Automated Detection of Printed Circuit Boards (PCB) Defects by Using Machine Learning in Electronic Manufacturing: Current Approaches

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Abstract. The manufacturing of a printed circuit board in the SMT assembly line goes through multiple phases of automatic handling. To ensure the quality of the board and reduce the number of defects, inspection tasks such as solder paste inspection and automatic optical inspection are conducted. The inspection tasks are carried out at various phases of the assembly line. The paper aims to answer the questions of how machine learning technology can contribute for better PCB fault detection in the assembly line and at which parts of the assembly line this technology has been applied. The paper discusses the PCB defect detection by using machine learning and other approaches. The current research shows that PCB defect detection using machine learning is miniscule. Early detection is still unexplored and experimented in the industry.

1. Introduction
Surface-mount technology (SMT) is a method for producing electronic circuits in which the components are mounted or placed directly onto the surface of Printed Circuit Boards (PCB)s. PCB are boards with electronically connected lines, tracks and paths to connect electronic components. These paths are connected by a substrate laminated by copper material which allow electric to conduct from one component to another. To stick the component on the board, solder paste solution is printed on the board via solder paste printing process. Assembling those fine pitch components poses significant challenges to solder paste printing. The semiconductor industry reports that the 60% to 70% of defects are associated with solder paste printing process depends on various generalized factors like process, squeegee, substrate, printer machine, stencil and solder paste [1].

Each and every factor affects the solder volume deposition either directly or indirectly. The solder paste printing process is a crucial part of the assembly line as 50%- 70% of production defect is contributed from volume related defect in this process as stated in the journal authored by Burr et al (1997)[2]. It is a widely believed fact that 52-71% of SMT defects can be attributed to the solder paste printing process [3] as shown on the chart in figure 1.
As the SMT pads corresponding to the part leads have become smaller and denser, the corresponding aperture in the stencil used to apply the solder paste have also become smaller and denser [4]. With reduced width-to-thickness aspect ratio, the stencil aperture is prone to clogging with dried solder paste, resulting in poor application of solder paste to the circuit board pad. Human visual inspection is the traditional method of choice to reveal defects in the physical quality of solder paste bricks for most manufacturers of SMT assemblies. Unfortunately, this method is inherently inefficient and subject to operator variability. Human visual inspection only provides an approximation of actual quality levels due to the limitations imposed by normal fatigue an eye strain. Other variability is associated with differences between operators.

The research production defects is important in today’s world where consumerism is at its peak. To help the industry meet its supply and demands, catching a defect at an early stage such as on the assembly line, where the PCB is assembled, can increase yields by prevention of defects and ensure the company does not have a loss by having to rework defective products. Quality control has advanced from determining defective boards during final inspection to using process control to reduce the number of defects occurring. Thus, making in-process inspection become more important than ever. Manufacturing engineers are turning to in-line, post-print inspection equipment for implementing process control systems for their board assembly line.

This paper aims to investigate the available machine learning approaches that have been applied for PCB defect detection. This helps us to understand the available gaps we aim to identify the potential points in the SMT assembly line that can be improved by using machine learning.

The paper is organized as follows, section 2 introduces the backgrounds of SMT assembly line and two main stream methods on defects detection. Section 2 details the available works that utilized machine learning for PCB defect detection. Other PCB defect detection works that do not apply machine learning approaches are given in section 3. Finally, conclusions is shown in section 4.

2. SMT Assembly Line
This section discusses the main processes in the SMT Assembly line. Then, two inspection concepts that common in the SMT processes: Solder Paste Inspection and Automatic Optical Inspection, are briefly explained.

2.1. Main Processes
Generally, the SMT assembly line in electronic industry consists of six main processes (as described in figure 2): the PCB board registration, solder paste printing, component placement, mounting, repaneling and testing.
Figure 2. Processes in the SMT Assembly Line

Start with the PCB Board Registration, the board’s serial number is recorded to ensure the board is traceable in the assembly line and can be monitored. Then, the PCB is printed with the solder paste (in Solder Paste Printing) and then the solder paste inspection will inspect the quality of the printing. Any rejected PCB with an error in the solder paste printing will produce a warning to alert the operators in charge. The error free PCB will go through the Component Placement where the components will be arranged. The PCB is then scanned again with the line scanner and before it undergoes the Mounting (Oven). The oven ensures the component sticks to the PCB board by mounting the component to the PCB board. Automatic Optical Inspection (AOI) machine is used to check if the components are error free. After all this, the PCB’s goes to the Repanelling, where the PCB is cut into separate pieces. Finally, the repanelled PCB’s undergoes Testing to confirm the components are working properly.

2.2. Solder Paste Inspection

It is now generally recognized that solder paste printing is a crucial process in controlling the solder joint quality on finished boards. The solder paste depositing inspection is very important in the process of surface mounting for printed circuit board (PCB). It is essential to develop the process that assists in depositing the correct volume of solder paste on the solder pads. Nowadays, most of the electronic manufacturing using solder paste inspection system to inspect and study the solder paste deposition on Printed Circuit Board after printing. The defects related to solder paste printing are captured using inspection system. It helps to find an optimum process setting that makes our printed circuit board as defect free. Solder paste inspection is conducted right after the solder paste in printed on the PCB. During the inspection, electronic assemblies which does not meet the criteria are sorted after solder paste printing. This is to avoid unnecessary cost due to placement of components.

2.3. Automatic Optical Inspection

The automatic optical inspection is an important tool which aids in detecting faulty component on a printed circuit board. This technique utilizes high performance scalable modular camera technology with four colour illuminations from all spatial directions to produce optimum contrast value for many defects during feature value extractions. An example of the colour illuminations technique in AOI inspection is shown in figure 3.
3. PCB Defect Detection by Using Machine Learning

3.1. Defect Detection By Using Artificial Neural Networks
Wu, Zhang, Kuang, & Lu (2008) argued that the currently inspection for solder paste which are mainly performed by laser-based systems is not practical due to high cost and low inspection speed[6]. They proposed a real-time inspection approach based on the machine vision. First, a new fast image matching method was applied to align the PCB and determination of region of interest. Second, the images of the PCB are analysed, and the two-dimensional feature and a pseudo-3D feature are obtained. Finally, the artificial neuron network was established for classification the solder pastes.

Acciani, Brunetti, and Fornarelli (2006) [12] introduced a diagnostic process to detect solder joint defect by using Neural Network System which processes the image of the solder joints of the integrated circuits mounted on the board. The PCB tested images are pre-processed by means of several methods to reduce the amount of data to feed to the neural networks. The board images are acquired and then pre-processed to extract the regions of interest for the diagnosis which are the solder joints of the integrated circuits. First, image segmentation was performed for board extraction, followed by I.C extraction. Finally, image segmentation was performed for pins extraction. During feature extraction, two feature vectors have been extracted from each region of interest, the “geometric” feature vector and “wavelet” feature vector. Both vectors feed the neural network system constituted by two Multilayer Perceptron neural networks and a Linear Vector Quantization network for the classification. The experimental results are devoted to comparing the performances of a Multi-Layer Perceptron network of a Linear Vector Quantization network, and of the overall neural network system, considering both geometric and wavelet features.

3.2. SPI Inspection Using Probabilistic Approaches
A probabilistic approach called, the Hierarchical Marked Point Process (HMPP) framework was proposed by Benedek (2011)[9]. It is able to handle paste and scooping extraction problems simultaneously, so that the solder pastes and scoops have a parent-child relationship. A global optimization process attempts to find the optimal configuration of entities, considering the observed data, prior knowledge, and interactions between the neighbouring circuit elements. The proposed method is evaluated on a real PCB image set containing more than 3000 solders paste data with 600 scooping artefacts [9]. A morphology-based baseline method is also introduced for the problem and used as reference for qualitative and quantitative comparison against the proposed model.

3.3. PCB Defect Detection by Using Ensemble Machine Learning
With the continuous development of the electronics industry, the number of PCB has grown at a rapid rate, and the requirements for the detection, the main reference is the comparison method. However, in
real scene, here are a series of problems such as non-uniform illumination, tilting of the camera angle, and the like, resulting in a less satisfactory effect of the reference comparison method. Lu, He, Xiang, & Liu (2018) proposed a cross-reference comparison framework of PCB defect detection [11]. They intended to solve the problem in the reference comparison method such as non-uniform illumination and tilting of the camera angle that result in a less satisfactory. This framework achieves good result in speed and accuracy. The authors extract the histogram oriented gradient and local binary pattern features for each PCB image respectively, put into the support vector machine to get two independent models. Then, according to Bayes fusion theory, the authors fuse two models for defect classification. The authors have established a PCB data set that includes both defective and defect free. It has been verified that the accuracy of the verification set is improved compared to the individual features using the fused feature. The authors also illustrate the effectiveness of Bayes feature fusion terms of speed.

3.4. PCB Defect Detection by Using Deep Learning
Robust and precise defect detection is of great significance in the production of the high-quality PCB. Due to the complexity of PCB production environments, most previous works still utilize traditional image processing and matching algorithms to detect PCB defects. In Zhang, Shi, Li, Zhang, & Liu (2018) [13], an improved bare PCB defect detection approach is proposed by learning deep discriminative features, which also greatly reduced the high requirement of a defect dataset with some artificial defect and affine transformation to increase the quantity and diversity of defect data. Then, a deep pre-trained convolutional neural network is employed to learn high-level discriminative features of defects. They fine-tune the base model on the extended dataset by freezing all the convolutional layers and training the top layers. Finally, the sliding windows approach is adopted to further localized the defects. Extensive comparison with three additional shallow features-based methods demonstrate that the proposed approach is more feasible and effective in PCB defect detection area. Srimani and Pratibha (2016) [13] also presented a deep learning neural network and hybrid genetic algorithm for PCB defect detection. Deep learning neural network was used for classification. For feature selection, genetic algorithm was applied to optimize the feature reduction process. This work focused on feature generation by applying filtering scheme which provides feature ranking procedure by considering gain ratio, GINI index, and correlation. In addition, two stage optimal solution selection was adopted.

3.5. PCB Defect Detection by Using Speed-Up Robust Feature and Random Forest
Yuk, et al (2018)[15] proposed defect detection method by using speeded-up robust features (SURF) and Random Forest. SURF was used to extract the features from the PCB images and then Random Forest learned the fault pattern and obtained the probabilities. By using the probabilities to set the weights, the Weighted kernel density estimation (WKDE) map is generated and this provides the density of the features. Based on the density information, the area of the defects can be identified.

4. Other PCB Defect Detection Approaches

4.1. SPI Using Multi-Frequency Moiré technique
Stansfield (2014) [5] discussed the SPI machine that measures the values of the solder paste deposition by using a dual projection technology, where by two projection light is shone on the solder paste and a camera sits directly on top. A technique known as Multi-Frequency Moiré technique is used in providing a 3D image acquisition with a true and easy to use production tool. This technique is a method where a single or multiple projector are used to project a shifting pattern of lines on a given region of interest to which a digital camera captures the image of deformed lines as it shifted across the solder paste deposits’ surface [5]. Then, after applying phase shift analysis and unwrapping techniques, the 3D profile of the solder paste surface is reconstructed and measured.
4.2. SPI Using Machine Vision

An integrated inspection approach based on the machine vision was presented in Shenglin, Xianmin, & Yongcong (2008) [7]. The method developed can identify the major defects of the solder paste depositing, such as displacement, deficiency, excess, bridge and reflow. Firstly, position compensation is applied to improve the section accuracy. Secondly, an image enhancement algorithm based on the texture is developed, which can enlarge the difference of the grayscale values between the PCB images and the solder paste images. This makes the multi-threshold method more stable and precise. Thirdly, the images of the printed PCB are analyzed by using the particle analysis method and the two-dimensional 2D inspection results are obtained. A pseudo three-dimensional 3D inspection approach is further proposed to identify the defects in the 3D state. The 2D and pseudo 3D inspection approach can be used to inspect the solder paste depositing defects effectively.

Jiang, Cheng, & Tao (2012) [8] proposed a new defect detection scheme for solder paste based on learning the colour biological feature sub-manifold. The biologically inspired colour feature (BICF) is applied to represent the solder paste images and introduced a sub manifold learning method to extract the intrinsic low-dimensional BICF manifold embedded in an extrinsic high-dimensional ambient space. This scheme mimics the function of human visual cortex in recognition tasks and can separate poor quality solder pastes from good quality ones.

Wu and Chen (2011) introduced image-array-based automatic optical inspection system captures multiple images of the inspected printed circuit board through synchronous exposure [10]. Therefore, a correct mosaic of images is very import to subsequent solder paste inspection. However, design error of the mechanism always leads to geometric errors in the image such as translation, rotation and scaling distortion. These errors make severe displacements in the image. To solve such problems, a concise and rapid error correction algorithm is proposed base on multiple point interpolation. Experiments show that the algorithm can assure rapid and correct mosaic of images of the whole printed circuit board [10].

4.3. Solder Joint Detection by Using X-Ray Imaging

(Kong, Su, & Scale, 2005) deals with the detection of defects at BGA solder joints in PC boards by using the X-ray imaging. It is possible to detect defects of solder joints by visual inspection, but only by utilizing X-ray method could inspect all BGA joints within the area array because they are hidden under the IC package. In traditional production, the inspection of BGA depends on the fiction test of electric circuits or boundary lighted inspection. Now with the employment of X-ray in solder joints inspection, it becomes very important about the detecting algorithm based on X-ray imaging (Kong, Su, & Scale, 2005). This paper discusses the flow of detecting defects based on the X-ray imaging and describes an approach to automatic inspection of BGA solder joint defects by using seed filling and contour extracting. Experimental result reveal that the proposed method shows practical usefulness in BGA solder joints inspection.

5. Conclusion

In this paper, we have presented, in detail, a current approaches of PCB defect detection. Foecussing on the machine learning approaches, we have discussed several techniques of PCB defect detection by using machine learning techniques. Our review shows that deep learning, random forests, neural networks, and probabilistic approaches have been applied for PCB defect detection with automatic optical inspection. Although the methods have shown good result for PCB defect detection, it is desirable to apply machine learning in forecasting the potential of future PCB defect before the solder printing takes place.

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