PCB Open, Short and Shift Defects Detection by Logical Comparison of Mask Images

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Abstract. The known skeletonization algorithm was realized and the skeleton specific points were found. The algorithm was applied to printed circuit boards to detect the main defects: wire and contact breaks, short circuits. Mask images on a base of specific points and logical comparison to select and to mark places with defects were realized. The example of applications is shown.

1. Introduction
Mechatronics, robotics and many other automation systems could not be projected without usage of electronic control devices. The last ones are based mainly on PCB and chips. All manufacturing processes have probability of making defects in the product. Algorithms of computer vision in this case help to detect and to eliminate defects increasing reliability and duration of a mechanical system work. An open connection is the main defect on the PCB and is caused by a lack of contacts within the lead, between the lead and pad. Shorts occur when solder is connecting one lead to another. Component shift is being described as the misalignment of constructive elements to their designed positions. These three defects occupy two third of all defects. In the paper [1] the proposed algorithm combines parallel and sequential processes in iterative procedure. The proposed method conducted into experiments of many benchmark dataset were used to evaluate the algorithm robustness. The article [2] a quantum version of Hilditch's algorithm is proposed where the quantum images were used. The paper [3] considers five stages of the algorithm: Image rebuilding, inspection image normalization, image subtraction, defects separation and defect classification. The system recognizes different types of defects, for example, open, pinhole, missing conductor and so on. The given method produces good results. In the article [4] classification of the defects on PCBs was made by a hybrid algorithm: a morphological image segmentation algorithm and simple the image processing. Also, good results were obtained. In the paper [5] topological information on PCBs is introduced. The topological comparison method compares the inspection graph obtained from the skeletons of the conductor and insulator images. The approach in the article [6] is based on the comparison between the standard PCB image and the target image. Multiple images of the qualified PCBs are used at the same position. An average of the images is taken as an initial standard image. The article presents the algorithm of the etalon and real PCB image skeletons comparison by logical operation with mask images taking into account a tolerance for a distance between suspicious places.

2. Image pre-processing
An example of the PCB image from [10] is taken for experiments. There are three colors in Fig.1: dark green background, light green routes and light gold contacts. This image is being transformed to a binary form because preliminary conditions of the main algorithm need to input the PCB image with a white background and black routes and contacts.
For pixels of the PCB image a cumulative histogram is being calculated:

\[ G(s) = \{ \sum g(j), j = 0, \ldots, s \}, s = 0, \ldots, 255 \]  \hspace{1cm} (1)

where \( G(s) \) is a value of the cumulative frequency in the \( s \)-th interval, \( g(j) \) is a number of pixels in the \( j \)-th interval of intensity.

Images of manufactured PCBs differ between themselves by the reason of irregular lightning, changing background etc. Thus, the colors of the background of the PCB and routing wires and contacts are not uniform.

This fact is being confirmed by a cumulative histogram which plot in Fig.2 ununiformly increases reflecting changes of pixel intensity.

A cumulative histogram is being approximated by piecewise-linear function \( g(x) \) determined on the interval \( a_i \leq x_i \leq a_{i+1} \) with a set of sections having the end points \( (a_i, \beta_i) \) and \( (a_{i+1}, \beta_{i+1}) \). The function \( g(x) \) minimizes the approximation error \( \epsilon \) got by the following formula:
For piecewise-linear approximation of the histogram function the realized Ramer–Douglas–Peucker (RDP) algorithm from [11] was taken as basic.

To find a threshold value for the PCB image in Fig.1a method of multilevel segmentation based on linear piecewise linear approximation of a cumulative histogram is being used. A result of approximation is shown in Fig.3. The main threshold value is 45 which we increase by 5 points to 50 and transform the image to binary form replacing pixels in the interval 0-50 by black color and in the interval 51-255 by white pixels. Then for the resulting image of PCB cumulative histogram is given in Fig. 1 (flat chart). To satisfy the input conditions of the skeletonization algorithm the resulting binary image is being inverted (Fig.4).

![Figure 3. Cumulative histogram and its piecewise approximation](image)

The resulting image from Fig.4 is being taken as input data for the skeletonization algorithm which gives the skeleton image in Fig.5.

![Figure 4. Binarized PCB image.](image) ![Figure 5. Skeleton of PCB image.](image)

Having a technique for an image evaluation, segmentation, inversion and transformation to skeletons it is possible to widen these services to obtain more practical instruments.
3. PCB skeleton and its specific points
The skeleton of a binary image \cite{7,8,9} was used to analyse the components of printed circuit boards to find irregularity and defects of routing wires and their groups of contacts. In Fig 5 an example of the PCB image skeleton is given. For it the endings and switches are found and marked by blue and red rectangles as it is shown in Fig.6. A switch indicates connections of wires with contacts or between themselves. On the skeleton endings indicate coordinates of rectangular contacts and wire breaks. There are two skeletons in Fig.6: one has marked switches by blue rectangles and the second red rectangles indicate endings. There are no defects on these skeletons. Switches are native for the original PCB image and endings on the second skeleton are also native and mark breaks of routes on the edge of the image and the ends of the contacts. In common, endings on the edge could not be considered.

![Figure 6. Etalon PCB skeletons with specific points of switches (a) and endings (b)](image_url)

4. PCB open and short detection
In Fig 6 specific points of endings and switches do not always indicate defects. They characterize some constructive elements needed for normal work of the circuit. Having the skeleton and coordinates of its specific points it is impossible to find defects by only one real sample of the PCB image. For specific points classification as defects or robust elements of the PCB it is needed to build the image skeleton, to find its specific points, to repeat these manipulations with the etalon PCB image and to take decision about types and placement of defects.

After building two skeletons for the PCB etalon and real PCB images there are four sets of specific points: for the skeleton of the etalon (reference) PCB image a set of endings \( E_r = \{ e_{r1}, e_{r2}, \ldots, e_{rn} \} \) and a set of switches \( W_r = \{ w_{r1}, w_{r2}, \ldots, w_{rm} \} \) and for the skeleton of the real PCB image a set of endings \( E_d = \{ e_{d1}, e_{d2}, \ldots, e_{dn} \} \) and a set of switches \( W_d = \{ w_{d1}, w_{d2}, \ldots, w_{dm} \} \).

Elements of these sets are coordinates of different detected specific points, for example, \( e_{r1} = (x_{r1}, y_{r1}) \), \( w_{d1} = (x_{d1}, y_{d1}) \) etc. There are two fragments of skeletons in Fig.7 obtained from the PCB image having two breaks of wires. First of them has only switches and one specific switch near contact is missing due to the break of wire near contact. This case is illustrated by Fig.7a the second fragment in Fig.7b demonstrates three endings for two breaks of wires.
If the PCB image has many elements, wires and contacts it is difficult by a visual observation to separate rectangles related to defects from those belonging to correct elements. An idea how to detect, to mark and to select places with defects on the PCB area is considered. The procedure is based on four sets of specific points given by their coordinates. Four images are being built: two for the etalon PCB and two for the real manufactured PCB. They are called masks: $M_{ee}$, $M_{es}$, $M_{re}$, $M_{rs}$. Every mask image has dimension of the corresponding PCB image. Black circles (in our case for switches blue and for endings red) are being drawn on a white or transparent background. Centers of circles have coordinates of found specific points: endings or switches. A radius of a circle reflects a manufacturing precision. Its value is being taken from the interval of 0 - 5 pixels. Two examples of the etalon mask and the real PCB mask are shown in Fig.8.

For every pair of masks $M_{ee}$, $M_{es}$ and $M_{re}$, $M_{rs}$ logical operations are being realized:

\[
\begin{align*}
(M &= M_{ee} \text{ XOR } M_{es} \\
(M &= M_{re} \text{ XOR } M_{rs})
\end{align*}
\] (3)

At the beginning of these operations the etalon mask is being accepted as the resulting image. In these operations a pixel of the resulting image changes its color if two components of the operation have different colors. That is if a pixel was black it becomes white and if it was white it becomes black. If pixels of two components have the same color the resulting pixel remains as white or accepts white color being before as black. The resulting image for operations (3) upon images from Fig.8 is shown in Fig.9a.
In practice centers of circles on the etalon PCB and the real PCB masks do not coincide exactly and the resulting image contains figures having a form of intersected circles two examples of which are shown in Fig.10. These examples illustrate a case of two switches: one of the etalon masks and one of a real image mask. A size of the intersection area is inversely proportional to a distance between centers of corresponding circles on the etalon and real masks.

Intersected parts are marked by white color or are being assigned to a transparent property. Non-intersected parts have two possibilities: they accept colors of initial circles or become transparent. A criterion for elimination of non-intersected parts of circles is being formed by a relation between an area of the intersected part and an area of the full circle:

\[
\frac{S_i}{S_f} < Tol
\]

where \(S_i\) and \(S_f\) are squares of an intersected part and a full circle, \(Tol\) is a relative tolerance value to control a distance between corresponding elements of the etalon PCB and the controlled samples. Practically this parameter reflects a number of pixels by which real PCB image is shifted from the etalon PCB image.

After performing logical operations of the formulas (1) for switches or ending we obtain four types of mask objects: 1) circles when the etalon mask has no a switch and the real mask has a switch (or vice versa), 2) intersected circles when the etalon mask and the real mask have switches shifted between themselves, 3) intersected circles with non-marked intersected part when two intersected circles are only on the etalon mask or only on the real mask and, 4) circles without intersected part when to the case in point 3 opposite mask has one circle. Examples of these types are shown in Fig.11.

\[\text{Figure 11. Types of figures after logical comparison of masks}\]
Presented figures happen with the highest frequency. Theoretically intersected figures could have more complicated form because places of defects and shifting of their position are unpredictable. To make obtained figures transparent for defects observation an algorithm for edge detection was applied. The resulting images are of two colors and a filter based on the following matrix for convolution operations is used:

\[
EM = M \times M_c
\]

where

\[
M_c = \begin{pmatrix}
-1 & -1 & -1 \\
-1 & 8 & -1 \\
-1 & -1 & -1 \\
\end{pmatrix}
\]  

(5)

The borders in Fig.12 indicate places containing suspicious defects caused by open, short or shift errors.

![Figure 12. Types of edges](image)

The tolerance value also has a function to control the drawing process: to show these borders on the resulting image or to hide them. The edge mask image EM is being imposed on the original manufactured PCB image to underline found and suspicious defects that is demonstrates on the example in Fig.13.

![Figure 13. PCB with marked defects of switches and endings](image)

So, researches have an opportunity to investigate PCB images by two control parameters: diameters of circles and the tolerance value of shifting.

Resulting images of five stages given by developed software are demonstrated in Fig.14.
Conclusions
The Hilditch’s skeletonization algorithm was realized and used for binary PCB images to find two types of feature points: endings and switches of skeleton. First ones indicate the wire breaks and the second ones indicate short circuits. Mask images with suspicious places of defects were formed and logical XOR operations to manipulate them were used. The developed software can be used for PCB defects detection in automated system of control devices design and manufacturing.

References
[1] Abu-Ain W Abdullah S N H S Bataineh B Abu-Ain T and Omar K 2013 Skeletonization algorithm for binary images Procedia Technology 11 704-709
[2] Naseri M Heidari S Gheibi R Gong L H Rajii M A and Sadri A 2017 A novel quantum binary images thinning algorithm: A quantum version of the Hilditch’s algorithm Optik 131 678-86
[3] Morrison P and Zou J J 2005 An effective skeletonization method based on adaptive selection of contour points Third International Conference on Information Technology and Applications (ICITA) 1 644-49
[4] Rau H and Wu C H 2005 Automatic optical inspection for detecting defects on printed circuit board inner layers The International Journal of Advanced Manufacturing Technology 25(9-10) 940-6
[5] Putera S I and Ibrahim Z 2010 Printed circuit board defect detection using mathematical morphology and MATLAB image processing tools 2nd International Conference on Education Technology and Computer 5 V5-359
[6] Ito M and Nikaido Y 1991 Recognition of pattern defects of printed circuit board using topological information Eleventh IEEE/CHMT International Electronics Manufacturing Technology Symposium 202-206
[7] Hilditch's Skeletonization Algorithm
   http://cgm.cs.mcgill.ca/~godfried/teaching/projects97/azar/skeleton.html

[8] Zhang T Y and Suen C Y 1984 A fast parallel algorithm for thinning digital patterns
   Communications of the ACM 27(3) 236-9

[9] Lee T C Kashyap R L and Chu C N 1994 Building skeleton models via 3-D medial surface axis
   thinning algorithms CVGIP: Graphical Models and Image Processing 56 462-78

[10] Why Do We Use Copper to Make PCB Traces?
    https://yic-assm.com/why-do-we-use-copper-to-make-pcb-traces/

[11] Douglas D H and Peucker T K 1973 Algorithms for the reduction of the number of points
     required to represent a digitized line or its caricature Cartographica: the international
     journal for geographic information and geovisualization 10(2) 112-22