# Image Segmentation and Trimming for Ink-Jet Fabrication of Electronic Circuits

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## Abstract

*With different dot overlap distance and surface property, the ink-jet line tracking on substrate will present different line width. To be a fabrication process, for example, form circuit on flexible substrate by ink-jet printing technique, the line width will dominate by the factors of image transfer loss, the pattern type of image and its overlap rate, and the hydrophile-hydrophobic surface property. This paper discussed the image transfer loss and the effects of pattern for direct ink-jet patterning method of forming circuit. A standard file (Gerber RS274X) for printed wire board (PWB) is first transferred into half-tone image, and prepared for discharging by ink-jet printing control. By image segmentation, the image characteristics are abstracted into sub-patterns. Those distinguishable patterns include circle via, horizontal trace, slant trace, vertical trace, square, and blank. The system consists four major phases; the first step is segmentation of Gerber image into sub-patterns in raster data, the second step operates superposition on the abstracted sub-patterns, the third step performs verification and inspection, and the final step optimizes the printing route. Experimental results demonstrated the necessity of the proposed algorithms, and data showed that the variation of circuit line width can be controlled within ±15%.*

## Introduction

An ink-jet printing system for forming circuit patterns onto the surface of a printed circuit board (PCB) has a different input data format from classic PCB processes. The standard protocol is Gerber RS274X format for conventional PCB processes. Gerber is a description language used for plotting which is not suitable for the ink-jet date format, and need further transfer. However, due to the wettability on the substrate is independent on the image define, it causes the line width is different with the origin data. Therefore, a compensation of the printing result with original image is needed.

An example is to clarify this concept. If one wants to print a 75µm line-width, and its dot overlap is 30µm distance. The simplest concept is printing two rows data (30*2=60 um), to form a line. The wettability will dominate its spreading and may forming a 90 µm (speeading factor ~1.5), over the need of 75µm. Therefore, one solution is improving the surface property, make the spreading factor near 1.25, and get the ideal width of 75µm. Or alternative, change the data overlap distance to about 15µm or below, after printing and flow wetting, forming near 75µm line width. Obviously, the overlap distance is related for different kinds of substrate and ink.

Moreover, the horizontal line, vertical line and slant line have different overlap distance due to the innate of fix resolution. If the horizontal and vertical line has the same resolution, generally the slant line will be a factor of their root mean square. Figure 1 shows array printing may cause varied gap between dots. It will cause the different line width present for horizontal, vertical, and slant line, even though these line width define in original image were the same. For compensating this defect, we develop an algorithm to deal with these issues. In the next section, we explain our approach in details.

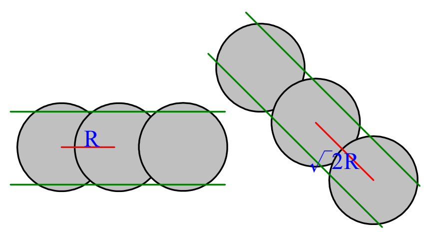


*Figure 1. Width difference between slant and vertical line*

## Algorithm Flow

Figure 2 shows the flow of visual processing. The processing contains four steps. The first step of image process is converted RS274X format into binary image array data. Converted resolution is selected in order to achieve at desired registration precision level of the PCB, such as 5µm or 5080 dpi. The second step is to identify the binary image into small parts for image segmentation. Each small part will be trimmed and piece together to form a new trimmed-image, according each part original position. The third step is the identification step used for distinguishing image such as circle, horizontal line, slant line, vertical line, square, filled and blank, etc.[1] All of these verified patterns will be trimmed by respective modifying rules in the final step. These modifying rules are set from some results of printing experiment. With the revise, all pieces are used to reconstruct the final printing route.

### *Image Transferring*

Gerber data format is a describing image format so that it can provide high image resolution with small file size. When we apply ink-jet technology in PCB forming circuit, the acceptable data for printing must be a dot matrix or drop number on desired location. A commercial program was used for converting the Gerber RS274X data into TIFF binary image on predetermined resolution. From the concept of Fig. 1 and experiment results, we can evaluate the minimum transferring resolution with 1) maximum distance between dot and dot $= \sqrt{2}$ pixel resolution and 2) distance between dot and dot $\leqq$ 0.5 dot diameter D, so the restriction of transferring resolution TR is

$$TR \le \frac{1}{3} D \tag{1}$$

High resolution conversion and large panel bring a huge image. For example, a 50cm × 50cm Gerber image converted with 5µm resolution will become a 100,000 × 100,000 image, so we may separate some components from Gerber file and convert one by one to release system load.

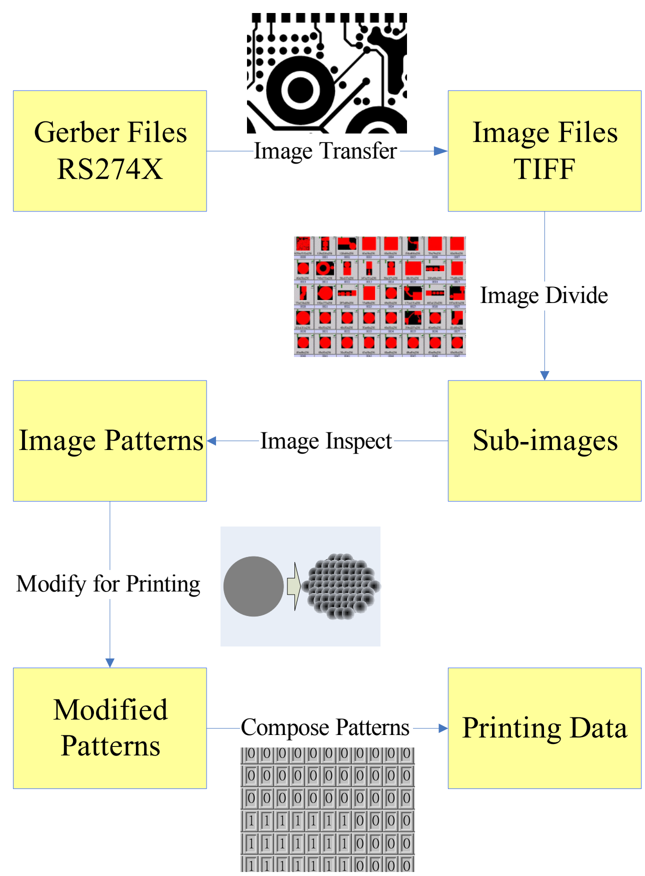


*Figure 2. Flow of Process*

## Image Segmentation

Segmentation is a common skill in computer vision to refer to several kinds of image decomposition techniques. Typically segmentation is used in the extraction of contours of an image,[2] extraction of regions of an image,[3] boundary detection,[4] and PCB inspection.[5] In the context of PCB inspection, the main goal of the segmentation is to simplify the patterns in the PCB layout for further processing. In the graph based inspection systems, the segmentation algorithm recognizes basic patterns in a PCB segment using the shape information from the thinned pattern images.[6] Template matching algorithm is one of the most widely used techniques in commercial and experimental optical inspection system.[7] An easy approach to apply template matching to this PCB segmentation problem is to define all possible window templates for basic PCB sub patterns and then apply every templates to the target PCB images. A serious problem with this simple approach is that there are too many templates needed to be identified, and it takes a lot of calculation time to match tiny templates in huge images. This paper separates huge image into sub-images for identification and these sub-images can be applied to find all discrete images with region growing algorithms. A simply region growing algorithm has the steps: 1) Describe the region based on the current pixels that belong to the region 2) Find all pixels adjacent to the current region. 3) Add an adjacent pixel to the region if the region description also describes this pixel (*e.g.* it has a "1" intensity at binary image). 4) Return to step 1 as long as new pixels continue to be added.

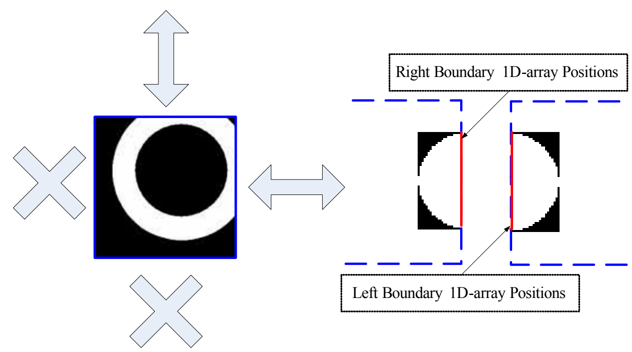


*Figure 3. Left) Connective Properties Right) Evaluating Neighbor images*

A problem on discrete image is separated by above sub-images operation. The size of sub-images affects the quantity of these separated discrete images. Template training found a size of 10 times lager than that of discreted image can discriminate all images. Two separated discrete images only connected to each other can combine to one, and separated discrete images connected to more than 2 side can put into large pattern group. Check the connective boundary pixel array to merge the right two images. Figure 3 shows the concept of merging images.

## Image Identification

A large number of PCB inspection algorithms have been proposed in the literature to date. The referential methods execute a point-to-point comparison with a reference sample images stores in an image database. These methods are used to detect errors and differences from our reference. This paper modified raw data into a printable data, it needs to know the classification of these discrete images from above process. The Canny edge detector method is the most popular edge detection algorithm though the binary image is more easily to obtain the edge information. After the algorithm is applied to detect edge, the gradient magnitude and direction can indicate the location of horizontal line edge and vertical line edge by symmetrical positive and negative gradient magnitude and nearly width. Parts of the images, which are confirmed having one characteristic, are pulled out to be modified by its trimming algorithm before the final printing array is reconstructed. Slant line detection follow above two operations, use remaining images to find “raise” and “fall” edge with approximate slope. Circle detection is applied on remaining images with circle fitting edge positions; examine the deviation of fitting result for evaluation. There are many image inspection algorithms, which can be used here, but it is a meaningful process only if there are modified methods supported. After all processes execute, remainder images are classified in large pattern group.

### *Image Trimming*

The wetting spread of ink on the substrate is the basis for modifying process. Ink-jet printing system for different applications has different requirement of output modification. In the case of PCB printing process, circles (holes) pattern need gray level discharging to fill catalyst within via, the gray level is depend on the thickness of substrate. Therefore, circles in all discrete images apply an enhanced on drop numbers. The principle of other kinds of discrete images is printing on substrate surface only, i.e, a binary level discharging is enough. The modifying methods are defined from experimental results. Figure 4 indicates the results of modifying methods.

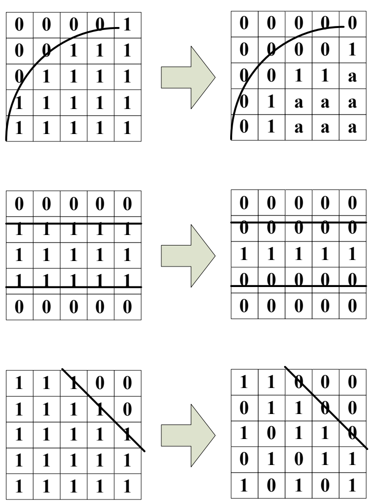

*Figure 4. Representation of modifying data*

***Case (a): Circle:***

The algorithms of these results in figure 4 are presented in the following sections at the cases of circle, horizontal line and slant line. In the circle case, the volume of the circle hole $V_h$ is

$$Vh = A \times Ts \tag{2}$$

where A is the circle area which can be calculated from image inspection and Ts is the thickness of the substrate. The transferring resolution TR and dot diameter D are defined before, and the spread pixel number $A_e$ is

$$A_e = \mathrm{int}\left(\frac{D - TR}{2}\right) \tag{3}$$

An erode algorithm is applied on original circle discrete image with shirking factor. The edge of output image is set to 1 for keeping the outline, the residue pixels are set to a

$$a = \mathrm{int}\left(\frac{V_h / V_d - N_e}{N_r}\right) \tag{4}$$

When $N_r$ is the amount of residue pixels, $N_e$ is the amount of the edge pixels, and $V_d$ is average size of one drop.

***Case (b) : Horizontal Line***

The line width W can simply calculated by modifying level from the original image. From the experimental results, the additional line width (one side) $W_a$ is a necessary factor involved in calculation for reducing the spread effect. So the total number $A_h$ of pixels formed the right line width is

$$A_h = \mathrm{int}\left(\frac{W - 2 \times W_a}{TR}\right) \tag{5}$$

If $A_h \geq 3$, we may skip some dots for more flatness. Each edge of the line is set with no skip just like circle case for keeping the outline and all other pixels need to skip some ones.

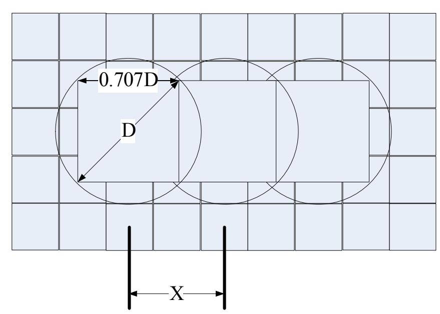


*Figure 5. Sketch of skip process*

Figure 5 shows the skip condition. X is n times of TR, and the restriction is 100% full cover of target area

$$n \times TR = X \leq \frac{1}{\sqrt{2}} D \tag{6}$$

The skip function can save materials and prevent the ink overflow.

***Case (c) Slant Line:***

There is only one difference from horizontal case, which is the edge-modifying requirement. As the slope of slant line is changing, the interval between dots also changes. When the image digitizes, slant line would have some broken points in diagonally connected pixels. A simple solution is that double the edge width of output image, hence changing from one pixel to two pixels. The skip function can also apply onto this case. Figure 4 is an example for D = 30μm and TR = 10μm.

Printing data is the last step to optput the result of all algorithms. Each identified discrete image is modified by adjustable functions, while images which can not be identified by the inspection above are modified with same eroding factor assuming that there are no detailed modifications needed.

## Results and Discussion

An experiment is set for forming metal wires where the patterning method follows the steps of providing a FR-4 substrate modified with PEM (polyelectrolytes membrane) contains PAH Poly (allylamine hydrochloride) and PAA (Poly (acrylic acid) immersing for 12 minutes, respectively; micro dispensing a catalytic modifying pattern for forming metal wires; and depositing Cu on the catalytic pattern on the surface of the substrate by an electroless plating process.[8]

The estimated dot diameter D is 30μm and ink-jet printing system dispenses the catalytic with no skip dots. Figure 6 shows optical images of FR-4 substrate after electroless deposition process.

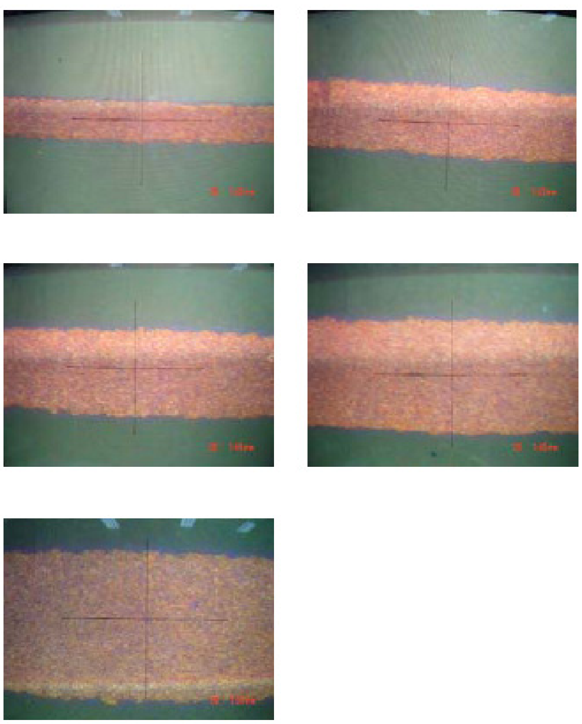

*Figure 6 pictures of different wire width (75μm, 115μm, 150μm, 185μm, 225μm)*

**Table 1: Experimental Results of Line Width**

| Width (μm) | E1 | E2 | E3 | E4 | E5 | M.E. (%) |
|---|---|---|---|---|---|---|
| 75 | 75 | 75 | 76 | 76 | 75 | 1.33 |
| 115 | 129 | 130 | 122 | 126 | 121 | 13.04 |
| 150 | 165 | 168 | 162 | 167 | 160 | 12.00 |
| 185 | 195 | 200 | 206 | 212 | 203 | 14.59 |
| 225 | 252 | 235 | 227 | 243 | 247 | 12.00 |

Maximum Error(M.E.)=Max(E1,E2,E3,E4,E5)/Width

The image trimming factor was verified in Table 1. The average line width of all wires are measured and recorded at table 1. We do five experiments for each condition. The results indicate that the 75μm line width is almost same with origin pattern but others have larger variation. The reason is that the 75μm line only has 3 rows to form it and others have too many rows (catalytic) to print making the line width expanding.

## Conclusion

An image modifying algorithm for ink jet printed circuit is presented in this paper. This algorithm provides PCB printing system a necessary transference from Gerber RS274X to printable data format. The algorithm includes image transferring, image segmentation, image inspection, image modifying, and image reconstruction. Image inspection and Image modifying are designed to fit many special PCB images and to optimize by experimental results from new ink or substrate. When the objects of PCB are becoming smaller in scale, the printing optimum algorithm will obviously become a key factor for improving the printing quality. Experimental results demonstrated the necessity of the proposed algorithms, and the results showed that the variation of circuit line width can control within ±15%. In near future, combining the factors of wetting behavior caused by ink-substrate interface, a ideal image trimming process for ink-jet fabrication can be realized.

## References


1. M. Moganti and F. Ercal, Segmentation of Printed Circuit Board Images into Basic Patterns, Computer Vision and Image Understanding 70, 1998, 74-86.
2. G. Storvil, A Bayesian approach to dynamic contours through stochastic sampling and simulated annealing, Trans. Pattern Matching Mach. Intell. 16, 1994, 976-986.
3. R. K. Falah, P. Bolon, and J. P. Cocquerez, A region-regoin and region-edge cooperative approach to image segmentation, First IEEE Int. Conf. On Image Process, Austin, TX, Nov. 13-16, 1994, pp. 470-474, IEEE Comput. Soc., Los Alamitos, CA, 1995
4. F. Ercal, M. Moganti, W. V. Stoecker, and R. H. Moss, Detection of skin tumer boundaries in color images, IEEE Transcation on Medical Imaging 12(3), 1993
5. Ahmed M. Darwish, and Anil K. Jain, A rule based approach for visual pattern inspection, IEEE Transactions of Pattern Analysis and Mach. Intell. PAMI-10(1), 1988, 56-58.
6. M. Moganti and F. Ercal, A subpattern level inspection system for printed circuit boards, Computer Vision and Image Understanding 70, 1998, 51-62.
7. S. H. Oguz and L. Onural, An automated system for design-rule-based visual inspection of printed circuit boards, in Proceedings, 1991 IEEE International Conference on Robotics and Automation, April 1991, pp. 2696-2701.
8. Ming-Huan Yang, Wanda W. W. Chiu, Jane Chang & Kevin Cheng, "Method for Forming Cu Metal Wires by Microdispensing Pattern, Part I: Self Assembly Treatment & The Ink-Jet Process", accepted by *NIP20*: International Conference on Digital Printing Technologies, 2004.


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