Fast retrievals of test-pad coordinates from photo images of printed circuit boards

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***Abstract*—This paper presents a data analytics approach for recovering test-pad information from images of printed circuit boards. The main aim is to obtain highly accurate information as input to a robotic flying probe tester. Such a tester is a mechatronic system that is able to perform a great variety of diagnostic testing on printed circuit boards without any additional circuit board documentation. In this work, a two-stage clustering process was applied on a dataset with 71040 pixel records obtained from an electronic circuit board image. In total, the method discovered 128 locations on the circuit board that are potentially the test pads. Visual inspection found that all the 120 legitimate test pads on the circuit board were retrieved. The other eight locations were not really test pads and were removed (i.e., Recall = 100%, and Precision = 93.25%). We propose this image analytics approach as an effective way to speed up the recovery of test-pad locations from printed circuit boards.**

Keywords*—*data mining; clustering; image analysis; flying probe tester; reverse engineering; printed circuit board.

I. INTRODUCTION

The advent of data and analytics technologies gives rise to new opportunities of their applications to tackle problems that are challenging or tedious to solve. This paper presents a novel application of image analytics in the reverse engineering of electronic circuit board information.

Recovering important circuit board information is particularly useful when the technical information needed to solve a problem at hand is not readily available. For example, reverse engineering a printed circuit board (PCB) to recover the schematic drawing could be useful for repairing equipment when the board-level documentation is not available [6].

The lack of technical information is a common problem in organizations that rely heavily on legacy industrial or military systems to fulfill their operational needs. Such systems are usually being deployed for several decades; and over time, the maintenance of such systems do become increasingly difficult and challenging. Some common issues include the lack of high priority maintenance support from the supplier, or even discontinuation of support due to obsolescence. Other issues include incomplete or missing technical information, and parts obsolescence. Of these issues, the lack of circuit-board-level information could impede the repair process for printed circuit boards used in such systems.

In this paper, we demonstrate the use of clustering techniques to speed up the recovery of test pad location information from the image of a printed electronics circuit board. Although this type of information appears to be fairly basic, it is key to guiding a robotic flying probe tester [2] to perform a great variety of automatic tests on an electronics circuit board. The robotic flying probe tester is a mechatronic system made up of (at least) two robotic arms, each mounted with a test probe, and are capable of moving to any test pad and performing electronics test and measurements. As a result, it is possible to perform automated testing and diagnosis of printed electronic circuit boards even without any circuit board documentation (e.g., a schematic diagram). This makes the approach particularly appealing in situations where little or no documentation is available to aid the testing and repair of a circuit board—a common issue faced by organizations using legacy systems.

One example of tests that a flying probe tester is able to perform is the connectivity test. A flying probe tester can be programmed to move its robotic probes to access all possible pairs of test pads on a circuit that is *known to be good*, and *record* all the connectivity test results (i.e., either open or short circuits) between every possible pair of test pads. This set of test results can be saved as a reference. Subsequently, a technician could test a faulty circuit board by performing the same set of automatic measurements. If any of these measurements deviates from the corresponding measurement recorded from the known good board, it will be reported to the technician. Based on the locations of the test pads involved in the test, further analysis and diagnostic steps can then be taken. Apart from connectivity tests, other possible tests include passive component (e.g., resistors and capacitors) testing, impedance testing, voltage-and-current signature testing, etc.

In this paper, we apply cluster analysis on the photo image data of a printed circuit board in order to recover all test pad locations on the board. While the method also identifies some additional points that are not really test pads, these erroneous points can easily be identified and removed.

The rest of this paper is organized as follows. Section 2 discusses related work. Section 3 presents the circuit board image data and explains how the board image is analyzed. Section 4 presents and evaluate the results, and Section 5 concludes this paper.

II. RELATED WORK

The reverse engineering of printed circuit boards (PCBs) has been of interest to engineers and researchers working in the area of maintaining legacy or obsolete systems that are still in use to fulfill organizational objectives [e.g., see 1, 5, 8].

There are basically two approaches to PCB reverse engineering, namely the destructive approach and the non-descrtuctive approach. The destructive approach (e.g., [3]) usually involves the removal of solder mask, delayering, and so on. This approach is usually required when there is a need to recover as much information as possible from a printed circuit board. For example, if the aim is to recover all the design details of an entire circuit board, it is usually necessary to break the physical circuit board down into various individual components in order to gain a full understanding of the design.

On the other hand, the non-destructive approach involves recovering circuit board information without causing any actual damage to the physical circuit board. For example, some previous work [6] have shown that one can recover a netlist from the photo image of a printed circuit board. The use of image analysis is not only useful at the PCB level, but also at the micro-chip level [10].

The above discussions about reverse engineering boils down to two inter-related factors for considerations. The first factor is the amount of the information to be recovered from the reverse engineering process. This can be as simple as only recovering only certain features of a circuit board (such as the schematic diagram only, where a netlist suffices), or as complex as recovering the full design details of an entire circuit board, which would require more information (such as PCB layout, track design, and component information, etc.) to be recovered.

The second factor is whether to adopt a destructive or non-destructive reverse engineering approach. When attempting to recover circuit board information, the non-destructive approach should always be considered first because it does not cause damage to the circuit board. The destructive approach should only be adopted after careful considerations of the constraints, benefits and costs required to complete the reverse engineering task.

In this paper, we are only interested in the location of the test pads on the circuit board, and this information can be recovered by applying cluster analysis on the circuit board image. Hence, the approach used here is non-destructive. Although the type of the information to be recovered (i.e, test pad location) is simple, the challenge here is to achieve a high level of precision and recall in the retrieval task so as to minimize corrective actions due to any errors.

III. DATA AND METHOD

A. PCB Data

We obtain the photo image of a printed circuit board (PCB) with permission from an image owner. Using a simple Java program, the location and the color attributes of each pixel of the PCB digital image are extracted into a numerical dataset. In particular, the key variables of this dataset are X, Y, R, G and B. Here, X and Y represent the position of the individual pixel on the horizontal axis and vertical axis, respectively. While R, G and B values represent the Red, Green and Blue attributes of a color pixel. Each of RGB attributes has a range of [0, 255], where a higher value means a higher intensity of the colour component in the pixel.

Each row of entries in the dataset therefore represents one pixel within the digital image. Since there are 71040 pixels in the circuit board image, there are 71040 records.

Figure 1 shows a sub-image cropped from of the original PCB image, which shows that the board has many grey circular dots that represent test pads. The aim of this project is to recover the location of these test pads.

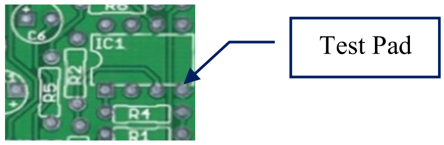

Fig. 1. Digital image of a small part of the PCB used to generate the dataset.

B. A Two-Stage Clustering Appraoch

We use a two-stage clustering approach to retrieve the test pad locations. The first stage is to group the pixels into clusters of similar colours. The idea is to find the clusters that contain grey pixels, which represent the colour of test-pads on the PCB.

Once the grey pixels are found, they serve as inputs to the second stage of the clustering process. This time, the grey pixels are clustered according to their locations on the circuit board, and the idea is to assign each grey pixel to a unique test-pad cluster.

The following gives a more detailed description of the two-stage clustering process.

Stage 1: Identifying Grey Clusters

The first stage is to cluster pixel records based on the R, G and B attributes. For the given circuit board, the obvious colours on the PCB image include different intensities of Green, White, Black and Grey. We estimate the number of clusters to be around 10 to 12.

Based on the number of clusters estimated, we use the K-Means [7] clustering method to generate three clustering solutions, namely the 10-, 11- and 12-cluster solutions. Here, we are interested in clusters that contain grey pixels because such pixels form the test-pads on the PCB. Using the common knowledge that grey pixels of different shades generally have $R \approx G \approx B$ [4], it is observed that the 12-cluster solution consists of two clusters with colors being the closest to grey. In this solution, the first grey cluster has average RGB values of R=131, G=147, B=153, and the second grey cluster has R=93, G=113, B=115.

To verify the validity of the above grey-pixel clusters, we make a scatter plot of the grey pixel records in these two clusters using their X and Y coordinates. Figure 2 shows that most of the points are quite similar to the test pad layout on the actual circuit board.

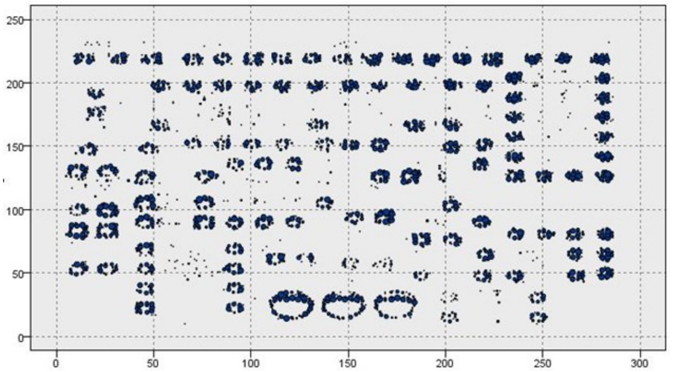

Fig. 2. A scatter plot of the two grey-pixel clusters identfied in Stage 1 of the clustering process.

Stage 2: Identifying Test Pad Location Clusters

The second stage is to cluster the *grey pixel records* based on their X and Y location attributes. For the given circuit board, the number of legitimate test pads is 120. In addition, Figure 2 shows that there are approximately 50 sporadic grey pixels on the circuit board that are not really test pads. We need to take this into account when determining the number of clusters, as the sporadic grey pixels are some form of noise that we do not want to include in any test pad clusters.

To address the issue of noisy sporadic pixels, we allow the generation of additional clusters to store these sporadic pixels so that they do not get included in any legitimate test-pad clusters and thus do not distort the final clustering result. Here, we set the number of clusters to be 170, and we use the K-Means and the Two-Step [9] clustering methods. When the clustering solutions are generated, all the small clusters with 10 pixels or less are excluded and the *centroid* of each cluster represents a test pad location.

Based on the results generated, we find that Two-step clustering produces a better output as it contains fewer non-test-pad clusters compared to the output generated by K-Means. We believe this is due to the pre-clustering step of Two-step method, which would have 'captured' the sporadic pixels and contained them in some smaller clusters, and these smaller clusters never get agglomerated into bigger clusters in the second step. Unlike Two-step, K-Means could use some of the sporadic pixels as cluster centroids right from the start of the clustering process; thus it is more likely to mistake some of these sporadic pixels as test pad clusters.

IV. RESULTS

To illustrate the accuracy of the Two-step output, Figure 3 shows an overlay of the final output on the PCB image. It can be seen that almost all the 120 test pads have been correct identified.

However, if we examine the plot carefully, we will identify a few errors made by the Two-step clustering method. These errors are highlighted in Figure 4, which indicates five points that are not actually the locations of any legitimate test pads. In addition, there are three duplicate test pads generated in three of the biggest test pads. Since these points are not useful, they can be removed from the output.

In summary, the two-stage clustering method manages to recover all the 120 test pad locations on the circuit board (i.e., recall = 100%), however, it also returns eight irrelevant points, hence the precision is 93.75% (i.e., 120/128). We have also shown that the remaining 6.25% errors can be easily removed through visual inspection.

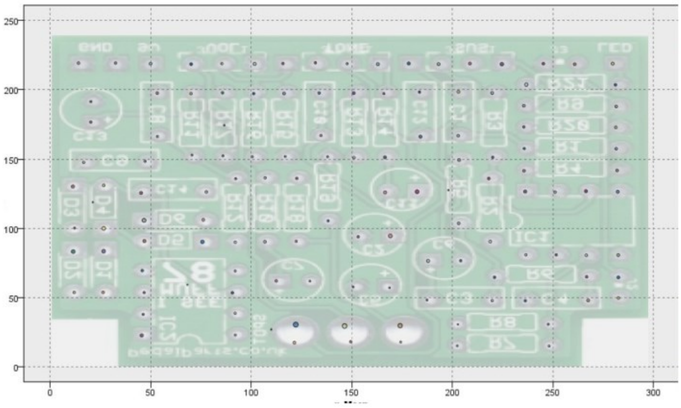

Fig. 3. The Two-step clustering output overlaid on the PCB image. The centroid of each test pad cluster is represented as a dot.

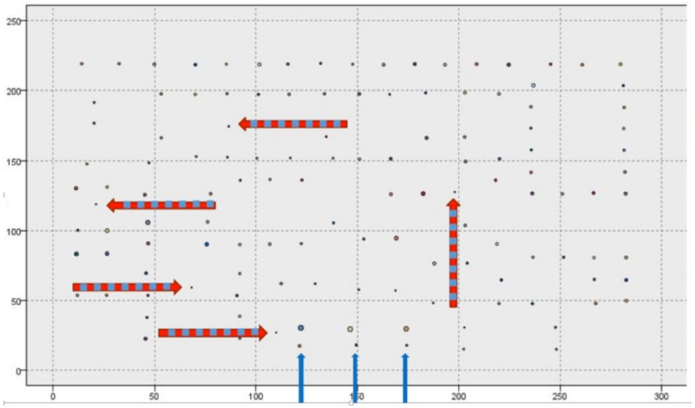

Fig. 4. Erroreous test pads: Five non-test-pads are shown by the thick dotted arrows; and three duplicate test pads are shown by the thin solid arrows.

V. CONCLUDING REMARKS

We have demonstrated that the use of data analytics could help service and maintenance engineers to recover important test pad location information from printed circuit boards. Although this type of information can also be obtained manually, it is prone to human errors as it relies on a human operator to locate each test pad. Moreover, the manual process of recovering test pad locations is tedious and time consuming.

The two-stage cluster analysis approach presented in this paper has been shown to be an effective and efficient way to speed up test pad retrieval process with good accuracy. The test pad location information can then be used as the key input to a robotic flying probe tester, which is able to perform a range of automatic testing and diagnostic of circuit boards used in long-living legacy systems.

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