AI-based failure mechanism prediction system and method for PCB solder joints

FIELD OF THE INVENTION

[0001] The present invention relates to an artificial intelligence (AI)-based printed circuit board (PCB) soldering failure mechanism prediction system and method, in particular a PCB soldering failure mechanism prediction system and method based on a camera-based PCB soldering region detection module, a thermal imaging camera-based detection module for PCB failure mechanisms under high current usage, and a PCB failure mechanism prediction module.

BACKGROUND OF THE INVENTION

[0002] PCBs have emerged as a critical component in electronic products, providing essential mechanical support to various circuit components. PCBs are characterized by their high set neutrality and reliability, rendering them conducive to daily production, design, and maintenance. Significant advancements have been made in mechanical automation and product efficiency as a result of their utilization. Given these advantages, PCBs have found extensive application in diverse fields, including the computer, automotive, and aerospace industries.

[0003] However, in the PCB production process, some defects will occur because of human error, machine malfunction, etc. These defects, such as shortness, openness, mouse-bite, etc., can affect the remaining useful life of a product, threaten users' lives, and cause economic losses. In recent years, two trends have emerged in the electronics industry with PCBs. The first one is Pb-free soldering in electronic packaging and assembly, and the second one is the miniaturization of electronic products. Both trends have led to new challenges for electronic materials and manufacturing. Soldering has become a very complex process due to many factors (e.g., non-wettability, dewetting, wrong solder mask design, warpage effect, and cracks) affecting the final quality of the solder joints of the products. In the soldering process, there are also many reasons for the formation of defects and imperfections. Some primary causes include a poorly designed technological process setup, improper use of materials, design errors, and environmental impact.

[0004] The evaluation of the reliability of solder joints is of utmost importance in the domain of electronic packaging. The longevity of a PCB is largely dependent on the durability of its solder joints. The vulnerability of PCB solder joints to the initiation and propagation of cracks and fractures poses a significant risk to the overall performance of electronic products, especially when subjected to harsh conditions such as high or low temperatures and intense vibrations. Any presence of voids and cracks can lead to damage to the pins of electronic components, consequently compromising the reliability of their solder joints and, in some cases, drastically reducing the operational lifespan of the PCB. According to literature review, approximately 60% of electronic product failures can be attributed to solder joint failure. With recent advancements in the PCB industry, particularly in terms of high precision, high density, and high reliability, there is a heightened demand for improving the reliability of the PCB manufacturing process. Therefore, it is imperative to thoroughly investigate and analyze the reliability of PCB solder joints in order to meet these increased demands.

[0005] Traditional manual quality checks for PCB defects such as soldering defects consume huge amounts of manpower, and there is a tendency to replace manual inspection with machine-automated inspection. The use of handcrafted features to diagnose has been shown to increase diagnostic performance. Due to the complex nature of identifying failure modes and/or causes, pinpointing defect types, and defining the levels of degradation, diagnosis is sometimes referred to as a classification problem. Similarly, handcrafting a good collection of features is a time-consuming, problem-specific, and non-scalable operation. Consequently, there is a growing demand for software that can automatically discover attributes relevant for anomaly detection, diagnosis, and prognosis. In recent years, the flourishing development of deep learning has created opportunities for the application of deep learning models in the detection of PCB defects based on visual appearance.

[0006] Also, automated optical inspection (AOI) systems are commonly employed in the electronic manufacturing industry to capture images of PCBs and assess the quality of their solder joints through image feature extraction, processing, and analysis. While AOI systems are effective in testing solder joints on high-density boards and small electronic components, they may not be suitable for detecting and inspecting defects in PCB soldering due to the wide diversity of soldering processes and materials employed. Therefore, there is a need to have a data-driven AI model with a deep learning algorithm in combination with AOI for inspecting and detecting defects in PCB soldering of components.

[0007] Besides, failure mechanisms of solder joints can be referred to as the processes by which a system, component, or material fails to perform its intended function. The assembly of PCB is frequently subjected to numerous temperature changes, which can compound the impact on the material. Consequently, the PCB material must be capable of enduring these multiple instances of exposure to high-temperature environments. Currently, SAC305 is the principal lead-free solder widely utilized in PCB manufacturing due to its high performance and low cost. However, the reliability of solder joints remains a crucial area of research in the field of electronic packaging. The lifespan of a PCB board is heavily reliant on the durability of its solder joints, which are often considered weak points in electronic products. FR-4 is the prevailing material employed for PCB fabrication. It is a composite material made up of woven fiberglass cloth with a flame-retardant epoxy resin binder. However, this material falls short in its ability to withstand high temperatures during lead-free soldering processes.

[0008] The material characteristics of PCB alter when exposed to such high temperatures, especially if the temperature is extremely close to the glass transition temperature (Tg) of PCB. The glass transition temperature (Tg) is a critical normative parameter for the base material because it dictates the temperature at which the resin matrix transitions from a glassy, brittle state to a soft, elastic one. The glass transition temperature of the base material establishes an upper limit at which the resin matrix decomposes and delamination occurs. It is thus not the highest functioning temperature, but rather the temperature that the material can withstand for a relatively short period of time.

[0009] The glass transition temperature (Tg) of a printed circuit board (PCB) can vary depending on the material used to make the PCB. PCBs can be made from a variety of materials. Different materials have different Tg values. For example, FR-4 typically has a Tg of around 130-140°C. It is important to consider the Tg of the material used in the PCB design to ensure that it can withstand the intended operating temperature range. The Tg of a PCB can have an effect on the coefficient of thermal expansion (CTE) of solder joints of electrical or electronic components mounted on the same PCB. The CTE of a material is a measure of how much it expands or contracts with temperature changes.

[0010] When a PCB is subjected to temperature changes above its Tg, the material becomes more pliable and its CTE increases. However, the CTE of the electrical or electronic components mounted on the PCB remains relatively constant or changes only slightly with temperature. As a result, the thermal expansion and contraction of the two materials become mismatched, leading to stress on the solder joints connecting the components to the PCB. Initially, the increased pliability of the PCB could allow it to absorb some of the stress generated by the mismatched CTEs. However, as the temperature rises further above the Tg, the PCB becomes increasingly soft and starts to deform under the stress. This deformation can cause the solder joints to crack or fracture, leading to the failure of the component connection. The failure mechanism is essentially a failure where the expansion and contraction of the solder joints due to temperature changes eventually cause them to weaken and fail. The failure may not occur immediately but can happen over time as the PCB is exposed to thermal stress during normal operation. To prevent this failure mechanism, one existing approach is to design the PCB with an appropriate Tg for the intended operating temperature range and to ensure proper thermal management to minimize the thermal stress on the solder joints. Additionally, the second approach is to select a solder with a higher ductility, which can also help reduce the likelihood of solder joint failure due to CTE mismatch. However, these approaches are time-consuming and ineffective in identifying the failure mechanism of solder joints. Also, previous works, such as those by other researchers, focused more on a failure detection model for the solder joints of PCBs with the use of only a visual inspection system (e.g., RGB images). An effective approach for developing a failure prediction model for the solder joints of PCBs is scarce based on the literature review.

[0011] Predictive maintenance is the condition monitoring of machinery using smart sensors and other Internet of Things (IoT) technologies. The data acquired from the condition monitoring provide information and a prognosis on the health state of the equipment. Therefore, early identification of flaws and failures helps the maintenance operators take timely action, thereby lowering the frequency of machine failures. It delivers thorough proactive early warning and downtime predictions in advance, so the service team possesses a means to select what to prioritize or to plan early replacement for the manufacturing component in a proactive approach rather than responding upon downtime. The traditional experimental-based soldering failure mechanism detection method can be a time-consuming and costly process, which may only allow for a limited number of PCB solder joints to be examined during the manufacturing process.

[0012] Therefore, there is a need to have a system and method to prevent significant degradation of the machine and its systems. Reducing the degree of degradation can prevent the proliferation of other faults and defects. A reduction in equipment failures enhances production as the maintenance staff and managers are free to focus on important maintenance tasks. The maintenance cost covers the staff costs and maintenance department overhead, plus the spare parts and tools required. The cost of maintenance is therefore decreased by reducing the severity of the damage through predictive maintenance.

[0013] China Patent No. 113409250 A discloses a welding spot detection method based on a convolutional neural network model, which comprises the steps of firstly collecting a PCB welding spot data set, preprocessing the data, and then 6abelling and storing the data; then establishing a neural network model based on computer vision; and finally, training the established neural network model by using the welding spot data training set and testing the established model by using the welding spot data testing set. The method improves the YOLOv3 network structure, detects the welding spot target through five feature detection layers with different scales, and improves the detection effect of the target detection network on the small-scale target; the loss function of the convolutional neural network consists of four parts, and the result can be optimized in different aspects by using multiple loss functions for constraint, so that the model is ensured to have high precision; the improved convolutional neural network model can achieve real-time detection while ensuring accuracy, and meets the actual production requirements of factories. However, the method is merely an AI-based method for solder joint defect detection but does not provide early prediction for the failure mechanism of solder joints during a manufacturing process. Therefore, there is a need to have a more advanced and automated system and method to improve the detection and prevention of soldering defects.

[0014] China Patent No. 114372949 A discloses a PCB surface defect detection method based on an improved YOLOv5 algorithm. The method comprises the following steps: preprocessing an original PCB data set and establishing a network structure of a YOLOv5 algorithm; determining a YOLOv5 network loss function and a performance evaluation index according to the GioU; the method improves the neck part of the network structure, adds adaptive feature fusion (ASFF), fully utilizes the features of different scales, and enhances the small target detection performance; the method for finally predicting the bounding box is improved; and target box weighted fusion (WBF) is used for replacing Non-Maximum Suppression (NMS) as a method for selecting the finally predicted bounding box; training the network structure by using a transfer learning idea according to the improved YOLOv5 algorithm network structure; inputting the sample data of the PCB surface defects to be detected into a trained PCB surface defect detection model based on the improved YOLOv5 algorithm; and outputting the position and category information of the PCB surface defects to be detected. Through example detection, the invention realizes the high efficiency and high precision of the surface defect detection of the PCB. Although the method provides highly efficient and precise accuracy in detection, it can only detect solder joint defects. Therefore, there is still a need to have a failure mechanism prediction system and method for solder joints.

[0015] China Patent No. 115906573 A discloses a PCB service life analysis method based on reliability analysis, which comprises the steps of obtaining main faults of a circuit board card according to the expected use environment and design information of the circuit board card; constructing a CAD simulation model based on the circuit board card design file; acquiring the natural frequency of the circuit board card, and performing harmonic vibration test and random vibration test on the CAD simulation model under different working conditions according to the natural frequency to acquire fault data; performing thermal analysis to obtain failure data of the circuit board under different simulation working conditions in an expected life cycle; performing welding spot fatigue analysis and electroplating perforation fatigue analysis to obtain welding spot fatigue failure data and electroplating perforation fatigue failure data of the circuit board card; and acquiring the expected life of the circuit board card according to the fault information vector, the fault data, the failure data, the welding spot fatigue failure data and the electroplating perforation fatigue failure data of the circuit board card. The accuracy of circuit board card fault diagnosis is improved, and the fault frequency of the circuit board card in the usage process is reduced. However, the method is based on CAD simulation and thermal analysis for failure mode diagnosis and remaining useful life prediction for PCBs. The method therefore does not provide defect detection for PCB solder joints.

SUMMARY OF THE INVENTION

[0016] It is an objective of the present invention to provide a non-destructive AI-based PCB soldering failure mechanism prediction system and method that can effectively detect and predict the failure mechanisms of solder joints.

[0017] It is also an objective of the present invention to provide an AI-based PCB soldering defect detection and failure mechanism detection system and method that can perform early detection of solder joint defects and failure mechanisms on the production line.

[0018] It is also a further objective of the present invention to provide a PCB soldering failure mechanism prediction system and method that provide high prediction accuracy, have high automation, are cost-effective and suitable for mass production.

[0019] Accordingly, these objectives can be achieved by following the teachings of the present invention, which relates to a printed circuit board (PCB) soldering failure mechanism prediction system based on artificial intelligence (AI). The system comprises: a camera-based PCB soldering region detection module comprises a PCB defect classification model; a thermal imaging camera-based detection modulefor PCB soldering failure mechanisms under high current usage; and a PCB failure mechanism prediction module wherein the camera-based PCB soldering region detection module and the PCB failure mechanism prediction module utilize deep learning models to identify PCB solder joints, classify defects, and predict failure mechanisms. The thermal imaging camera-based detection module performs experiments to provide information for training the PCB failure mechanism prediction module.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The features of the invention will be more readily understood and appreciated from the following detailed description when read in conjunction with the accompanying drawings of the preferred embodiment of the present invention, in which:

[0021] **FIG.1** illustrates an AI-based PCB soldering defect detection module in the present invention;

[0022] **FIG.2** illustrates a schematic diagram depicting the conditions of possible failure mechanisms in solder joints due to temperature changes and CTE mismatch;

[0023] **FIG.3** illustrates a thermal imaging camera-based detection module for PCB soldering failure mechanisms under high current usage in the present invention;

[0024] **FIG.4** illustrates an experimental set up for the detection of PCB soldering failure mechanisms in the present invention;

[0025] **FIG.5** illustrates examples of testing PCB boards with different soldering defects;

[0026] **FIG.6** illustrates experimental results for the detection of PCB soldering failure mechanisms in the present invention;

[0027] **FIG.7** illustrates a training process of the PCB failure mechanism prediction module (1004) in the present invention;

[0028] **FIG.8** illustrates an overall diagram for PCB solder joint defect detection and failure prediction in the present invention;

[0029] **FIG.9** illustrates a weight ensemble of the ResNet50 derived from two pretrained ResNet50;

[0030] **FIG.10** illustrates the inference process for PCB failure mechanism prediction in the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0031] For the purposes of promoting and understanding the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and described in the following written specification. It is understood that the present invention includes any alterations and modifications to the illustrated embodiments and includes further applications of the principles of the invention as would normally occur to one skilled in the art to which the invention pertains.

[0032] The present invention teaches a printed circuit board (PCB) soldering failure mechanism prediction system based on artificial intelligence (AI) **1000**, comprises: a camera-based PCB soldering region detection module **1002** comprises a PCB defect classification model **104**; a thermal imaging camera-based detection module **302** for PCB soldering failure mechanisms under high current usage; and a PCB failure mechanism prediction module **1004** wherein the camera-based PCB soldering region detection module and the PCB failure mechanism prediction module **1004** utilize deep learning models to identify PCB solder joints, classify defects, and predict failure mechanisms.

[0033] In a preferred embodiment of the present invention, the camera-based PCB soldering region detection module further comprises a PCB soldering region detection model **102**. The PCB soldering region detection model **102** adopts YOLOv4 model and the PCB defect classification model applies ResNet50.

[0034] In a preferred embodiment of the present invention, the PCB defect classification model **104** is a pre-trained model.

[0035] In a preferred embodiment of the present invention, the thermal imaging camera-based detection module **302** comprises PCB boards, thermal camera **402**, electronic load and direct current (DC) power supply. The thermal imaging camera-based detection module **302** is configured to perform RGB image annotation and to predict and monitor temperature changes of the PCB solder joints to classify defectiveness.

[0036] In a preferred embodiment of the present invention, the thermal imaging camera-based detection module **302** is further configured to perform experiments to provide information for training the PCB failure mechanism prediction module **1004**.

[0037] The present invention also teaches a printed circuit board (PCB) soldering failure mechanism prediction method based on artificial intelligence (AI), comprising the steps of: capturing an RGB image; detecting PCB soldering region based on a deep learning model; extracting the PCB soldering region and feeding to a PCB failure mechanism prediction module **1004** for predicting a thermal temperature; and obtaining inference results to detect and predict the failure mechanism of solder joints.

[0038] In a preferred embodiment of the present invention, the detecting of PCB soldering region comprises the steps of: capturing images of the PCB using a camera positioned to capture images at various angles and distances; collecting an image dataset containing PCB soldering regions with various soldering defects; annotating data by labeling the images with bounding boxes around the soldering regions to indicate defects; augmenting data by generating new variations of the images; feeding the images into a YOLOv4 model in a PCB soldering region detection model **102**; applying ResNet50 to a PCB defect classification model **104** for classifying images into different types of defects; and outputting inference results of predicted labels indicating the types of defects present in the image of PCB soldering regions. The applying of ResNet50 to the PCB defect classification model **104** further comprises the step of training the model on an image dataset with labels indicating the types of defects present in the PCB soldering regions.

[0039] In a preferred embodiment of the present invention, the method further comprises the step of generating real-time alerts or notifications when a defect is detected in the solder joints of a printed circuit board.

[0040] In a preferred embodiment of the present invention, the extracting of the PCB soldering region and feeding to the PCB failure mechanism prediction module **1004** comprises the steps of: setting up an experimental PCB circuit by connecting it to a power supply and electronic load; setting up a thermal imaging camera; applying stress-loading to the circuit; collecting thermal images and RGB images; and detecting failure mechanism by predicting and classifying the thermal temperature of the PCB soldering region. The method further comprises the step of continuously monitoring temperature changes of the PCB soldering region to detect any potential defects. The predicting and classifying of the thermal temperature and monitoring of the temperature changes further comprise the step of classifying the soldering region as defective and has a thermal failure when the temperature of the soldering region reaches 125 °C.

[0041] In a preferred embodiment of the present invention, the method further comprises the steps of: training the PCB failure mechanism prediction module **1004**. The training of the deep learning model further comprises a step in such training using a small dataset of PCB soldering images with known defect classifications. The training of the PCB failure mechanism prediction module **1004** further comprises a step in such training using a dataset of thermal images collected during testing and stress-loading of the PCB.

[0042] In a preferred embodiment of the present invention, the method comprises the steps of: inputting the PCB defect classification model **104** with ResNet50 as a pre-trained model; and utilizing the RGB image and corresponding temperature label obtained from the detection of failure mechanism to train the PCB failure mechanism prediction module **1004**.

[0043] In a preferred embodiment of the present invention, the method further comprises the steps of: fine-tuning the ResNet50 on the PCB defect classification model; ensembling the weights of the pretrained ResNet50 and the fine-tuned PCB defect classification model **104** by averaging the weights; and fine-tuning the detection of failure mechanism dataset using the average weights.

[0044] In a preferred embodiment of the present invention, the predicting and classifying of the failure mechanism is based on the thermal temperature of the PCB soldering region and known defect classification.

[0045] In a preferred embodiment of the present invention, the printed circuit board (PCB) soldering failure mechanism prediction method based on artificial intelligence (AI) further comprises the step of simultaneously updating an output feedback to the PCB failure mechanism prediction module **1004**.

Exemplary embodiments

[0046] A flow chart of a camera-based non-destructive PCB soldering region detection module, in particular an AI-based PCB soldering defect detection model is illustrated in **FIG.1**. The AI-based PCB soldering defect detection model comprises an RGB image capture system, PCB soldering image data collection, data annotation, data augmentation, a PCB soldering region detection model **102**, a PCB defect classification model **104**, and inference results. The process begins with the image capture system that collects different soldering images. Images of PCBs are captured using a camera positioned to capture images of the PCB from various angles and distances. At least one camera may be mounted on a stand or an automated arm to facilitate movement and positioning. Then, a large dataset of images is gathered, containing PCB soldering regions with various soldering defects such as bridging, cold joints, and insufficient solder. The images from the large dataset are labeled with bounding boxes around the soldering regions to indicate which PCB soldering regions are good or defective during data annotation. The module further generates new variations of the images by applying transformations to increase the size of the dataset through data augmentation. For example, the said transformations include but are not limited to rotating, flipping, and scaling.

[0047] The images are then fed into the YOLOv4 model, which has been trained on a large dataset of labeled images in the PCB soldering region detection model **102**. The trained YOLOv4 model is fine-tuned on the soldering region dataset for soldering region detection by adjusting the weights of the model to improve performance. Once the model has been trained, it can be applied to new images of PCBs to automatically detect soldering regions. The images of PCB soldering regions are further classified into different types of defects by applying ResNet50 to the PCB defect classification model **104**. The said model can be trained on an image dataset with labels indicating the types of defects present in the soldering region. Therefore, the output of the PCB defect classification model **104** is a predicted label indicating the type of soldering defects present in the input image of the PCB soldering region. The model takes the soldering region image as its input and outputs a specific label that corresponds to the classification of the soldering defect. The output of the process is a list of defects along with their locations on the PCB. This process is highly efficient, accurate and can significantly reduce the time and cost associated with manual inspection of PCBs. It is widely used in manufacturing and quality control processes and has the potential to improve the reliability and performance of electronic products. Accordingly, early detection of PCB soldering defects can be performed on the production line.

[0048] The thermal failure mechanisms of solder joints caused by high current usage are a common issue in electronic devices. When a device experiences high current flow, the heat generated can cause the temperature of the solder joints to rise. If the temperature exceeds the glass transition temperature (Tg) of the material, the solder joints can soften and lose their rigidity, leading to cracking or failure of the joint. This can result in a loss of electrical contact and a potential malfunction or failure of the device. Therefore, it is crucial to detect the temperature of the solder joints under high current usage to ensure that the solder joints would not exceed their Tg and remain within their intended operating temperature range. An experimental-based soldering failure mechanism has been developed in the present invention for early detection of PCB soldering failure mechanism by allowing manufacturers to identify potential issues and take corrective action before any damage occurs. To ensure the reliability and safety of electronic devices, it is necessary to implement sampling strategies when testing solder joints. These strategies include simple random sampling, stratified random sampling, cluster sampling, and systematic sampling. By using these methods, a representative sample of solder joints can be tested to detect potential issues and improve the overall reliability of electronic devices. **FIG.2** illustrates a schematic diagram depicting the conditions (e.g. Case 1: Plated through-hole soldering, Case 2: Surface mount technology soldering, etc.) of possible failure mechanisms in solder joints due to a PCB subjected to temperature changes above its Tg and causing a CTE mismatch between the base materials of components and the PCB. Firstly, when a PCB is subjected to temperature changes above its Tg, the material becomes more pliable and its CTE increases. Secondly, as a result, the thermal expansion and contraction of the two materials become mismatched, leading to stress on the solder joints connecting the components to the PCB. Eventually, failure may occur at the solder joints.

[0049] As illustrated in **FIG.3**, a thermal imaging camera-based detection module **302** for PCB soldering failure mechanism detection under high current usage is disclosed. Firstly, the circuitry of PCBs is set up and connected with a DC power supply and an electronic-load. Then an image capture system, in particular a thermal imaging camera, is set up. The placement of the thermal camera is then designed and located on the PCB assembly, around the solder joints of the PCBs. Afterwards, the circuit with stress loading through high currents of 40A, 50A, and 55A for every 20 minutes is applied, and the change of electric currents with time is recorded. The mechanism further collects thermal and RGB images. The change in temperature on the thermal images for different soldering locations is subsequently inspected and recorded. The obtained data is input into the detection of failure mechanism for further analysis to classify defectiveness.

[0050] When the PCB has completed the soldering process with the required electronic components on the production line, a reliability test is conducted to evaluate whether the heat generated by the solder joints exceeds a measured temperature of about 130°C under a high current condition of above 40A. The temperature limit of 130 °C is to avoid the solder joints exceeding the glass transition temperature (Tg), which is an important parameter used for the identification of PCB soldering failure mechanisms. The set classified value in the present invention, 125°C of the detection of PCB soldering failure mechanism is about 5°C lower than the Tg (130°C) value of PCBs. This difference is required and could facilitate subsequent work for AI-based early detection of soldering defects and AI-based prediction of the failure of solder joints. Lastly, a detection of failure mechanism is conducted to predict and classify the thermal temperature of the PCB soldering region. Therefore, the thermal failure mechanism used in the present invention is simply defined as follows: a soldering region is classified as normal if the recorded temperature does not reach 125 °C. Otherwise, the soldering region is regarded as having a thermal failure and is classified as defective.

[0051] **FIG.4** illustrated an experimental set-up for the detection of PCB soldering failure mechanism. As shown in **FIG.4**, a thermal camera, a high-current DC power supply, and an electronic load, are used to detect the failure mechanism of different soldering defects. For instance, eight PCB boards are tested, of which two are normal and the other six have different soldering defects, as shown in **FIG.5**. In the experiments, each PCB board was maintained for every 20 minutes at a DC current of 40A, 50A and 55A alternately, and then their corresponding maximum thermal temperatures on the solder joints were measured with a thermal camera **402**.

[0052] The PCB boards are control circuit boards used in high-power electric tools such as sanding machines and electric drills. The PCB samples either have no soldering defects or have soldering defects in the interconnections. The thermal camera **402** is a measurement device, as shown in **FIG.4**, that can capture the temperature distributions on object surfaces without touching the object. The thermal camera **402** is used to record the thermal change and profile of different solder joints. Further, the use of electronic loads has also become a common practice in testing power supplies. Electronic loads are therefore used in various sizes and applications, ranging from low to high power consumption. They provide a resistance for drawing current from a DC power supply, which allows for testing of devices such as batteries, solar cells, electronic components, and portable chargers. The DC power supply provides direct current voltage to power the device under test, such as a circuit board or an electronic product. It is used accordingly to provide a current of 40A to 60A to the circuits of the PCB samples.

[0053] **FIG.6** shows the experimental results for the detection of the PCB soldering failure mechanism, which can effectively perform an early detection of the solder joint failure mechanism. Therefore, the experimental-based thermal imaging camera in the present invention provides early detection of PCB soldering failure mechanism under high current usage conditions. The detection of PCB soldering failure mechanism uses the said deep learning models to improve the quality and reliability of PCBs by identifying and addressing potential manufacturing defects, diagnosing issues with existing PCBs, predicting potential failure mechanisms, and providing feedback for product design and improvement. In addition, RGB image annotation is performed for training the PCB failure mechanism prediction module **1004**.

[0054] The thermal imaging camera-based detection module **302** for PCB soldering failure mechanism in the present invention enables different current levels at the solder joints through the circuits of the PCB samples. The temperature differences between the areas around solder joints of normal and defective samples can be checked. The temperature, current, and voltage changes from images of solder joints can be captured using software. A feature recognition system is used in the present invention to distinguish the difference between solder joint images of normal and defective samples for early detection of specific failure mechanism. Accordingly, a detection model based on the images for the reliability of solder joints can be found in the present invention.

[0055] A camera-based capture system with an AI model for the prediction of failure mechanisms in solder joints is further disclosed in the present invention. The system utilizes computer vision techniques to capture images of the solder joints and analyze their appearance to identify potential defects or areas of concern. The AI model is trained on a dataset of images of solder joints with known defects and failures, allowing it to learn patterns and features that are indicative of potential issues. By analyzing the appearance of solder joints in real-time, the AI model can provide early warnings of potential failures, allowing for proactive maintenance and repair.

[0056] The ResNet50 soldering defect classification model is employed as an input to pre-train the model for the prediction of PCB failure mechanisms. The RGB image and corresponding temperature label (i.e., to be marked with the maximum temperature recorded) obtained from failure mechanism detection are utilized to train the failure mechanism prediction module. **FIG.7** illustrates the training process of the PCB failure mechanism prediction module **1004** in the present invention. The PCB failure mechanism detection system provides a temperature label for the solder joint image as an additional input feature for training a failure mechanism prediction module. The temperature labels can be obtained through thermal imaging or other temperature sensing techniques and can provide valuable information about the thermal behavior of solder joints. However, it is optional to apply the said temperature label, as the model can learn to detect and predict potential failure mechanism based solely on the RGB image input.

[0057] The limited data of RGB images with thermal information is collected and applied in the soldering failure mechanism detection system to fine-tune the parameters of the ResNet to perform the PCB failure mechanism prediction. **FIG.8** illustrates the overall diagram for PCB solder joint defect detection and failure prediction in the present invention.

[0058] Furthermore, the performance of the PCB failure mechanism prediction can be improved in the present invention by applying the pre-trained PCB defect detection model for transfer learning, which significantly reduces the amount of data and training time required. This is because the features and patterns learned by the pre-trained model are applicable for both detecting PCB soldering defects and predicting soldering failure mechanisms. Due to the fact that the number of training images is extremely small, a special finetuning method is required. Two training methods have been tested in the present invention. The first method is pretraining the model by using a modified version of weight-space ensemble for fine-tuning (WISE-FT). In WISE-FT, it maintains the accuracy and robustness of a pretrained model even under distribution shifts. However, the pretrained model in the present invention uses an ImageNet-pretrained ResNet and fine-tunes it on the task of PCB defect classification to obtain a model that has the same domain as the target domain. The PCB defect classification is trained on images of the same type of printed circuit boards with the same top view. It enhances the modeling ability of feature extraction in the PCB images. After that, the weights of the ImageNet-pretrained ResNet and the fine-tuned PCB defect classification model are ensembles by averaging the weights. The averaged weight is then used to robustly fine-tune on the PCB failure mechanism dataset. **FIG.9** illustrates the weight ensemble of the ResNet50 derived from a two pretrained ResNet50, which allows it to be fine-tuned robustly.

Table 1: The confusion matrix of the PCB failure mechanism prediction module using the modified WISE-FT model

		Predicted	
		< 125 °C	>= 125°C
Actual	< 125 °C	14.3%	14.3%
	>= 125 °C	0.0%	71.4%

[0059] Table 1 shows the confusion matrix of the PCB failure mechanism prediction module **1004**. The evaluation metrics for failure mechanism prediction suggested that the AI model performs well overall. The F1 score of 0.9091 indicates a high level of accuracy in predicting failure mechanisms. The sensitivity of 1.0 shows that the AI model correctly identifies all instances of failure mechanisms, indicating a strong ability to detect failures. The precision of 0.8333 means that out of the predicted failure mechanisms, 83.33% are actually true positives, demonstrating a reasonably good level of precision. The accuracy of 0.8571 indicates that the AI model correctly classifies 85.71% of all instances, regardless of their positive or negative nature. Although the Matthews Correlation Coefficient (MCC) of 0.645 suggests a moderate level of correlation between predicted classifications and actual observations, the overall performance of the AI model is quite good based on the other metrics. **FIG.10** illustrates the inference process for PCB failure mechanism prediction module **1004**. In the inference process of the failure mechanism prediction, only the RGB image is needed to predict the potential failure mechanisms of the PCB solder joints. The trained model can use the RGB image as its input and use the information learned during training to make predictions about potential failure mechanisms. After the capture of the RGB image, the AI-based PCB soldering region detection model **102** is utilized, wherein the machine learning model could accurately identify and locate the solder joint regions on the PCB. Once the solder joint regions of the PCB have been identified and located, the regions are extracted and fed to the PCB failure mechanism prediction module **1004** for thermal temperature prediction. Subsequently, the inference results are obtained to detect and predict the failure mechanism of solder joints. By identifying the said thermal temperature early, manufacturers can take corrective action to improve the quality of the PCB, thus improving the overall quality and reliability of the products. Therefore, the PCB failure mechanism prediction module **1004** in the present invention can help manufacturers identify and address potential solder thermal failures before they occur, enhancing the overall reliability and performance of their products.

[0060] AI-based PCB soldering failure mechanism prediction in the present invention has several advantages over experimental-based PCB soldering failure mechanism detection techniques in terms of accuracy, reduction in steps, non-destructiveness, time-saving, mass production, cost-effectiveness, automation, and higher flexibility for testing all PCB samples with solder joints, etc. The AI-based model is a non-destructive process, as it only requires a camera to monitor the solder joint and an AI model to predict if the solder exceeds the Tg during the manufacturing process. The present system and method can quickly and accurately examine all the PCB solder joints on the production line, enabling manufacturers to identify potential issues and take corrective action before any damage occurs. AI-based models are better suited for mass production as they can analyze large amounts of data quickly and accurately, allowing for corrective action to be taken before large batches of products are produced. This AI-based model is a cost-effective solution, as it eliminates the need for expensive equipment and materials required for the traditional experimental-based detection method. This makes it a more accessible solution for manufacturers of all sizes, allowing for greater flexibility and scalability in the production process. AI-based models can automate the process of identifying potential defects, which can reduce the need for manual inspection and analysis. This can improve efficiency, reliability, and consistency.

[0061] The present invention explained above is not limited to the aforementioned embodiment and drawings, and it will be obvious to those having an ordinary skill in the art of the prevent invention that various replacements, deformations, and changes may be made without departing from the scope of the invention.

CLAIMS

WHAT IS CLAIMED:

1. A printed circuit board (PCB) soldering failure mechanism prediction system based on artificial intelligence (AI) (1000), comprising:

   a camera-based PCB soldering region detection module (1002) comprises a PCB defect classification model (104);

   a thermal imaging camera-based detection module (302) for PCB soldering failure mechanisms under high current usage;

   a PCB failure mechanism prediction module (1004);

   wherein the camera-based PCB soldering region detection module (1002) and the PCB failure mechanism prediction module (1004) utilize deep learning models to identify PCB solder joints, classify defects, and predict failure mechanisms.

2. The printed circuit board (PCB) soldering failure mechanism prediction system based on artificial intelligence (AI) (1000) according to claim 1, wherein the camera-based PCB soldering region detection module (1002) further comprises a PCB soldering region detection model (102).

3. The printed circuit board (PCB) soldering failure mechanism prediction system based on artificial intelligence (AI) (1000) according to claim 2, wherein the PCB soldering region detection model (102) adopts YOLOv4 model and the PCB defect classification model (104) applies ResNet50.

4. The printed circuit board (PCB) soldering failure mechanism prediction system based on artificial intelligence (AI) (1000) according to claim 3, wherein the PCB defect classification model (104) is a pre-trained model.

5. The printed circuit board (PCB) soldering failure mechanism prediction system based on artificial intelligence (AI) (1000) according to claim 1, wherein the thermal imaging camera-based detection module (302) comprises PCB boards, thermal camera (402), electronic load and direct current (DC) power supply.

6. The printed circuit board (PCB) soldering failure mechanism prediction system based on artificial intelligence (AI) (1000) according to claim 5, wherein the thermal imaging camera-based detection module (302) is configured to perform RGB image annotation and to predict and monitor temperature changes of the PCB solder joints to classify defectiveness.

7. The printed circuit board (PCB) soldering failure mechanism prediction system based on artificial intelligence (AI) (1000) according to claim 6, wherein the thermal imaging camera-based detection module (302) is further configured to perform experiments to provide information for training the PCB failure mechanism prediction module (1004).

8. A printed circuit board (PCB) soldering failure mechanism prediction method based on artificial intelligence (AI) (100), comprising the steps of:

capturing an RGB image;

detecting PCB soldering region based on a deep learning model;

extracting the PCB soldering region and feeding it to a PCB failure mechanism prediction module (1004) for predicting a thermal temperature; and

obtaining inference results to detect and predict the failure mechanism of solder joints.

9. The printed circuit board (PCB) soldering failure mechanism prediction method based on artificial intelligence (AI) (100) according to claim 8, wherein the detecting of the PCB soldering region comprises the steps of:

capturing images of the PCB using a camera positioned to capture images at various angles and distances;

collecting an image dataset containing PCB soldering regions with various soldering defects;

annotating data by labeling the images with bounding boxes around the soldering regions to indicate defects;

augmenting data by generating new variations of the images;

feeding the images into a YOLOv4 model in a PCB soldering region detection model (102);

applying ResNet50 to a PCB defect classification model (104) for classifying images into different types of defects; and

outputting inference results of a predicted label indicating the type of defects present in the image of PCB soldering regions.

10. The printed circuit board (PCB) soldering failure mechanism prediction method based on artificial intelligence (AI) (100) according to claim 9, wherein the applying of ResNet50 to the PCB defect classification model (104) further comprises the step of training the model on an image dataset with labels indicating the type of defects present in the PCB soldering regions.

11. The printed circuit board (PCB) soldering failure mechanism prediction method based on artificial intelligence (AI) (100) according to claim 9, wherein the method (100) further comprises the step of generating real-time alerts or notifications when a defect is detected in the solder joints of a printed circuit board.

12. The printed circuit board (PCB) soldering failure mechanism prediction method based on artificial intelligence (AI) (100) according to claim 8, wherein the extracting of the PCB soldering region and feeding to the PCB failure mechanism prediction module (1004) comprises the steps of:

setting up an experimental PCB circuit by connecting it to a power supply and electronic load;

setting up a thermal imaging camera;

applying stress-loading to the circuit;

collecting thermal images and RGB images; and

detecting failure mechanism by predicting and classifying the thermal temperature of the PCB soldering region.

13. The printed circuit board (PCB) soldering failure mechanism prediction method based on artificial intelligence (AI) (100) according to claim 12, wherein the method further comprises the step of continuously monitoring the temperature changes of the PCB soldering region to detect any potential defects.

14. The printed circuit board (PCB) soldering failure mechanism prediction method based on artificial intelligence (AI) (100) according to claim 12 or 13, wherein the predicting and classifying of the thermal temperature and monitoring of the temperature changes further comprise the step of classifying the soldering region as defective and thermal failure when the temperature of the soldering region reaches 125 °C.

15. The printed circuit board (PCB) soldering failure mechanism prediction method based on artificial intelligence (AI) (100) according to claim 8, wherein the method further comprises the step of training the PCB failure mechanism prediction module (1004).

16. The printed circuit board (PCB) soldering failure mechanism prediction method based on artificial intelligence (AI) (100) according to claim 10, wherein the training of the deep learning model further comprises a step in such training using a small dataset of PCB soldering images with known defect classifications.

17. The printed circuit board (PCB) soldering failure mechanism prediction method based on artificial intelligence (AI) (100) according to claim 15, wherein the training of the PCB failure mechanism prediction module (1004) further comprises a step in such training using a dataset of thermal images collected during testing and stress-loading of the PCB.

18. The printed circuit board (PCB) soldering failure mechanism prediction method based on artificial intelligence (AI) (100) according to claim 15, wherein the method comprises the steps of:

inputting the PCB defect classification model (104) with ResNet50 as a pre-trained model; and

utilizing the RGB image and corresponding temperature label obtained from the detection of failure mechanism to train the PCB failure mechanism prediction module (1004).

19. The printed circuit board (PCB) soldering failure mechanism prediction method based on artificial intelligence (AI) (100) according to claim 18, wherein the method (100) further comprises the steps of:

fine-tuning the ResNet50 on the PCB defect classification model (104);

ensembling the weights of the pretrained ResNet50 and the fine-tuned PCB defect classification model (104) by averaging the weights; and

fine-tuning the detection of failure mechanism dataset using the average weights.

20. The printed circuit board (PCB) soldering failure mechanism prediction method based on artificial intelligence (AI) (100) according to claim 8 or 12, wherein the predicting and classifying of the failure mechanism is based on the thermal temperature of the PCB soldering region and known defect classifications.

21. The printed circuit board (PCB) soldering failure mechanism prediction method based on artificial intelligence (AI) (100) according to claim 8, wherein the method further comprises the step of simultaneously updating an output feedback to the PCB failure mechanism prediction module (1004).

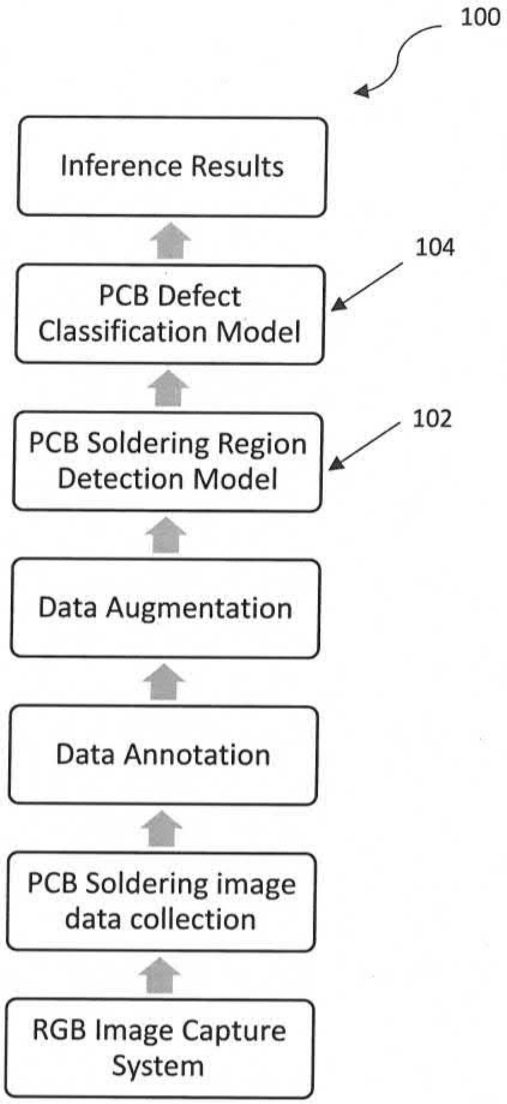

100
Inference Results
104
PCB Defect Classification Model
102
PCB Soldering Region Detection Model
Data Augmentation
Data Annotation
PCB Soldering image data collection
RGB Image Capture System

FIG.1

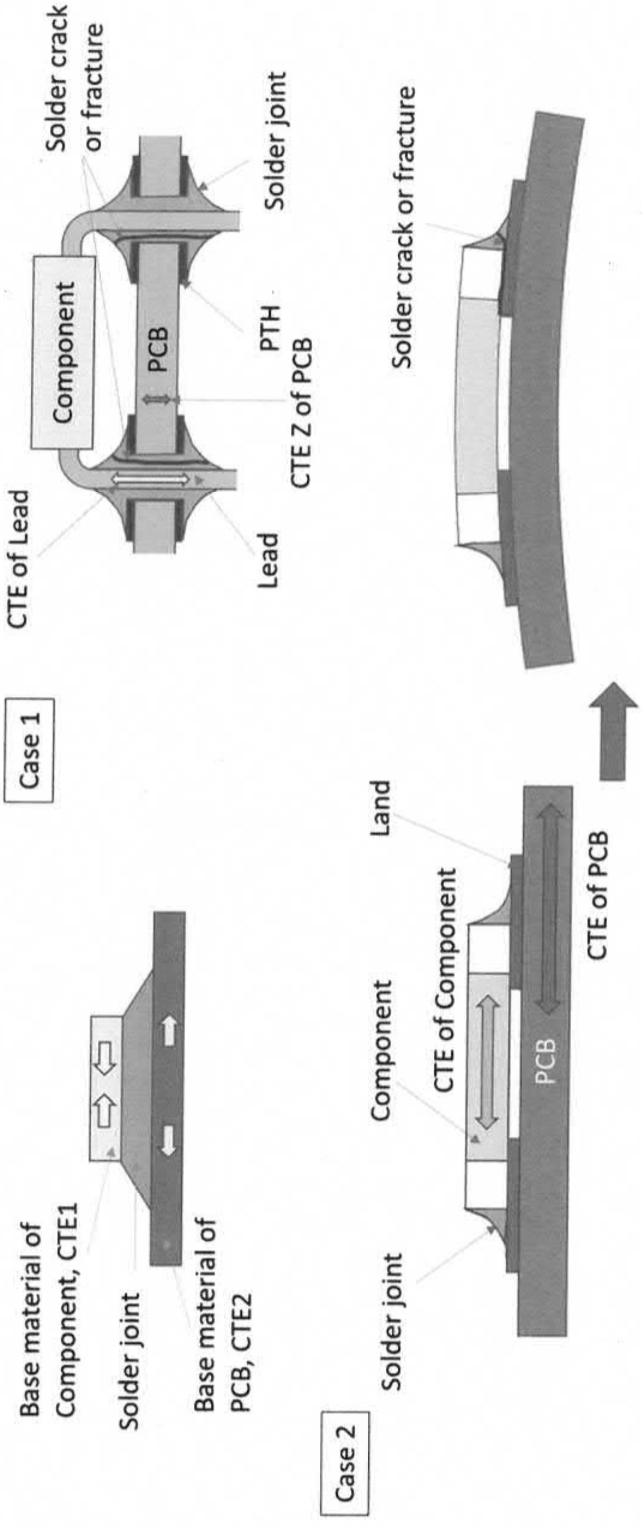

Case 1
CTE of Lead
Lead
Component
PCB
CTE Z of PCB
PTH
Solder crack or fracture
Solder joint
Case 2
Base material of Component, CTE1
Solder joint
Base material of PCB, CTE2
Solder joint
Component
CTE of Component
PCB
Land
CTE of PCB
Solder crack or fracture

FIG.2

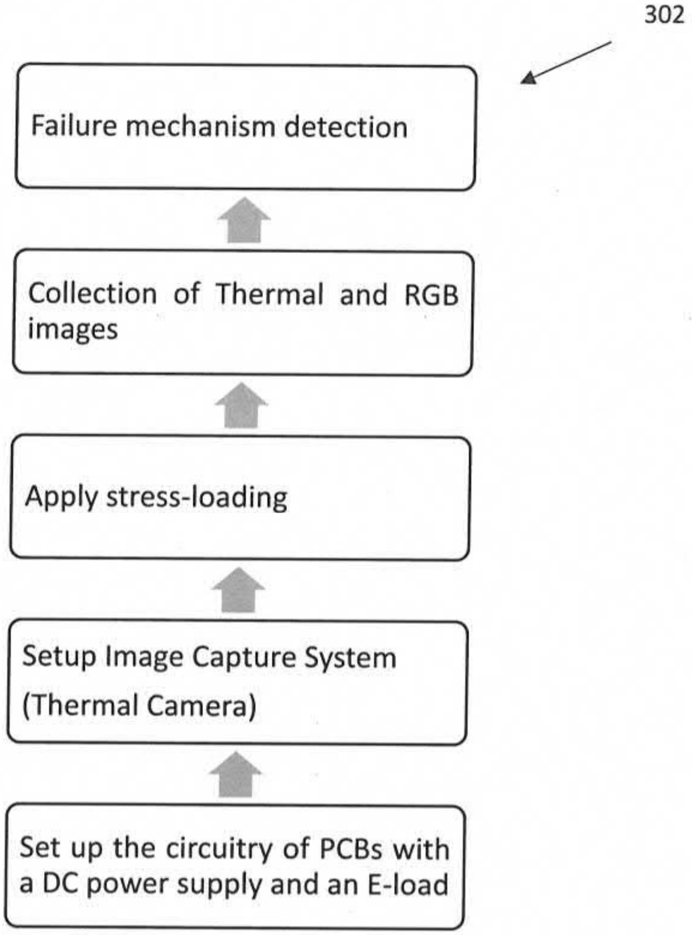

302
Failure mechanism detection
Collection of Thermal and RGB images
Apply stress-loading
Setup Image Capture System
(Thermal Camera)
Set up the circuitry of PCBs with a DC power supply and an E-load

FIG.3

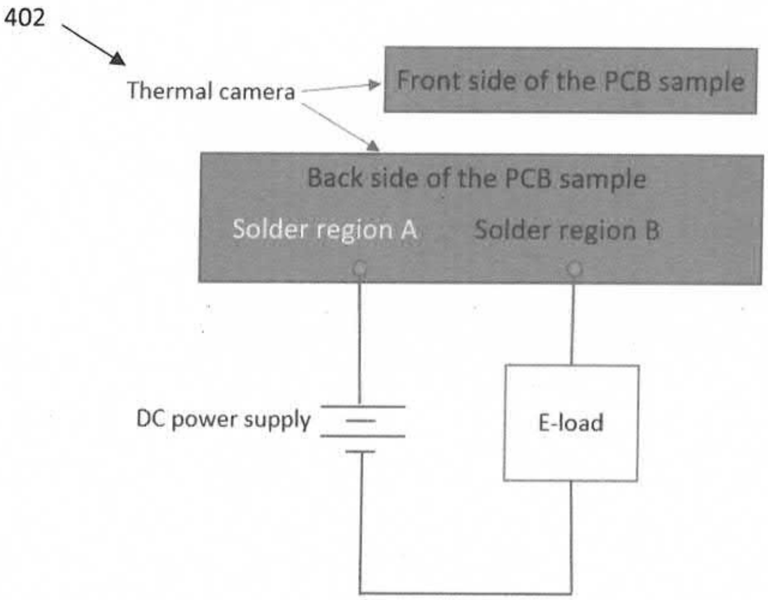


FIG.4

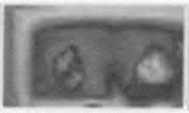
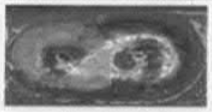
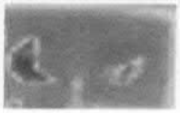
Types of soldering regions	RGB Image	Thermal Image	Number of RGB images	Failure (> 125°C)
OK			8	N
Pseudo Joint			4	Y
Copper Pad Exposed			4	Y
Sharp Edge			4	Y
Less Tin			8	Y
Too Much Tin			4	Y

FIG.5

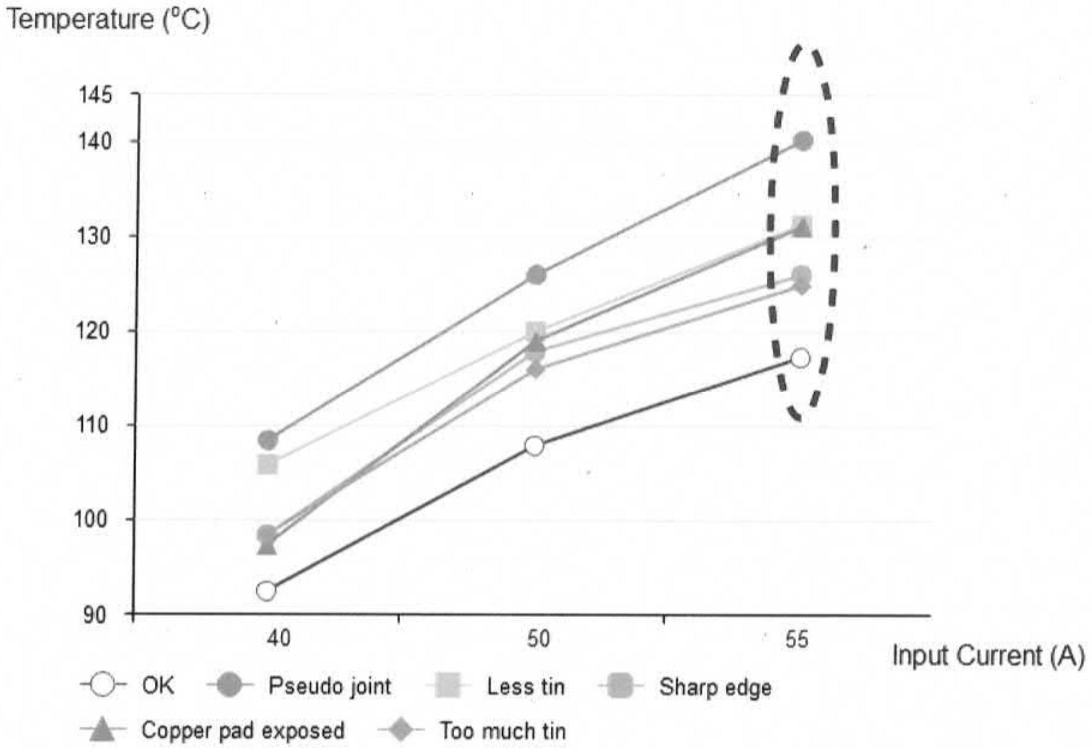

Temperature (°C)
145
140
130
120
110
100
90
40
50
55
Input Current (A)
OK
Pseudo joint
Less tin
Sharp edge
Copper pad exposed
Too much tin

FIG.6

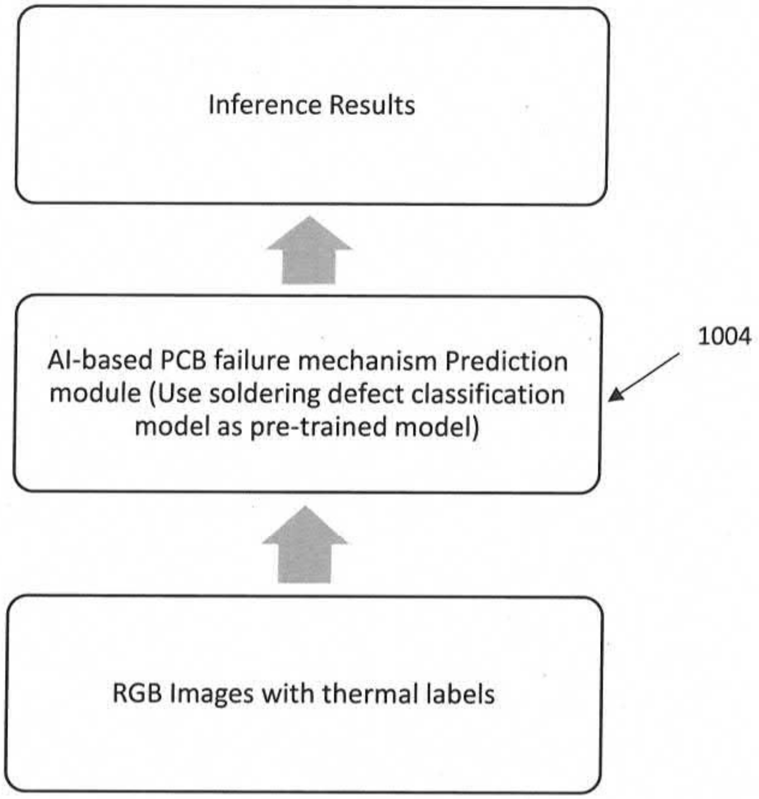

Inference Results
AI-based PCB failure mechanism Prediction module (Use soldering defect classification model as pre-trained model)
1004
RGB Images with thermal labels

FIG.7

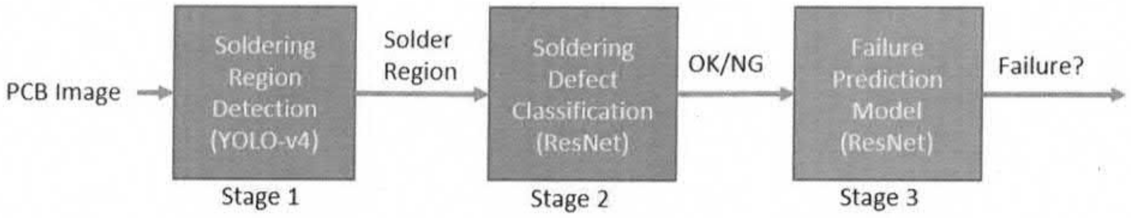

PCB Image
Soldering Region Detection (YOLO-v4)
Stage 1
Solder Region
Soldering Defect Classification (ResNet)
Stage 2
OK/NG
Failure Prediction Model (ResNet)
Stage 3
Failure?

FIG.8

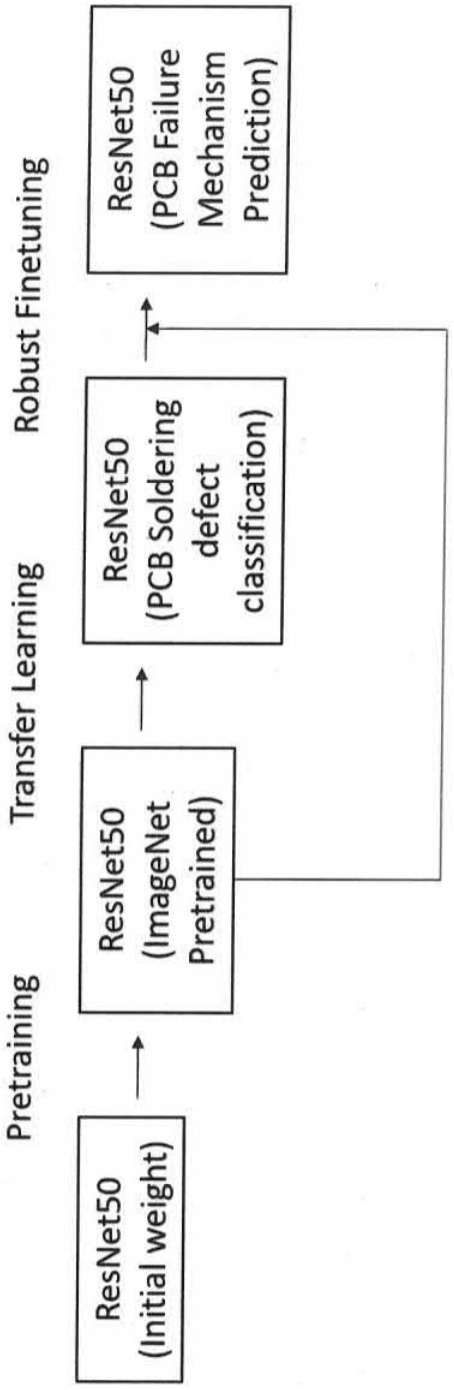

ResNet50 (Initial weight)
Pretraining
ResNet50 (ImageNet Pretrained)
Transfer Learning
ResNet50 (PCB Soldering defect classification)
Robust Finetuning
ResNet50 (PCB Failure Mechanism Prediction)

FIG.9

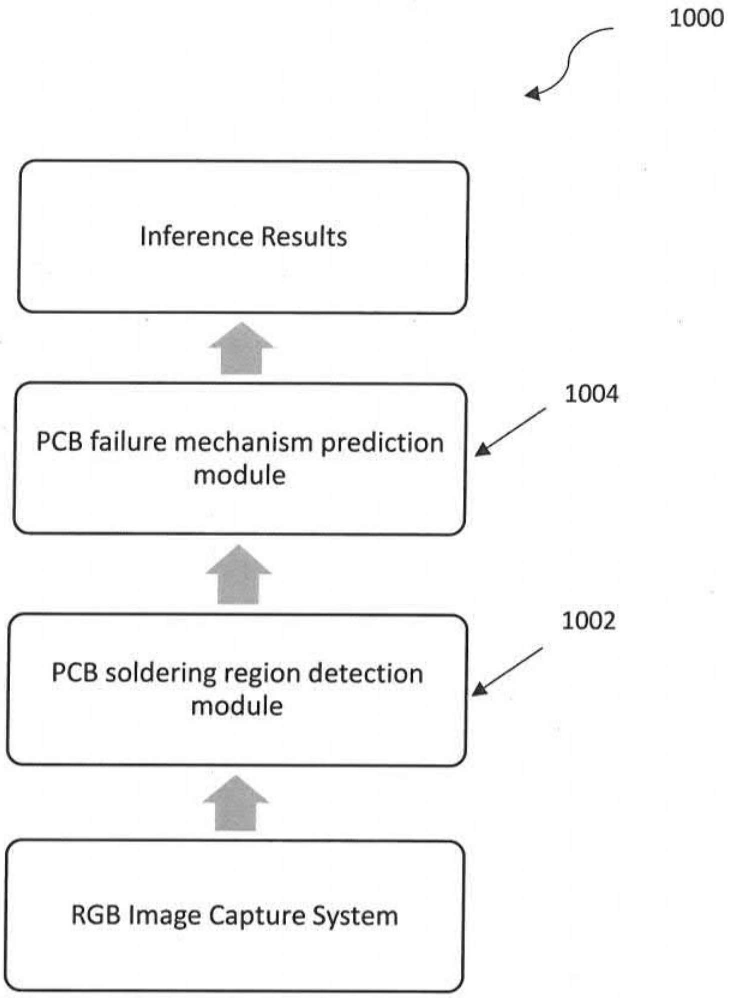

1000
Inference Results
1004
PCB failure mechanism prediction module
1002
PCB soldering region detection module
RGB Image Capture System

FIG.10