Kernel Density Estimation (WKDE) map, which considers feature density. WKDE diagrams are more effective in detecting regions that contain clumps of defects therefore they outperform detectors [5].

In case of traditional machine learning-based PCB defect detection, the main solution is the usage of standard images using template matching algorithms. Through comparing these standard images, then one can increase the accuracy in detection. Nonetheless, even under new conditions of detection environment, the detection system might fail to work well. This is because the actual

DOI: 10.54254/2755-2721/2026.32539

environment of PCB defects around is much more complicated and, therefore, man-made features do not always effectively capture the image.

4.2. Using deep learning-PCB defect detection methods

Further elaborate, more complex networks, are provided as feature extractors with the advent of CNN in the computer vision field (Table 1). The strengths of the PCB defect detection frameworks are as follows: The learned deep features have enough discriminative qualities to determine the differences between defects. In the meantime, deep learning systems are more elaborate and have wider applicability.

Table 1. Deep learning PCB defect detection methods analysis

Strategy	Benefit	Drawback
CNN	Compared to traditional methods, it demonstrates superior classification performance.	The uppermost layer of the network is somewhat simple in structure.
ResNet50 Feature Extraction	It is more able to work with slight defects.	
CNN-based Autoencoder Model	Reduced the training loss of the model and the predictive model performance.	
MobileNet-V2 Network Model	The accuracy of the PCB defects is better than that of the network model ResNet50	
CDI-YOLO-Based PCB Defect Detection Algorithm	Less complexity of the model and faster detection.	

Zhang employed CNN and conducted novel experiments on deep neural networks Zhang used CNN and made new experiments on the deep neural networks in PCB defect detection with a self-constructed small dataset. The findings showed that the defect classification performance was high in comparison to other conventional techniques of defect classification, which relied on manually extracted features [6]. Hu et al. introduced an automated system of PCB inspection that is based on CNN. In order to deal with the characteristics of PCB flaws, instead of using the initial Faster R-CNN to extract features, a more profound ResNet with 50 layers (ResNet50) backbone was employed. Grammar-Augmented Reverse Polish Notation (GARPN) was used to produce anchor boxes on-demand and replaced the Reverse Polish Notation (RPN). The results of the experiment showed that the confidence of the improved model is 94.2% [7]. Kim et al. suggested a CNN-based autoencoder algorithm that should be used to identify PCB faults accurately since it can capture the PCB images through industrial cameras with image sensors, including Complementary Metal-Oxide-Semiconductor (CMOS) sensors. The use of skip connections in the autoencoder minimized the training loss, besides lowering the similarity of the model, as well as improving the prediction accuracy [8]. The network model that Zheng et al. used is the MobileNet Version 2 (MobileNet-V2) and compared it to the ResNet50 network and the Visual Geometry Group 16 (VGG-16). There were four kinds of PCB defects categorization compared by the accuracy rates. Experimental findings show that the network model of MobileNet-V2 performed better than the ResNet50 and VGG-16 network models with a mean detection rate of 92.86 when each of the four PCB defect categories was considered. This established its effectiveness in determining and classifying PCB defects [9]. Xiao used the Cross-Domain Interaction YOLO (CDI-YOLO) algorithm in finding PCB defects. The algorithm includes the Channel Attention (CA) module to the YOLOv7-tiny object detection system. Chosen conventional convolutional units are substituted with Depthwise Separable

DOI: 10.54254/2755-2721/2026.32539

Convolution (DSC) ones. In addition, Inner Complete Intersection over Union (Inner CIoU) is adopted as the regression loss together with the boundary box and auxiliary bounding boxes are adopted to increase the speed of the model bounding box regression. The experimental findings show that CDI-YOLO is more precise in detection at its maximum Mean Average Precision (MAP) of 98.3% that is superior to the current methods. This method offers improved knowledge and application of the spatial data in reference to parameters, which improves the detection and judgment abilities on the defects in various locations on PCB. It simplifies the model, but enhances the speed of detection [10].

Deep learning PCB defect detection techniques have high detection accuracy as well as detection precision. Moreover, algorithms of the complex network models can contribute greatly to improving the speed of defect detection in the PCB in line with the requirements of the industrial assembly lines. Given that there have been no experimental studies done on the implementation of deep learning algorithms in the industrial production, future works should be on how to optimally utilize deep learning algorithms in the industrial setting thus enhancing their efficacy and efficiency in industry use [11,12].

5. Conclusion

The paper presents the defects and detection issues in printed circuit board defect inspection first. Then it introduces PCB defect detection methods using machine learning, both traditional machine learning and deep learning, and describes their basic principles respectively. Lastly, it examines research processes of PCB defect detection with the view to assessing the efficacy of CNN and the other intricate network models on PCB defect detection and examines benefits that deep learning methods offer.

Even to detect PCB defects, there may never be an easy solution because of poor quality PCB images, small finite pools of PCB defects, and the complexity of the network models. High quality PCB pictures can be achieved in the future with the help of high-performance imaging devices and other applicable imaging technologies such as 3D vision, micro-thermal sensors, and laser scanning thermal imaging. Moreover, use other forms of learning including unsupervised learning, semi-supervised learning and transfer learning in order to decrease the reliance of the network on large quantities of training data. In order to simplify the deep learning model, the parameters can be minimized by making the network architecture less complicated. Separable convolutions can be used to further reduce computational requirements by assuming that the standard convolution operations should be replaced.

References

[1] Yang, S., Cao, L., Yang, Y., et al.: A review of machine vision-based PCB defect detection algorithms. Computer Science and Exploration 19(4), 901–915 (2025)
[2] Baygin, M., Karakose, M., Sarimaden, A., et al.: Machine vision-based defect detection approach using image processing. In: 2017 International Artificial Intelligence and Data Processing Symposium (IDAP), pp. 1–5. IEEE, New York (2017)
[3] Wang, W.C., Chen, S.L., Chen, L.B., et al.: A machine vision based automatic optical inspection system for measuring drilling quality of printed circuit boards. IEEE Access 5, 10817–10833 (2016)
[4] Lu, Z., He, Q., Xiang, X., et al.: Defect detection of PCB based on Bayes feature fusion. The Journal of Engineering 2018(16), 1741–1745 (2018)
[5] Yuk, E.H., Park, S.H., Park, C.S., et al.: Feature-learning-based printed circuit board inspection via speeded-up robust features and random forest. Applied Sciences 8(6), 932 (2018)

DOI: 10.54254/2755-2721/2026.32539

[6] Zhang, C., Shi, W., Li, X., et al.: Improved bare PCB defect detection approach based on deep feature learning. The Journal of Engineering 2018(16), 1415–1420 (2018)
[7] Hu, B., Wang, J.: Detection of PCB surface defects with improved Faster-RCNN and feature pyramid network. IEEE Access 8, 108335–108345 (2020)
[8] Kim, J., Ko, J., Choi, H., et al.: Printed circuit board defect detection using deep learning via a skip-connected convolutional autoencoder. Sensors 21(15), 4968 (2021)
[9] Zheng, J., Sun, X., Zhou, H., et al.: Printed circuit boards defect detection method based on improved fully convolutional networks. IEEE Access 10, 109908–109918 (2022)
[10] Xiao, G., Hou, S., Zhou, H.: PCB defect detection algorithm based on CDI-YOLO. Scientific Reports 14(1), 7351 (2024)
[11] Park, J.H., Kim, Y.S., Seo, H., et al.: Analysis of training deep learning models for PCB defect detection. Sensors 23(5), 2766 (2023)
[12] Zhou, W.: Optimization and application of image recognition algorithms based on deep learning. China Broadband 21(7), 136–138 (2025)