DIGITAL STEREO RADIOGRAPHY, APPLICATIONS TO IMAGING OF PRINTED CIRCUIT BOARDS

Lewis J. Thomas III and M. Kent Cueman
Corporate Research and Development
General Electric Company
Schenectady, NY 12301

INTRODUCTION

Structures such as PC boards may be characterized as having quantized density variations (metal traces versus board material) which occur in known planes within the board. Digital stereo radiography involves taking two digital radiographs (a digitized version of a conventional radiograph) with the sample at two different angles relative to the direction of propagation of the X-rays. Assuming that edges of density variations can be identified on the digital radiographs we can locate the plane in which the density variation lies by determining the change in location of the edge between the two radiographs. This technique offers improved throughput for X-ray inspection of PC boards over laminography since only two views are required.

Modern laminography [1,2] for NDE involves taking several digital radiographs of an object at different angles and then backprojecting the digital radiographs to form a three-dimensional image. In this view, laminography represents an extreme case of three-dimensional, limited angle X-ray tomography. The usual reconstruction algorithm used (simple backprojection) avoids the usual artifacts due to reconstruction filters often seen in limited angle reconstructions, but also allows blurry images of objects to be projected into inappropriate regions of the image.

Traditional stereo radiography involves taking two radiographs (called a stereo pair) of a flawed part at different view angles. Then by using the change (with view angle) in location of the flaw relative to identifiable landmarks in the part, the depth of the flaw can be determined. Digital stereo radiography extends this concept in that digital radiographs are used and every feature in one radiograph of a stereo pair is paired with features in the other radiograph. The relative location of the two features is then used to determine the depth of the feature in the part. In the specific implementation of digital stereo radiography we present here, printed circuit boards are the object of interest, therefore, we can use the fact that metallization regions (the features of interest) lie in specified planes of the board. This allows a rather simple and fast algorithm to correctly assign metallization regions from the radiographs to the appropriate plane of the board, thereby producing high quality images of a single plane in a multi-layer printed circuit board with only two digital radiographs.

DESCRIPTION OF THE ALGORITHM

In Fig. 1 we show the geometry used for our digital stereo radiography algorithm. A parallel beam of X-rays passes through the printed circuit board and is incident on a linear array of X-ray detectors. For convenience we will refer to the side of the printed circuit board which is toward the X-ray source as the front, and the opposite side as the back. We will allow the board to be rotated by an angle θ about an axis on the front of the board.

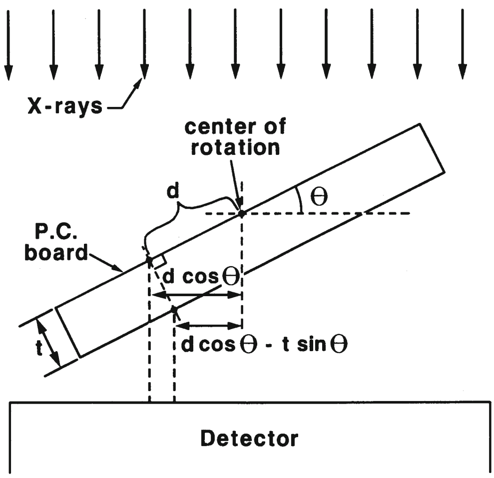


Fig. 1. Geometry for digital stereo radiography measurements.

Consider two points, one on the front and one on the back of the printed circuit board, each a distance d from the center of the board. As is shown in Fig. 1, when the board is at an angle θ, the projection onto the detector of the point on the front of the board is a distance $d\cos(\theta)$ from the center of the board, while the point on the back of the board is projected to $d\cos(\theta)-t\sin(\theta)$ where t is the thickness of the board. When the board is rotated to an angle -θ, the point on the front projects again to $d\,(\cos)\theta$, but the point on the back projects to $d\cos(\theta)+t\sin(\theta)$. Therefore, if we have two radiographs taken with the board at angles of θ and -θ we can conclude that features which are in the same location on the two radiographs are on the front surface of the board, and features which change location by $2t\sin(\theta)$ are on the back surface of the board. This observation is the heart of the digital stereo radiography algorithm.

Before we proceed with a detailed description of our algorithm, we must first describe a problem with the idea of matching features in a stereo pair of radiographs. In our work we are principally concerned with imaging printed circuit boards, the most easily identifiable features in these radiographs are the edges of traces. In Fig. 2 we show a simple printed circuit board at two angles which might be used to produce stereo radiographs. We also show the X-ray flux (linearized by taking the logarithm of the flux) and the spatial derivative of the linearized flux, which we use to identify edges. As is shown in Fig. 2, the problem with using edges is that an edge may be obscured by having two traces abut. In the right hand half of Fig. 2, the board is at an angle which causes the edge of a trace on the front of the board to exactly overlap the edge of a trace on the back, thereby resulting in an X-ray flux which looks like one wide trace rather than two narrow ones. Fortunately, this problem can usually be solved easily by applying the constraint that in the final image, we only allow each layer of the board to have either one or zero traces in any given location. (In other words, we will not allow the algorithm to superimpose two traces in the same layer of the board.).

As an example, consider again Fig. 2. The negative edge (indicating the start of a trace) labeled a_l is in the same location as the negative edge labeled a_r, therefore we would conclude that this edge is due to the beginning of a trace on the front surface of the board. The positive edge labeled d_l is shifted by $2t\ \sin(\theta)$ from the positive edge labeled d_r, therefore we conclude that this edge is due to the end of a trace on the back surface of the board. We are now left with the edges labeled b_l and c_l, obviously, we must consider the negative edge labeled b_l to be the start of the trace on the back of the board that ends with the edges labeled d_l and d_r. Similarly, the edge labeled c_l must be the end of the trace on the front of the board that begins with the edges labeled a_l and a_r. Any other assignment of edges b_l and c_l would result in having more than one trace on one side of the board or less than zero traces on one side of the board or both.

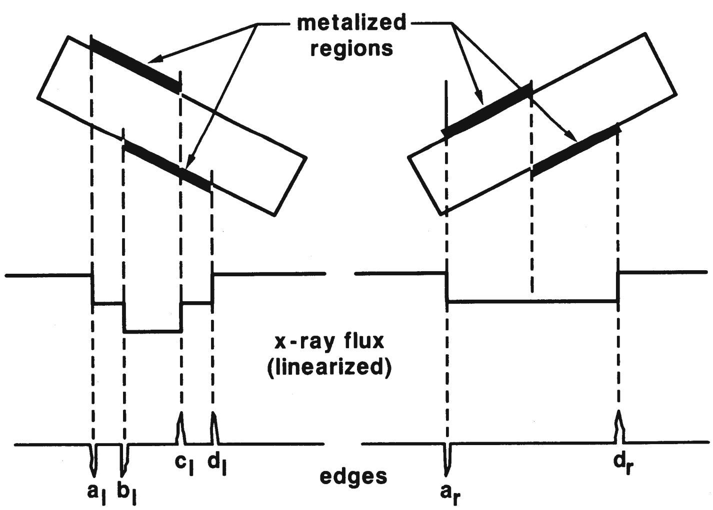


Fig. 2. Demonstration of how two edges can coincide to cancel each other.

In Fig. 3 we show a flowchart of the complete digital stereo radiography algorithm. Initially each line is considered independently. Edges which do not change location in the two stereo views are assigned to the front side of the board and edges which are shifted by $2t \sin(\theta)$ are assigned to the back side of the board. Then, unpaired edges are assigned to the front or back of the board as is necessary to satisfy the constraint of no overlapping traces on one side of the board. If the assignment of unpaired edges is not uniquely determined by this constraint, then unpaired edges are assigned according to the assignment of the nearest edges in the preceding line of data.

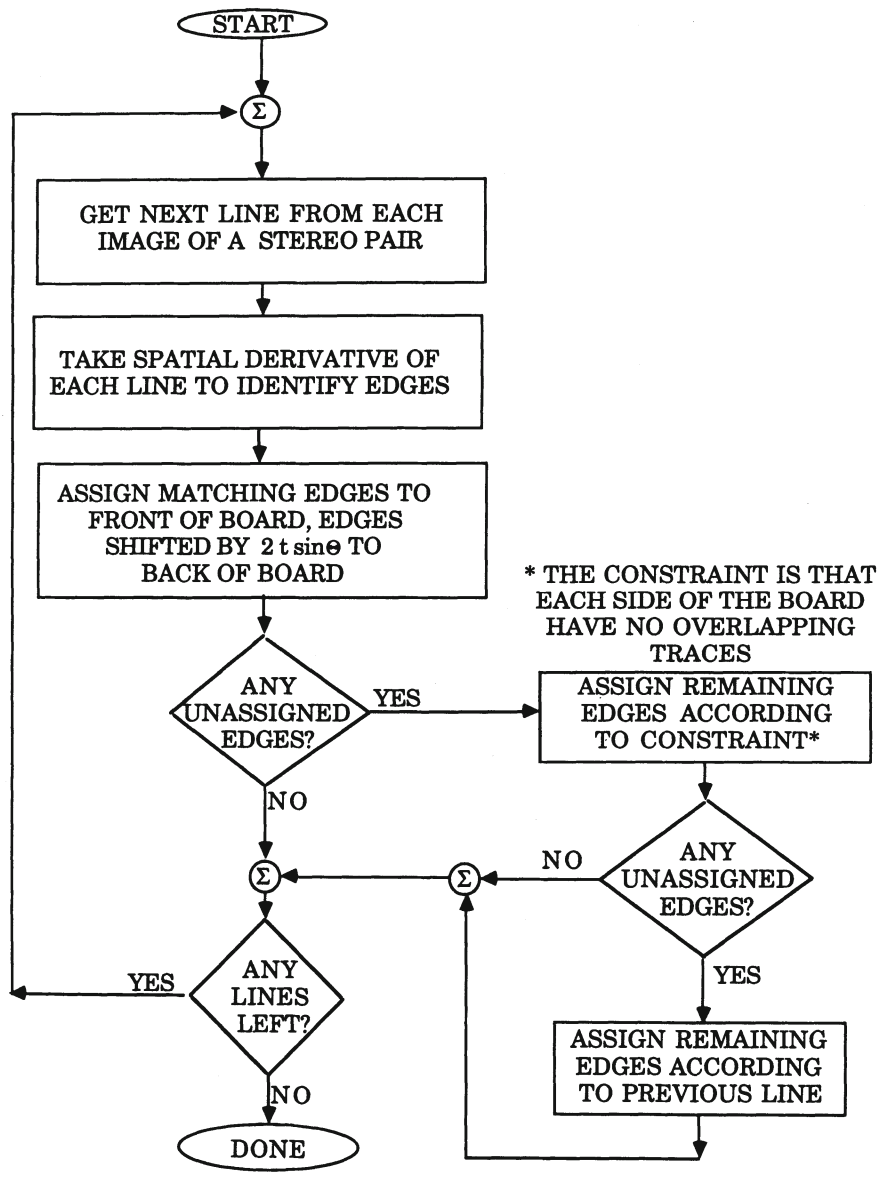
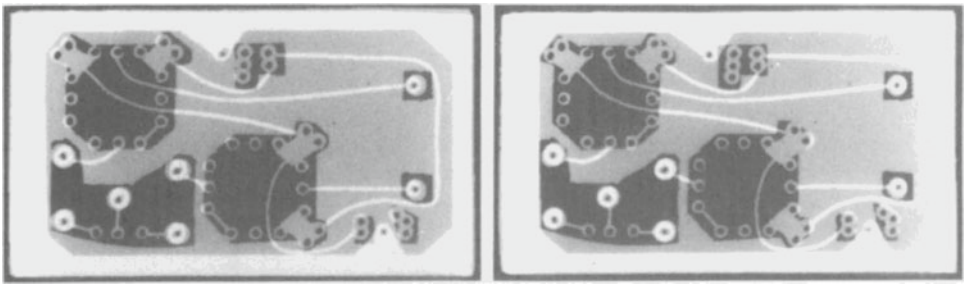


Fig. 3. Flowchart for digital stereo radiography algorithm.



LEFT **RIGHT**

Fig. 4. Simulated stereo pair of digital radiographs. The back image is shifted left 3 pixels in the left image and is shifted right 3 pixels in the right image.

Simulation of Data

In Fig. 4 we show a simulated pair of digital stereo radiographs. These data were simulated by imaging the front and back sides of a real printed circuit board with an acoustic microscope. (The method of obtaining these images is not important to the work here, we used our acoustic microscope because it provides high-resolution, high contrast images.) The images were then scaled such that traces are represented by one and other areas of the board are represented by zero. The stereo pair of radiographs were generated by shifting the image of the back of the board either left or right by three pixels and then adding the shifted image to the image of the front of the board. The resulting images are shown in Fig. 4. A careful examination of Fig. 4 will reveal that some features change location from one image to the other.

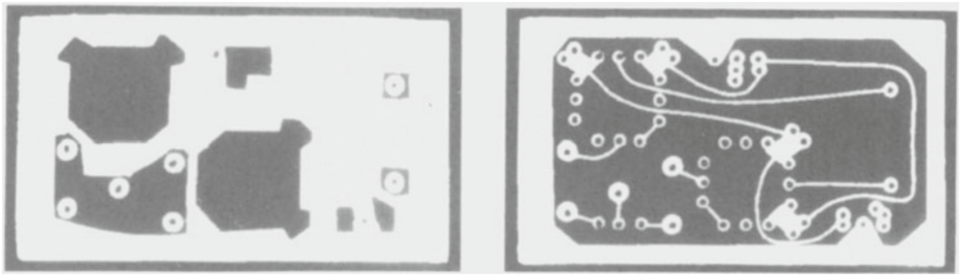
RESULTS

We applied the digital stereo radiography algorithm to the images shown in Fig. 4. The resulting images of the front and back of the board are shown in Fig. 5. We checked the accuracy of the algorithm by subtracting the front and back images determined from the stereo pair from the original images. No differences between the original and the calculated images were found. In only one case was the use of a preceding line (the last method used for assigning edges to the front or back of the board) required.

DISCUSSION

The results presented here on simulated data illustrate the potential value of digital stereo radiography. In samples where density variations occur in quantized steps and in known planes (such as a printed circuit board or a chip carrier) this technique offers the possibility of very good images with only two radiographs.

Before this technique can be applied to real situations several improvements need to be made. The most significant improvements are handling noisy data and printed circuit boards which have more than two layers.



FRONT BACK

Fig. 5. Front and back images determined from the stereo pair of radiographs in Fig. 4 using the algorithm outlined in Fig. 3.

The noise problem will show up as slight errors in the positions of edges, therefore edges which should line up will not quite line up. This can probably be handled by relaxing the requirement that edges exactly match to be assigned to the front of the board or that they be exactly shifted by $2t \sin(\theta)$ to be assigned to the back of the board. How much this condition can be relaxed without errors in assignment occurring is unclear at this time.

Boards with more than two layers should be relatively easy to accommodate. If we assign each layer a number starting with zero for the front of the board and increasing toward the back of the board (such that the number three is assigned to the back side of a four-layer board) and the layers are separated by a distance t, then the shift of an edge between radiographs is given by $n2t \sin(\theta)$ where n is the number of the layer. This would be relatively easy to include in the algorithm described here.

The algorithm presented here shows the capability of a technique which uses a priori information about the sample. Although several improvements need to be made before digital stereo radiography can be used as a real inspection technique, these modifications to the algorithm should allow high quality images of individual layers of printed circuit boards with a minimum of data.

REFERENCES

1. S. F. Buchele, "Quantitative Computerized Laminography," in Review of Progress in Quantitative NDE, University of California, San Diego, July 31-August 5, 1988.
2. M. D. Barker, "Laminographic Reconstruction From Real-Time Radiographic Images," in Review of Progress in Quantitative NDE, University of California, San Diego, July 31-August 5, 1988 .