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COMPUTER VISION SYSTEM FOR PRINTED CIRCUIT BOARD INSPECTION

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Abstract. *In this paper we present a Computer Vision system for printed circuit board (PCB) automated inspection. In the last years PCB industry has been invested in manufacturing automation improvement. This is known, especially in measurement and inspection field. We can note that the tolerances on PCB assembly become more accurate. With computer hardware and cameras advances, new Computer Vision algorithms should be developed, and applied in industry with low cost. Besides, new visual inspection systems using computers should be implemented to solve smaller tolerance requirements. A PCB consists in a circuit and electronic components assembled in a surface. There are three main process involved in its manufacture, where the inspection is necessary. The main process consists in the printing itself. Another important procedure is the components placement over the PCB surface. And the third is the components soldering. In the proposed Computer Vision PCB Inspection System we consider the first manufacturing stage, i.e., the board printing. We first compare a PCB standard image with a PCB image, using a simple subtraction algorithm that can highlight the main problem-regions. Then we used connection analysis to find fatal and potential errors, like breaks and circuit shorts. In other to develop this methodology in real PCB, we propose to magnify the problem-regions and start to find the errors in a set of PCB sections, which are smaller than the main PCB image. This approach seems to be very effective if applied in a real time inspection system. Therefore, we propose a new algorithm to solve PCB inspection problem, considering its efficiency in reducing the computational time.*

Keywords*: printed circuit board, inspection, computer vision, metrology.*

1. INTRODUCTION

Visual inspection processes automation has become essential to improve quality in printed circuit board (PCB) manufacture. Industry requires automated inspection since, in the manufacturing processes, there are uncertainties, tolerances, defects, relative position and orientation errors, which can be analyzed by vision sensing and computer algorithms. Hence, Computer Vision measurement techniques present regularity, accuracy and repeatability in non-contact measurements and inspections. Those systems differ to the subjectivity, fatigue, slowness and high cost associated to human inspection (Leta *et al.*, 2005). During the last years, in PCB industry there were many factors that encouraged automation. The most important one consists of the technological advances in PCB's design and manufacture. This occurs because of the fast board functionality innovations. New electronic technologies need new PCB designs, with smaller dimensions, new components and new functionalities. This tendency is generate new challenges and principally it is causing some difficulties to human visual inspection. The necessity of reduce the spent time to produce a PCB is another important reason that forces the automation. Nowadays the machines used in the manufacture process have high productivity; hence it is not possible to spend much time using employees to detect board fails.

In this context, here we will not evaluate the PCB design and its utilities. We are interesting in developing a computer vision inspection algorithm applied to bare printed circuit boards, i.e. boards without components. In the literature we can find a large number of PCB inspection techniques applied to bare PCB (Oguz and Onura, 1991) (Moganti and Ercal, 1998a) (Moganti and Ercal, 1998b) (Sasai, M. *et al.*, 2000) (Roh *et al.*, 2003) (Mashohor *et al.*, 2004) (Tsai and Yang, 2005) (Greenberg *et al.*, 2006). Generally, there are three main approaches: referential, non-referential and hybrid. The referential techniques perform a PCB comparison with a standard image, stored in an image database. Any pertinent difference between the model and the inspected board is reported. The non-referential methods verify the board based on the design specification data. In this case, each printed board is analyzed, according to the available artwork data. And finally, the hybrid systems use referential and non-referential techniques to analyze PCB (Moganti *et al.*, 1996).

Currently, whatever the method chosen, it should detect potential and fatal errors in the printed circuit board. Nowadays, these errors are important, because PCB layouts have their printed parts density augmented, with smaller tolerances and distance decrease between electrical contacts. Consequently, as a consequence of this complexity increase, the possibility of manufacture defects has also magnified. The inspection process should detect errors before they cause board failure. The inspection tasks on PCB production lines involve visual inspection and functional tests. There are many possible failure causes, like: component misalignment, open or partial open metal lines, bad solder joints, scratches or cracks, shorts, over etching, under etching, excess or residual metal, etc.

In this work, visual inspection techniques feasible to be applied on industry are presented and developed; these techniques are based on methods which aim is to bring improvement in printed circuit boards (PCB) production, principally concerning the acceptance or rejection of the bare-boards. Computer Vision techniques were used to develop an automatic visual inspection of bare-boards, which intends to evaluate the conductors and pads' conformity. The fault detection strategy refers to the use of referential inspection methods, in which the reference is a board artwork or a manufactured board without errors. The PCB defects are normally grouped in two categories, the fatal defects and potential defects. The system identifies the potential defects using an image comparison technique, subtracting the reference board image from the tested board image. To identify the fatal defects the system uses a connectivity approach, it finds any type of error like: scratches, breaks, bridges, under etching or over etching, which blocks the passage of electricity or make a short circuit. The results, obtained by the developed approach, are possible to be applied in automated industrial systems with some improvements.

2. PCB ERRORS

There are many different errors in printed circuit boards. Thibadeau (1985) presents a review about the PCB errors and their causes. He highlights some of them, like: possible distance variations between the printed lines, line thickness dissimilarities, false alarms because of dirty atmosphere, etc. Spitz (1987), Benhabib *et al.* (1990) and Jones (1985) show that partial or total line breaks, small holes, over printed or under printed lines are the most frequent defects in PCB manufacture. Those faults are attributed to: uncorrected position, thermal expansion, dirty, board distortions, etc. On the other hand, not all of these defects implies in a PCB rejection.

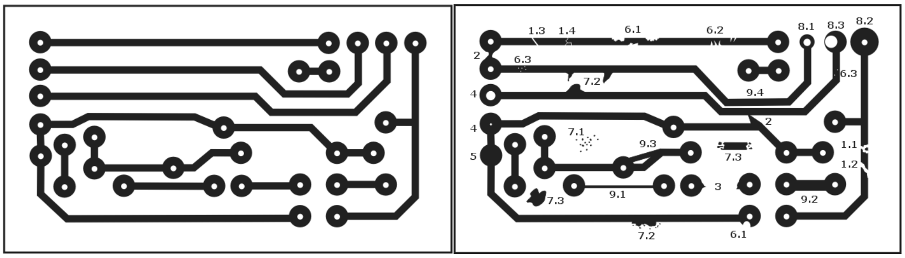
Although the PCB industry has implemented advances, nowadays the same kind of errors continues to exist, and it is still developing inspection solving. Greenberg et al. (2006), for instance, proposed a U.S.A. patent of an inspection system using a computerized design software database. The inspection system patented senses the coordinates and geometry of the features and compares the sensed information to that of the database. In this method, the system detects which PCB is acceptable and which have flaws considering the detected defects.

Bare PCB errors can be classified in two main categories: fatal and potential. Fatal errors are those in which the printed circuit boards don't perform the function they were designed for. Potential defects are those that may cause an error during PCB utilization.

There are many ways to designate PCB errors. Table 1 shows a compendium of all studied references approaches. Figure 1 illustrates the meaning of each classified error.

Table 1. PCB errors classification

FATAL	1 Breaks	1.1 Fracture
		1.2 Cut
		1.3 Scratches
		1.4 Cracks
	2 Shorts/bridges	
	3 Missing conductor	
	4 Incorrect hole dimension	
	5 Missing hole	
POTENTIAL	6 Partial Open	6.1 Mouse bit
		6.2 Nicks
		6.3 Pinholes
	7 Excessive spurious	7.1 Specks
		7.2 Spurs/protrusions
		7.3 Smears
	8 Pad violations	8.1 Under etching
		8.2 Over etching
		8.3 Breakout
	9 Variations between the printed lines	9.1 Small thickness wiring
		9.2 Large conductors
		9.3 Excessive conductors
		9.4 Incipient short (conductor too close)



(a) (b)

Figure 1. PCB schema without errors (a). PCB schema with errors (b).

3. PCB INSPECTION SYSTEM

The Computer Vision system for PCB inspection developed consists in an automatic inspection that identifies potential and fatal errors in bare-boards. The system is organized into two main modules; the first one is the calibration module and the second one is the test module. In the calibration module an ideal PCB (identified as standard PCB) is acquired and its characteristics are saved in a database. The obtained standard image and its characteristics are used in the first system stage, which compares the inspected image with the standard one. In this point it is important that the image should be in the same position of the standard PCB (aligned). Whatever position disparity it will imply in a false error detection. More details about the board alignment including image-sampling problem can be found in Feliciano (2007). The test module is divided in two steps; the first one identifies potential errors and consists in a simple image subtraction operation. The second stage recognizes the fatal errors based on Tatibana and Lotufo (1997) algorithm. We note that the idea of connectivity proposed is feasible to pictorial images, but when used to real boards many difficulties appear. For that reason, we implemented some innovations and applied the methodology to real printed circuit boards. The techniques used to identify potential and fatal errors are considered referential type. In Fig. 2 there is a schema of the system.

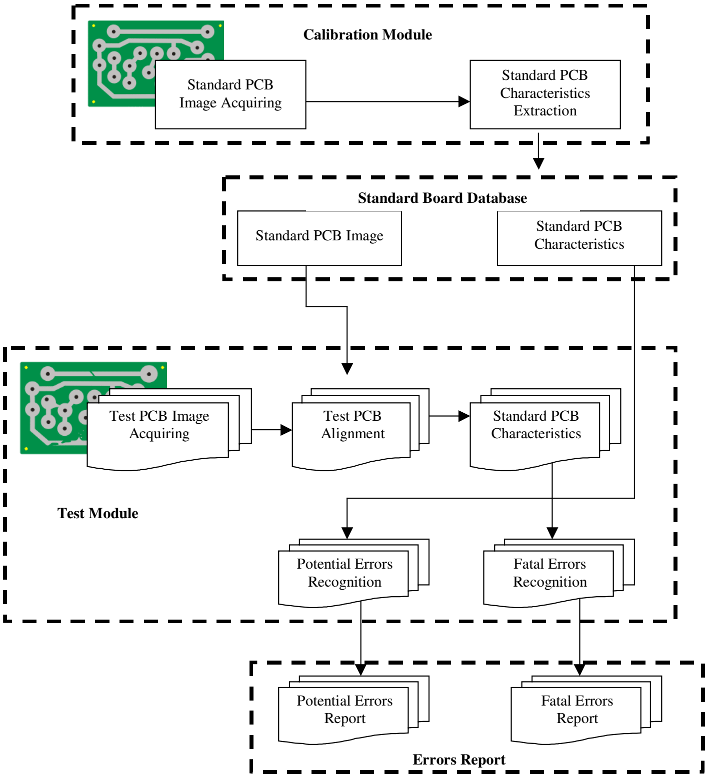
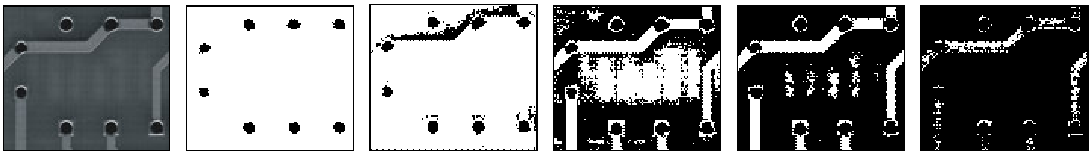


Figure 2. PCB Inspection System.

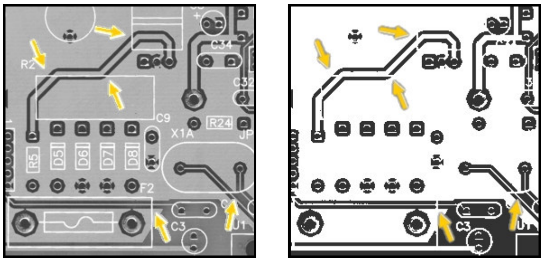
The standard and the inspected image are transformed into binary images. Although this represents an ordinary process, if it is not well applied, it can affect the final result. Due to non-uniform illumination conditions, it is impossible to distinguish the conductors from the background. Therefore, the system must be adjusted to the acquiring conditions and to the board category. The main problem consists in choose the best threshold factor. Figure 3 shows a board piece and some different thresholds. Observing Figure 3, it is understandable that this image processing should be well done to obtain good results. Göktürk et al. (1999), for instance, proposed a methodology to solve this problem, which consisted in a modified Canny edge detector and an unsupervised learning algorithm to discriminate regions on the PCB.



(a) (b) (c) (d) (e) (f)

Figure 3. (a) PCB part. Threshold value equal to: (b) 4, (c) 50, (d) 70, (e) 80 and (f) 110.

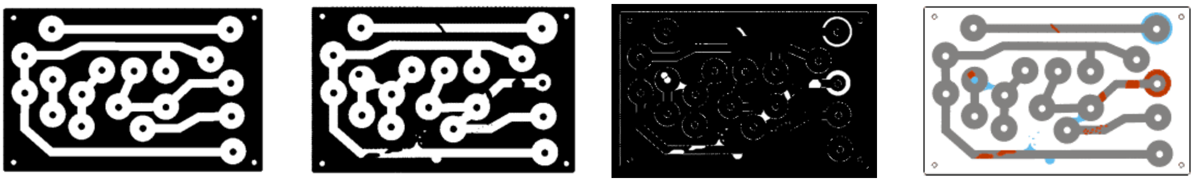
Another detected problem in pre processing stage consists in analyzing the PCB after printing information on it (Fig. 4). In this case the threshold method may cause an erroneous interpretation of conductor's breaks. Hence, it is recommended to make the inspection before this printing process.



(a) (b)

Figure 4. (a) Printed information that may cause wrong analysis. (b) Breaks highlighted after threshold.

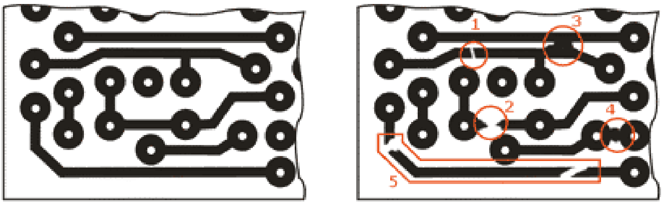
Solving these problems, the PCB image is aligned with the standard PCB (Feliciano, 2007). The potential errors identification is performed considering the differences between both images highlighted by an image subtraction operation. If the subtraction result in a pixel is positive (i.e. lack pixel), the system shows a red pixel, in the opposite case (i.e. excess pixel), a blue color will be assigned to the pixel (Figure 5). Lack pixels may indicate partial open, under etching, small thickness wiring or break. Excess pixels may cause circuit shorts. We can observe that some of these errors are fatal ones. The image can point to the system that it is necessary to make a zoom in the identified board zone to investigate if there is a break or a short circuit.



(a) (b) (c) (d)

Figure 5. (a) Standard PCB. (b) Inspected PCB. (c) Binary image. (d) Colored image.

The fatal errors are identified using a connection concept. The purpose of a PCB is connecting electronic components, allowing that the electric current flows in a correct way. In PCB there are many conductors that are connected, if this connection is broken or if there are connections that weren't printed we have fatal errors. In this paper we are interested in identify errors in bare PCB, for that reason we have studied the conductors and the holes of the printed layout. The system recognizes: breaks (1, 2), circuit shorts (3,4) and conductors without holes (5) (Fig. 1). Figure 6 presents some of these errors.



(a) (b)

Figure 6. (a) Standard PCB. (b) Inspected PCB with fatal errors.

The first step consists in identifying the conductors and the holes and creates a Connection Table. This table is compared to a Standard Connection Table, obtained in the Calibration Module. We used the same process to obtain the standard and inspected image tables.

In order to find the holes, we first threshold the image in two grayscale levels, black and white. We use a connectivity operator to take apart the white holes (Leta *et al.*, 2005) (Feliciano, 2007). The holes' central coordinates are computed and saved in a table (Fig. 7).

Comparing each hole index of the standard and inspected images, we could note that not always the same index represents the same hole in both images. In order to prevent this misinterpretation we implemented the influence maps algorithm proposed by Tatibana and Lotufo (1997), which presents good results. The influence map is based on the standard PCB image. This image is divided in different zones, according to the minimum distance between each hole central coordinates and each image pixel. The system calculates the distance of each pixel to each hole central coordinates. The minimum result corresponds to a hole and its specific zone. The intersection between the influence zones is fuzzy and it is not represented in Fig. 7.c. Considering that it is unusual that a hole lays in this position, we can use the influence zone map with success. The obtained result is showed in Fig. 7.c.

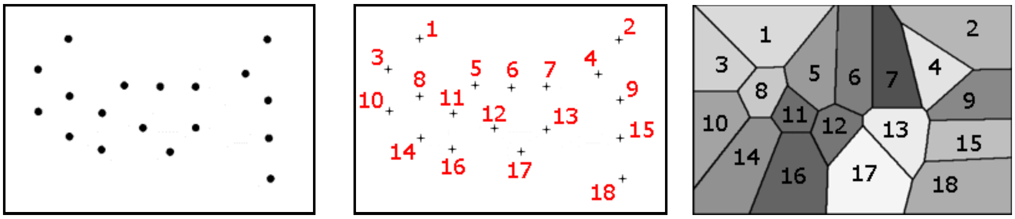
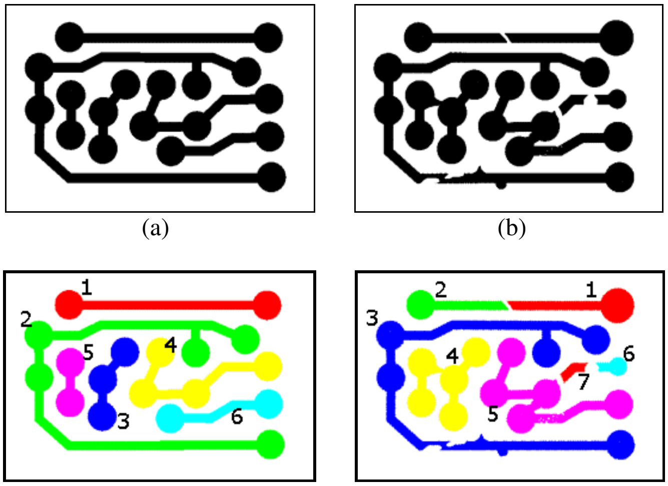


Figura 7. (a) Holes and (b) its central coordinates index (standard image). (c) Influence zone map.

To analyze the conductors, the holes are fulfilled with black color. A 4-connected operator (Leta et al., 2005) is applied to the new image, obtaining the images presented in Fig. 8.c and 8.d, which distinguish each conductor by color. If any conductor is broken the algorithm will print it in different colors (Fig. 8.d) as assigned in Tab. 2.



(a) (b) (c) (d)

Figure 8. (a) Standard image. (b) Inspected image. (c) and (d) conductors discriminated by color.

Table 2. Conductors index colors.

Index colors			
Standard Image		Inspected Image	
1	Red	1	Red
2	Green	2	Green
3	Blue	3	Blue
4	Yellow	4	Yellow
5	Pink	5	Pink
6	Cyan	6	Cyan
		7	Orange

Table 3 – Standard PCB connection.

Standard connections	
Hole Index	Conductor Index
1	1
2	1
3	2
4	2
5	3
6	4
7	2
8	5
9	4
10	2
11	3
12	4
13	4
14	5
15	6
16	3
17	6
18	2

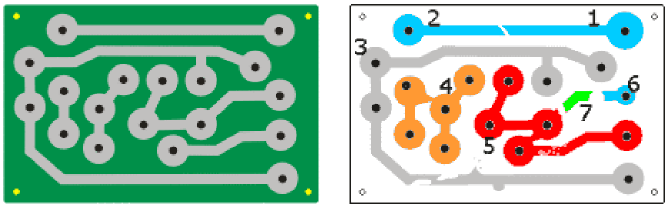
Table 4 – Inspected PCB connection.

Inspected board connections	
Hole Index	Conductor Index
1	2
2	1
3	3
4	3
5	4
6	5
7	3
8	4
9	6
10	3
11	4
13	5
12	5
14	4
15	5
16	4
17	5
18	3

We use the influence zone map to fit conductors and holes in an Inspected Board Connection Index Table, where each conductor connects two holes. If there is some break, it will be clear when comparing to the Standard Connection Index Table (Tab. 3 and 4). Table 5 shows the color code applied in the image result. The results obtained by comparison between standard and inspected board connection index tables are presented in Fig. 9. The implemented algorithm to execute the tables' comparison involves some checks and is based on Tatibana and Lotufo (1997) methodology. Figure 8 shows the result considering the color code accessible in Tab. 5.

Table 5. Color code

Color code		
Conductor	Color Value	Color
No error	0	Black
No hole association	4	Green
Break	6	Blue
Short-circuit	8	Orange
Break and short-circuit	10	Red



(a) (b)

Figure 9. (a) Standard PCB. (b) Inspected board final result.

4. APPLYNG THE SYSTEM IN A REAL PCB

A real PCB is extremely more complex than a pictographic board. It has several holes and conductors. To illustrate this, we tested the presented method in a real bare-board. Figure 10 shows the gray scale standard PCB that was used in the system calibration module. Figure 11 shows the board connections and the obtained influence zone map, both have been obtained from the proposed methodology.

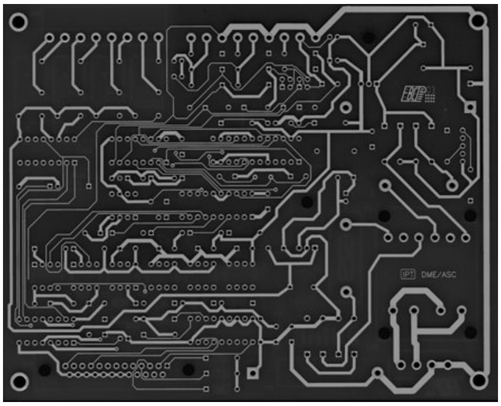
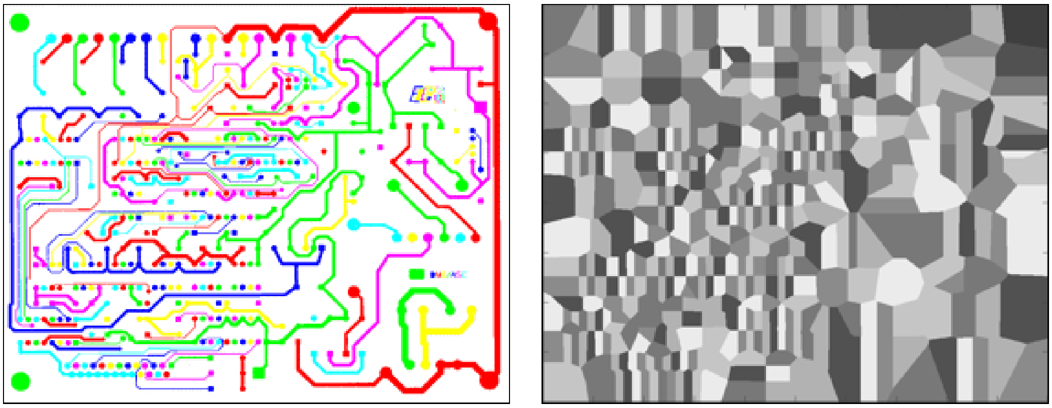


Figure 10. Standard PCB.

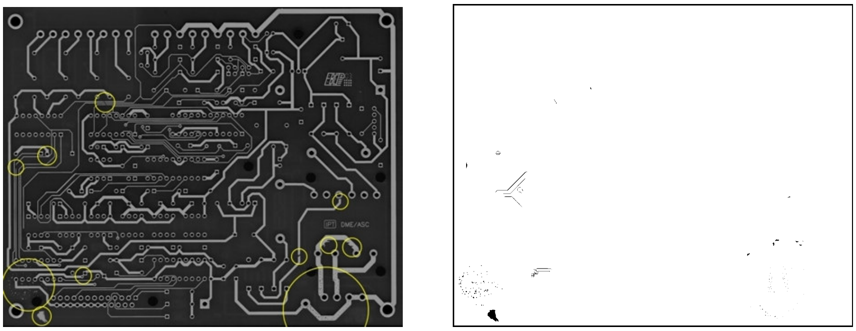


(a) (b)

Figure 11. (a) Connectivity PCB analysis. (b) Influence zone map.

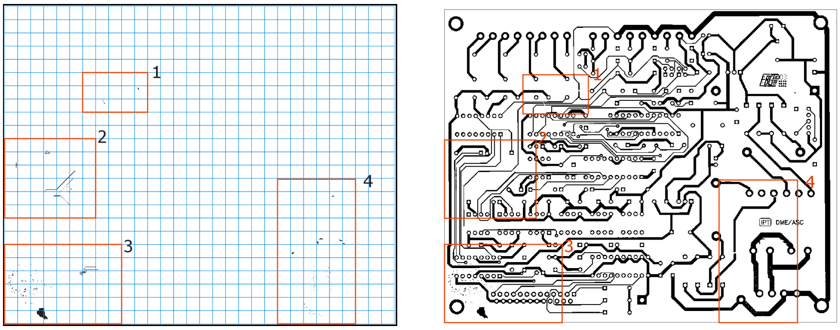
The inspected image has 1,8 Mpixel, the necessary computational time to process this image is huge if we use the presented method. If the system will be applied in industry, it is important to reduce this computational processing time, specially the time spent to obtain the influence zone map. Hence, in other to make this methodology more effective, we propose some improvements on it.

First of all, we implemented a subtraction procedure (standard board image minus tested board image). The resultant image gives information about critical board regions (Fig 12). Thus, image is divided into small areas, signed as red lines. For each small area the system identifies if there are errors (Fig. 13).



(a) (b)

Figure 12. Real PCB. (a) The circles show the region errors on the board. (b) Subtraction resultant image.



(a) (b)

Figure 13. Real PCB. (a) Subtraction resultant image divided into small areas. In red, the small areas identified. (b) Subtraction resultant image with highlighted error areas.

Areas that have any kind of error are grouped and saved in new images. Each image is considered as a new image board, and all techniques presented in item 3 are used. This approach reduces a lot the computational spent time because the algorithms are applied in smaller images than in the whole image.

The main difficulty in this approach consists in connecting the small images without loosing the information of the whole image. Each small image consists in an independent board, however this is not true and the information of conductors that cut through the red lines is important to perform the board connectivity analysis. This is solved considering in the small images that, when a conductor crosses the red line, we assign a provisional hole to this intersection point. Then, the influence zone maps and consequently the fatal errors can be obtained in each small board areas, as showed in Fig. 14-17.

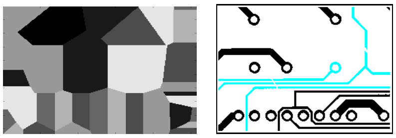


Figure 14. (a) Influence zone map and (b) Error identification of area numbered as 1.

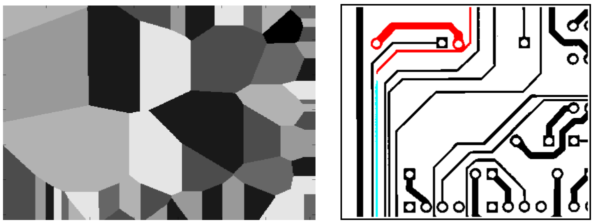


Figure 15. (a) Influence zone map and (b) Error identification of area numbered as 2.

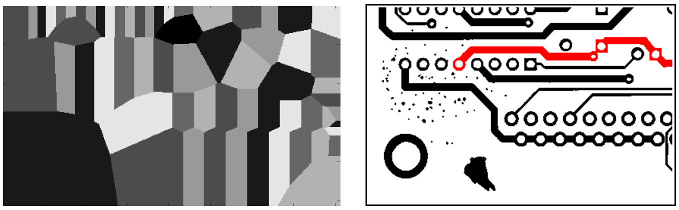


Figure 16. (a) Influence zone map and (b) Error identification of area numbered as 3.

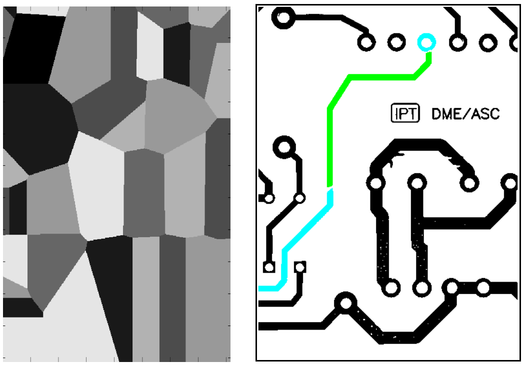
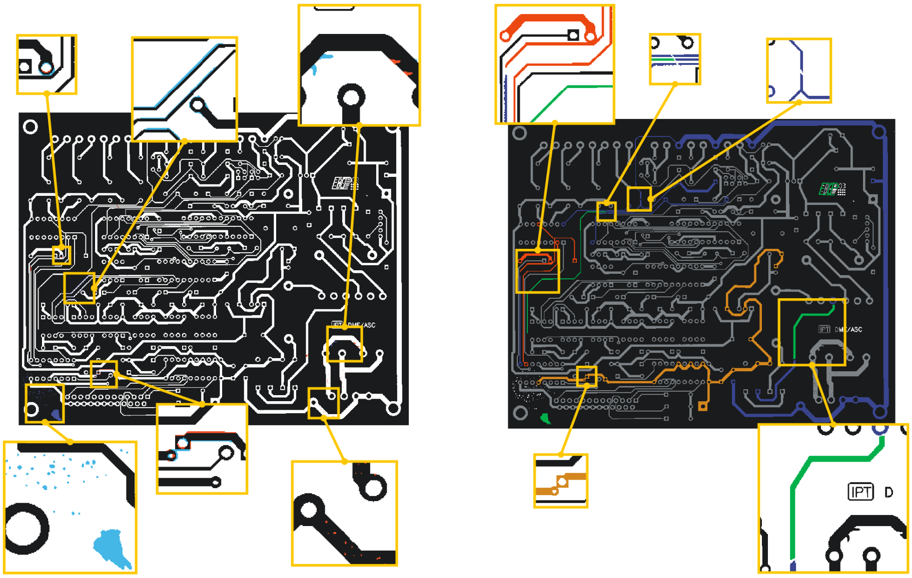


Figure 17. (a) Influence zone map and (b) Error identification of area numbered as 4.

After processing each error regions, it is possible to show the entire PCB image, highlighting its potential and fatal errors (Fig. 18).



(a) (b)

Figure 18. Potential errors (a). Fatal errors (b).

5. CONCLUSIONS

A Computer Vision system for printed circuit board (PCB) automated inspection was developed to detect bare-board manufacturing errors, like missing tracks, circuit shorts, missing holes, opens, breaks, etc. The system uses standard PCB images; their characteristics are saved in a database. The adopted referential approach compares PCB images to the standard images.

Some difficulties were observed. One of them consists in the pre-processing technique. It is important that the environment lighting should be uniform and that all inspected PCB belong to the same category. It permits to choose a satisfactory segmentation technique, which can be applied to all PCB images. In the other hand, if it doesn't happen, it will be necessary to calibrate the system every time we change the reference PCB or environment illumination.

Attempting to detect PCB fails, we propose a new methodology that reduces the computer complexity of scanning the whole board. We considered the PCB separated in small images. It is possible after the system identified the regions that contain fatal errors. A connection analysis method is applied to each small image.

The obtained results confirm that the methodology is feasible, however some new improvements should be done in other to convert the system in an industrial real time system. For instance, we can use parallel processing to test each small image detached. This should improve efficiency and reduce computational time.

Future works consists in revising the methods used to analyze PCB with components. In this case it should be detected components absence and replacement, misaligned components, etc.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Feliciano, F. F., 2007, "Inspeção de placas de circuito impresso sem componentes utilizando técnicas de processamento e análise de imagens", Programa de Pós Graduação em Engenharia Mecânica, UFF.

Göktürk, S. B., Akarun, L., Bozma, H.I., 1999, "Automated Inspection of PCB's using a Novel Approach", IEEE-EURASIP Workshop on Nonlinear Signal and Image Processing.

Greenberg, et al., 2006, Method for printed circuit board inspection", United States Patent 6, 990, 227.

Guerra, E. and Villalobos, J. R., 2001, "A three-dimensional automated visual inspection system for SMT assembly", Computers & Industrial Engineering, Vol. 40, pp. 175-190.

Leta, F. R. et al., 2005, "Discussing Accuracy in an Automatic Measurement System using Computer Vision Techniques", COBEM 2005.

Mashohor, S., Evans, J.R., Arslan, T., 2004, "Genetic Algorithms Based to Printed Circuit Board (PCB) Inspection System", IEEE International Symposium Consumer Eletronics.

Moganti, M., Ercal, F., Dagli, C. H. and Tsunekawa, S., 1996, "Automatic PCB inspection algorithms: A survey", Comput. Vision Image Understanding, Vol. 63, No. 2, pp. 287-313.

Moganti, M., Ercal, 1998, "Segmentation of printed circuit board images", Computer Vision and Image Understanding, Vol. 70, No. 1, 74–86.

Moganti, M., Ercal, 1998, "A Subpattern Level Inspection System for Printed Circuit Boards", Computer Vision and Image Understanding, Vol. 70, No. 1, pp. 51–62.

Oguz, S.H.; Onural, L., 1991; "An automated system for design-rule-based visual inspection of printed circuit boards", 1991. Proceedings. IEEE International Conference on Robotics and Automation, pp.2696 – 2701.

Sasai, M. et al., 2000, "Printed Circuit Board Inspection for Flexible Manufacture", 5th World Conference on Non-Destructive Testing Proceedings, Italy.

Tatibana, M. H., Lotufo, R. de A., 1997, "Novel Automatic PCB Inspection Technique Based on Connectivity". In: X Brazilian Symp.on Computer Graphics and Image Processing-SIBGRAPI'97, Campos de Jordão, Vol. 01. p. 187-194.

Tsai, Du-Ming and Yang, Ron-Hwa, 2005, "An eigenvalue-based similarity measure and its application in defect detection", Image and Vision Computing, Vol. 23, No. 12, pp. 1094-1101.

Tsai, Du-Ming and Tsai, Ya-Hui, 2002, "Rotation-invariant pattern matching with color ring-projection", Pattern Recognition, Vol. 35, pp.131-141.

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