An Automatic Optical Inspection System for the Diagnosis of Printed Circuits Based on Neural Networks

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Abstract. This work aims to define a procedure to develop diagnostic systems for **P**rinted **C**ircuit **B**oards (PCB) based on **A**utomated **O**ptical **I**nspection (AOI) with low cost and easy adaptability to different features. A complete system to detect mounting defects in the circuits is presented in this paper. A low-cost image acquisition system with high accuracy has been designed to fit this application. Afterward, the resulting images are processed using the **W**a**V**elet **T**ransform (WVT) and Neural Networks, for low computational cost and acceptable precision. The wavelet space represents a compact support for efficient feature extraction with the localization property. The proposed solution is demonstrated on several defects in different kind of circuits.

1 Introduction

In automatic industrial inspection of PCBs we can distinguish two important classes: electrical/contact methods and nonelectrical/ non-contact methods. Contact methods are characterized by a high cost, low speed and the fact that they can not detect non electrical defects, such as line-width or spacing reductions. On the other hand non-contact methods can improve the diagnostic capabilities in terms of speed and tasks. AOI plays a very important role in the automatic production process of PCBs. Advances in computers, image processing, pattern recognition and Artificial Intelligence have led to better and cheaper equipment for industrial visual inspection in the electronics industry, especially in **S**urface **M**ounting **T**echnology (SMT). Traditionally, PCB visual inspection is executed by the human operator, but the diagnosis is slow and a constant performance can not be guaranteed. Several authors [7, 6, 4] proposed the AOI approach, using different decision makers, such as Fuzzy Systems, Neural Networks or Expert System. Sometimes these AOI systems are either time consuming or they need complicated illumination sources, such as several lasers, a sophisticated lighting design [5], or many CCD cameras, making the acquisition of good images extremely complicated. The approach presented in this paper is particularly simple and cheap. In fact, it only needs one CCD camera, and the PCB does not even have to be placed onto a precision X-Y table. In this way the PCB can be located on an automatic conveyor line. The diagnostic system can be trained by a non expert operator. The system performs the diagnosis on the basis of a database of images of components and defects. The operator loads such images using a graphical procedure, and then the system automatically trains a neural network to recognize such images. The input data for the training, are the WVT coefficents. Indeed, WVT [2] has the advantage of decomposing an image into different contributions in several frequency bands and at different scales. Thus, the information of interest can be efficiently accessed in one of those contributions, that is the compact space.

2 The Diagnosis Approach

The diagnostic process works as a pattern recognition system where the patterns are the images of the components. Typically, a pattern recognition system is made up of three modules: a *transducer* which acquires the data on a physical device; a *feature extractor*, which reduces the amount of data and computes some features or properties; a *classifier*, which makes the final decision on the state of the device. In our AOI system the physical device is a PCB, the transducer is a CCD camera, and the classifier is a neural network. The purpose of the diagnostic system is to automatically detect a set of defects, which can be recognized by visual inspection. The architecture of the proposed diagnostic system is shown in Figure 1. The system consists of two procedures, one to train the diagnostic system, the other to test the circuit.

Training procedure: A set of neural networks are trained to diagnose all the possible components. Each neural network is trained using a set of patterns, corresponding to the defects to be diagnosed on the corresponding component.

Testing procedure: Given a board to diagnose, we acquire a circuit image with a CCD camera. This image is pre-processed to extract the significant features, and then used as an input to the set of neural networks previously trained to recognize the defects on that circuit. The outputs of the neural networks are the diagnosis of the system. The method used to create the training-set allows to set the diagnostic system before implementing the productive line. This is very useful, because it reduces the cost of the diagnosis and allows us to start the production line and the diagnostic system simultaneously.

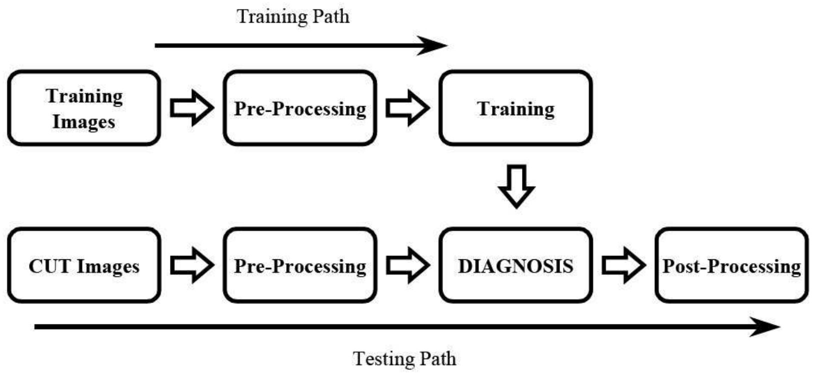

Fig. 1. Architecture of the proposed diagnostic system.

3 The Methodology

The described logical architecture has been implemented in a prototype, whose in Figure 2 the modular diagram and a picture are shown. In the following, the main parts of the system are described.

3.1 Image Acquisition System

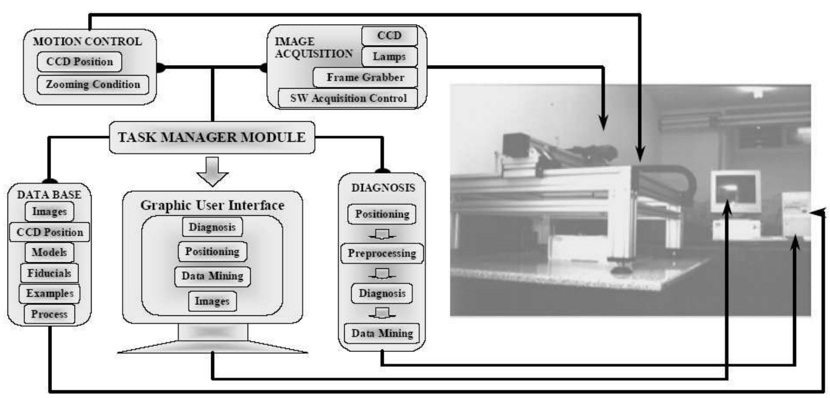

Fig. 2. The diagnostic system.

An X-Y positioning system supervises all the displacements of the CCD camera, while the dimension of the framed region by modifying lens zooming.

It is chosen to move the CCD rather than the board in order to obtain a faster and more flexible system, independent of the production line. In this way the AOI is very useful not only in the electronic industry but also in a wide range of applications. In order to control the illumination conditions, the acquisition system is covered with black screens, that avoids external light sources. The circuit under test is illuminated using commercial fluorescence lamps.

3.2 The Database

A database supports all the tasks the diagnostic system does. Such database, developed in SQL language, represents the knowledge of the system. A set of procedures permits to update the database, whether directly using a graphical interface or automatically, in the meantime the system is working. The main type of data stored in the database consists of images. Given the layout of a new circuit to test, an image without defect (Golden board) is built by assembling images of the components stored in the databank. The golden image has no application in the diagnosis process, but it is used as reference image by the operator. The databank stores the images of the components and the images of all the defects to detect. As for the golden board, it is possible to obtain an image of the faulty component, simply by superposing the defect image to the images without defects stored in the database. This procedure is totally automatic. The operators' job is simply to fix the defect set which the system must diagnose, therefore he only needs information about the process but not about the diagnostic system. The layouts of the circuits that have been produced in the farm are stored in the database. Each of them has a record, with all the data concerning the production, making them available for successive statistical analysis. Finally, the operators which work on the diagnostic system are also cataloged, with the corresponding grants and password, in order to avoid the knowledge of the system be corrupted cause of inadequate stills of the operator.

3.3 The Procedure

A number of procedures have been implemented in the system for the management of the tasks. The procedures performed by the diagnostic system have been developed in LabView^{TM} environment. The procedures executed with the operator are managed by means of a **G**raphical **U**ser **I**nterface (GUI), implemented in the same environment. In the following the main procedures are briefly described.

Template matching to individuate the fiducial points in the CUT. Thanks to this procedure the CCD camera can move on the reference point in the CUT, and from there it can move in sequence over each component, on the basis of the positions schedule.

Template matching to frame as precisely as possible each component and to correct the offset due to the mounting tolerance. Therefore, the CCD acquires an area larger than the component and then the reference image of the component is used as template in such area.

Feature extraction to reduce the amount of data and select the meaningful information for the diagnosis. To this purpose different procedures have been tested, obtaining with the Wavelets transforms the best results [3], in term of both data reduction and kept information.

Training of the neural networks. A **M**ulti **L**ayer **P**erceptron (MLP) [1] neural network is trained each time a new component is added to the database or new defects are considered for a component already stored. The training set is generated by retrieving the images of the components and of the defects from the database and by combining them to obtain the images of all the defects to diagnose. The collection of images is then pre-processed to extract the features and the neural network is trained. This procedure is entirely automatic. The operators job is to select the component and the defects from a list retrieved by the database.

Diagnosis of the CUT. The diagnosis procedure consists on a series of sub-procedures that terminate recalling the neural networks associated to the components. A report sheet summarizes the result of the diagnosis. Some ancillary procedures allow the operators to run the system only throughout the GUI.

4 The Experimental Results

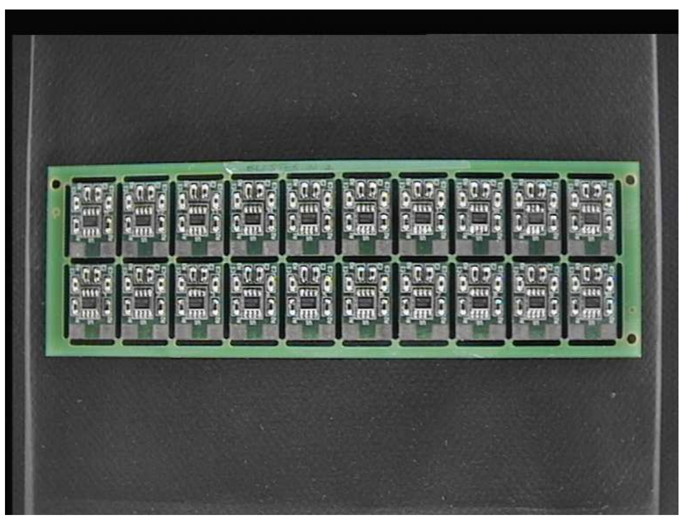

Fig. 3. Example of a sequence of PCBs

Figure 3 represents a sequence of PCBs production. Two shot views of PCB 11 and PCB 19 are depicted on Figure 4. Those images are taken by the moving

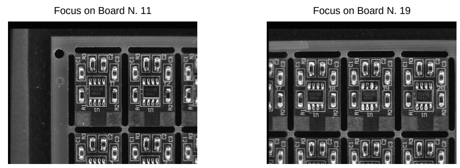

Fig. 4. A shot view of the CCD camera moving to the board 11 (Left: No defect), and to the board 19 (Right: with Defect at the right solder joins of the chip)

camera while inspecting the individual PCBs. It is clearly noticed the defect on PCB 19 such that the solder joins are missing on the two right pins of the mounted chip. On the other hand, PCB 11 seems to be defect-free. Figure 5 presents the Fourier representation of PCB 11 shot view while its wavelet representation for one scale is shown on Figure 6. The Mallat method [2] has been used for the wavelet decomposition. It is noticed the reduced and localized information on 3 different bands for the WVT case than the one with Fourier. This reduction consists of the compact representation of edges at dedicated space. Indeed, edges in images are the important features required for the processing.

The first test is related to the component showed in Figure 3 with the Golden board image in the wavelet space. The training set consists of nine configurations corresponding to the case without defects (Golden boards), and eight cases where one of the solder joints is faulty. The images are obtained by overlapping a defective solder joint image with the image of the component without defects. In this way we can build the training set automatically, without the real images of every defect we want to consider. It is important to ensure repeatability of the acquisition process, otherwise uncertainty due to acquisition can hide a defect we are looking for. We obtained a correct classification of the examined cases. To improve the robustness of the neural network, we extended the training set including patterns obtained from the original ones, by adding numerical noise.

The second test regarded the problem of absence of components. In the example shown in Figure 7, the training set consists of eight configurations relating to the case with all the components and seven cases where a component is absent. To obtain the images of the defective circuits we overlapped the component to be made absent with an area having the same color as the background. Once again the neural network gave a correct classification of the cases considered on the validation set, provided that the training set includes the noise patterns as described above.

5 Conclusions

In this paper, an AOI system neural network for the diagnosis of PCB has been presented. The neural network approach affords diagnostic systems that are very

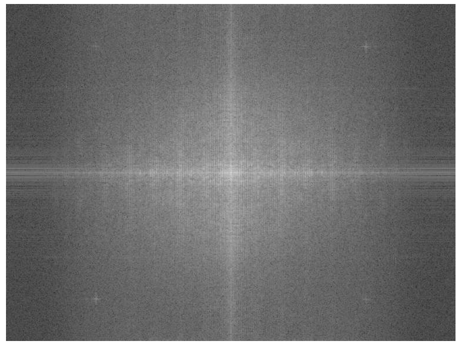

Fig. 5. Fourier representation of shot view of the board 11

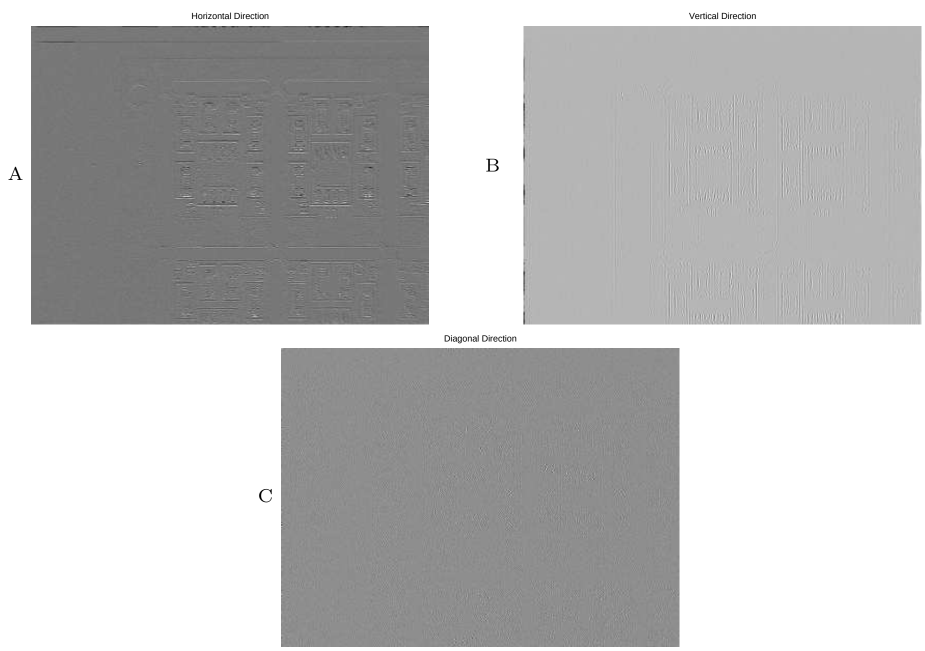

Fig. 6. One scale wavelet representation of shot view of the board 11, at three directions A. horizontal, B. vertical and C. diagonal

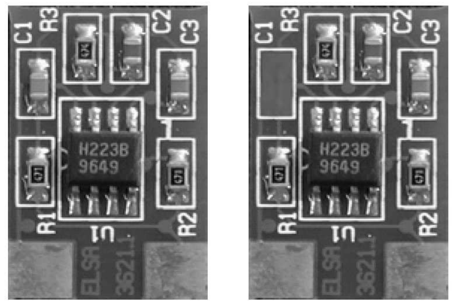

Fig. 7. Images for the test of component absence

easy to handle in the set up and diagnostic phases. The training and test data for the neural network are obtained using the wavelet analysis, which provides a compact and localized representation of information of interest in images. The promising results obtained with a low cost prototype point out the robustness of the system and the methods effectiveness.

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