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Determination of Hole Location on Printed Circuit Boards

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Project Leader:
R. D. Taylor
Department 445

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ON PRINTED CIRCUIT BOARDS

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DETERMINATION OF HOLE LOCATION ON PRINTED CIRCUIT BOARDS

BDX-613-814, UNCLASSIFIED, Distributed December 1972

Prepared by R. D. Taylor, D/445

An algorithm which determines the position of holes on printed circuit boards is described. Expected hole locations are input to the computer and true hole location and hole radius are determined from the digital image data. The true hole location and hole radius are presently printed out for human evaluation. Eventually hole location will be compared with land location to ensure that the hole is concentric to the land within a given tolerance.

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THE BENDIX CORPORATION

KANSAS CITY DIVISION

KANSAS CITY, MISSOURI

A prime contractor for the
Atomic Energy Commission

Contract Number AT(29-1)-613 USAEC

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FOREWORD

Since 1971, The University of Missouri—Columbia, under contract to Bendix Kansas City Division, has studied automated inspection methods of printed circuit boards. This report, prepared by Dale A. Ausherman, is the fifth in a series of progress reports submitted to the Bendix Kansas City Division by the Image Analysis Laboratory, Department of Electrical Engineering, University of Missouri—Columbia.

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SUMMARY

Automated quality inspection of printed circuit boards was achieved by developing algorithms for computer-controlled inspection. The prototype computer-automated printed circuit board inspection system proved successful in inspecting both the printed circuits and the wiring assembly of a board. True hole location and hole radius are determined from digital image data. Future effort will involve a comparison of hole location with land location.

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DISCUSSION

SCOPE AND PURPOSE

This study is part of an overall investigation of a prototype computer-automated printed circuit board inspection system (APCIS). Such an automated error detection system will be implemented on a digital computer which will provide such services on a printed circuit board (PCB) assembly line as an automated scanning system and an automated error detection package capable of detecting missing or misplaced components and lands, discontinued or misplaced solder connections, and any external damages to the board itself. Incorporated within this package is an interconnection path width measurement technique which uses the principle of chain coding.

A specific inspection task is to determine the placement of printed circuit holes and to test these locations for a given accuracy, in addition to hole radius. Also, an inspector must determine how well-centered the hole is in its associated pad or land. This report presents a set of workable computer algorithms which accurately determine the location of circuit holes and their radius. These computer routines, with slight modifications, are ready for inclusion in the inspection library of APCIS, as mentioned in the preliminary system specification.

PRIOR WORK

The problems, and partial solutions, associated with circuit board inspection have been stated in four previous Missouri University reports. This project for improvement of visual inspection began in 1968, and in 1971 a one-year subcontract was made with Missouri University to develop a computer-automated PCB inspection system.

ACTIVITY

Equipment and Test Material

The PCB shown in Figure 1 has gold-plated circuit paths and is nearly 4.5 inches (11.43 cm) in diameter. To simulate the high resolution for this application and to permit scanning with the present laboratory scanner and optics equipment, a magnified photograph was made of the board section containing the three test holes and a film transparency was produced for

Figure 1. Unwired Printed Circuit Board With Arrow Indicating the Three Holes to be Inspected

Figure 2. Photographic Copy of Film Transparency Used for Scanning

Figure 3. Flowchart for Inspecting Hole Locations

scanning purposes (Figure 2). By scanning this transparency using a 256-by-256-image raster a sampling frequency of 750 samples per inch (295 samples per cm) on the original board is simulated. If an edge can be determined to within ± 1 sample, the measurement accuracy is ± 1.34 mils (0.0034 cm). Nearly any desired accuracy can be obtained by using sufficient magnification prior to digitization.

The sequence the computer follows in this test is depicted by the flowchart in Figure 3. The expected location of each hole in the image to be inspected is input to the computer via punched cards containing the pairs of coordinates. In practice, these coordinates are easily obtainable from the PCB blueprints. The digital data in the vicinity of the expected coordinates is input and retained in core storage by routines TDSAVE or TCDUMP. The computer enters the image data currently in core storage. Using true hole location and radius, the computer then constructs a dotted circle on an output version of the digital image to provide a visual check on the algorithm performance. This process is repeated for each hole to be inspected.

The Algorithm

Input to the computer consists of a 256 by 256-image array of integers ranging from 0 to 32,767 in increments of 32 (1024 discrete gray shade values) on magnetic tape, and one card for each hole to be inspected. The input image array is shown in Figure 4 after reconstruction of a real image on a DICOMED/30 image display. The entire 256-by-256-image array does not have to be in core at any one time because only a subset is needed to determine hole location and radius. This algorithm requires that only a 128 by 128 array be in core for measurement extraction. This array, called a subimage, is determined by the coordinates (I, J) of an expected hole location. The point (I, J) is located at the center of the subimage (Figure 5). If elements of the subimage extend beyond the boundaries of the digital image, the elements are assigned a gray shade of zero. Data is dumped into core by routine TDSAVE or TCDUMP. When the first hole of a run is inspected, the image data resides on the input magnetic tape. The data is moved from the tape, through core, to a random access disc file. That data corresponding to the subimage defined by the first (I, J) expected hole location is retained in core for measurement extraction. This initial data transfer is accomplished by TDSAVE. For the second and all succeeding holes the transfer consists simply of dumping the subimages from the disc file into core by using the TCDUMP routine.

Once the subimage corresponding to a given hole location is in core, the routine MHLOC is entered by the computer. Figure 6 represents typical data in a subimage. The data is an array (I, J) where I and J are integers

Figure 4. Input Digital Image Array
Reconstructed on
DICOMED/Display

Figure 5. Subimage Specified by (I, J) , The Expected Hole
Location

(I, J) = EXPECTED HOLE CENTER

(T_I, T_J) = TRUE HOLE CENTER (UNKNOWN)

Y_1 = VERTICAL DISTANCE FROM (I, J) TO EDGE

X_1 = LEFT HORIZONTAL DISTANCE FROM (I, J) TO EDGE

X_2 = RIGHT HORIZONTAL DISTANCE FROM (I, J) TO EDGE

Figure 6. Distances X_1 , X_2 , and Y_1 Measured in Subimage (I, J) , to Determine True Center

between 1 and 128. The expected center of the hole is located at I=64, J=64, where the point (1, 1) is the upper left corner of the subimage. The true center of the hole (TI, TJ) and the radius can be determined by measuring the distances X1, X2, and TI, as shown in Figure 6. The true center and radius are given by

$$TI = I + \frac{X2 - X1}{2},$$

$$TJ = J - \frac{1}{2Y1} \cdot [Y1^2 - X1 \cdot X2], \text{ and}$$

$$\text{RADIUS} = [(TI-I)^2 + (Y1 + TJ - J)^2].$$

These equations result from finding the intersection of the perpendicular bisectors of the two chords determined by the pairs of points (X1, Y1) and (X2, Y1) using simple two-dimensional geometry.

The measurements X1, X2, and Y1 are obtained from the subimage by examining the 64th row and 64th column. A threshold is determined by finding the maximum and minimum grey shades contained in the subimage MAX and MIN, respectively.

$$\text{THRESHOLD} = \frac{1}{8} \text{ MIN} + \frac{7}{8} \text{ MAX}$$

Figure 7 shows how this threshold is used to determine the distances X1 and X2. The curve consists of the actual grey values from row 64 plotted on a calcomp plotter. The expected center, shown by the dashed line, is at X coordinate 64. Similarly, Figure 8 shows the determination of Y1 using data from the 64th column of the subimage. All values, are found by beginning at the expected center and stepping outward, counting steps until the threshold is exceeded.

Once the true center coordinates and radius are found, the accuracy of the algorithm-extracted measurements must be determined. To this end, an output image is produced using routine MARK to provide a visual check of this process. For each inspected hole three items are marked on the output image. The expected hole location is marked by a small cross

Figure 7. Measurement of X1 and X2

Figure 8. Measurement of Y1

Figure 9. Output Image With Expected Hole Locations, True Hole Locations, and Computer-Constructed Circles

measuring five samples across. The true hole location is marked with a large cross measuring nine samples across. Finally, a circle is drawn that is centered at the true location and has a radius corresponding to the radius measured by MHLOC. In addition, a message is printed on the line printer of the form:

HOLE NO. 3 TRUE CENTER IS (121, 52) RADIUS = 14.57.

An example of an output image with three holes inspected appears in Figure 9.

ACCOMPLISHMENTS

The algorithm developed in this project successfully determines circuit board hole location and radius, given expected hole location information. This is a significant step toward a totally automatic printed circuit inspec-

tion system. One disadvantage of the present algorithm is that it assumes a hole does exist and that the expected hole location will fall somewhere inside the actual hole. These limitations can be overcome by searching, with gray shade information, certain predefined neighborhoods of the expected hole location for the existence of a hole. The current procedure is fast (1.15 minutes to inspect three holes with a high degree of accuracy). In practice, the computer will use the actual circuit board as a read-only-memory, thus eliminating the intermediate storage devices, such as tape and disc.

FUTURE WORK

Additional routines should be added to the present package. Determination of pad location, pad size, and checking tolerances should be given first priority. Also, some of the techniques developed for measuring path width should be made compatible with this process.

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- ³Registration of Printed Circuit Boards. Image Analysis Laboratory, University of Missouri--Columbia, February, 1972.
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Appendix

SUBROUTINES TDSAVE, TCDUMP,
MHLOC, AND MARK

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```
0001 SUBROUTINE TDSAVE(NUPIC,BUF,PIC,IORG,JORG)
0002 INTEGER*2 NUPIC(128,128),BUF(1024),PIC(256,4)
0003 COMMON IPOINT,RBUF
0004 CALL CLEAR(NUPIC,32768)
0005 NUBOX=IORG+64
0006 NUBCY=JORG+64
0007 NLBCX=IORG-63
0008 NLBOY=JORG-63
0009 LNCT=0
0010 DO 40 NBK=1,64
0011 CALL READB(BUF,RBUF,NERR)
0012 DO 30 J=1,4
0013 LNCT=LNCT+1
0014 IF(LNCT.GT.NUBOY) GO TO 30
0015 IF(LNCT.LT.NLBOY) GO TO 30
0016 DO 20 I=1,256
0017 IF(I.GT.NUBOX) GO TO 20
0018 IF(I.LT.NLBOX) GO TO 20
0019 NX=I-NLBOX+1
0020 NY=LNCT-NLBOY+1
0021 NUPIC(NX,NY)=PIC(I,J)
0022 20 CONTINUE
0023 30 CONTINUE
0024 40 WRITE(3,NBK) BUF
0025 RETURN
0026 END
```



```
0001      SUBROUTINE MHLOC (NUPIC, IORG, JORG, ICEN, JCEN, RAD)
0002      INTEGER*2 NUPIC (128,128)
0003      CALL MXMNH (NUPIC (1,64), 128, MAX, MIN)
0004      NTHRES = (7*MIN) / 8 + MAX / 8
0005      DO 10 I = 1, 40
0006      IF (NUPIC (64-I, 64).GT.NTHRES) GO TO 20
0007      10 CONTINUE
0008      20 IDX1 = I
0009      DO 30 I = 1, 40
0010      IF (NUPIC (64+I, 64).GT.NTHRES) GO TO 40
0011      30 CONTINUE
0012      40 IDX2 = I
0013      DO 50 I = 1, 40
0014      IF (NUPIC (64, 64-I).GT.NTHRES) GO TO 60
0015      50 CONTINUE
0016      60 IDY1 = I
0017      61 CONTINUE
0018      DISPX = (IDX2 - IDX1) / 2.0
0019      DISPY = FLOAT (IDY1 * IDY1 - IDX1 * IDX2) / FLOAT (IDY1) / 2.0
0020      IDISPX = DISPX
0021      IDISPY = DISPY
0022      ICEN = IORG + IDISPX
0023      JCEN = JORG - IDISPY
0024      RAUSQR = (IDY1 - DISPY)**2 + DISPX**2
0025      RAD = SQRT (RAUSQR)
0026      RETURN
0027      DEBUG
0028      AT 61
0029      DISPLAY IDX1, IDX2, IDY1
0030      END
```

```

0001 SUBROUTINE TCDUMP(NUPIC,BUF,PIC,IORG,JORG)
0002 INTEGER*2 NUPIC(128,128),BUF(1024),PIC(256,4)
0003 COMMON IPOINT,RBUF
0004 CALL CLEAR(NUPIC,32768)
0005 10 CONTINUE
0006 NUBOX=IORG+64
0007 NUBOY=JORG+64
0008 NLBOX=IORG-63
0009 NLBOY=JORG-63
0010 NOFSET=NLBOX
0011 INBK=(NLBOY-1)/4+1
0012 LNBK=(NUBOY-1)/4+1
0013 IF(INBK.LT.1) INBK=1
0014 IF(LNBK.GT.64) LNBK=64
0015 IF(NLBOX.LT.1) NLBOX=1
0016 IF(NUBOX.GT.256) NUBOX=256
0017 DO 40 NBK=INBK,LNBK
0018 READ(3,NBK) BUF
0019 INC=(NBK-1)*4
0020 DO 30 J=1,4
0021 LNCT=INC+J
0022 IF(LNCT.GT.NUBOY) GO TO 30
0023 IF(LNCT.LT.NLBOY) GO TO 30
0024 DO 20 I=NLBOX,NUBOX
0025 NX=I-NOFSET+1
0026 NY=LNCT-NLBOY+1
0027 NUPIC(NX,NY)=PIC(I,J)
0028 20 CONTINUE
0029 30 CONTINUE
0030 40 CONTINUE
0031 11 CONTINUE
0032 RETURN
0033 END

```

```

0001      SUBROUTINE MARK(BUF,PIC,ICEN,JCEN,RAD,IORG,JORG)
0002      INTEGER*2 BUF(1024),PIC(256,4)
0003      COMMON IPOINT
0004      NTOP=JCEN-RAD
0005      NBOD=JCEN+RAD
0006      IBLK=(NTOP-1)/4+1
0007      LBLK=(NBOD-1)/4+1
0008      DO 50 NBK=IBLK,LBLK
0009      READ(3,NBK) BUF
0010      INC=(NBK-1)*4
0011      DO 40 J=1,4
0012      LNCT=INC+J
0013      NDOT=MOD(LNCT, 2)
0014      IF(NDOT.EQ.0) NVAL=0
0015      IF(NDOT.EQ.1) NVAL=32767
0016      IF(LNCT.GT.NBOD) GO TO 40
0017      IF(LNCT.LT.NTOP) GO TO 40
0018      Y=LNCT-JCEN
0019      FACT=RAD**2-Y**2
0020      IF(FACT.LT.0.0) FACT=0.0
0021      IXOFF=SQRT(FACT)
0022      PIC(ICEN-IXOFF,J)=NVAL
0023      PIC(ICEN+IXOFF,J)=NVAL
0024      IF(LNCT.NE.JCEN) GO TO 21
0025      DO 20 I=1,4
0026      PIC(ICEN-I,J)=32767
0027      20 PIC(ICEN+I,J)=32767
0028      21 CONTINUE
0029      IF(LNCT.NE.JORG) GO TO 31
0030      DO 30 I=1,2
0031      PIC(IORG-I,J)=32767
0032      30 PIC(IORG+I,J)=32767
0033      31 CONTINUE
0034      IF(LNCT.GT.JCEN+4) GO TO 32
0035      IF(LNCT.LT.JCEN-4) GO TO 32
0036      PIC(ICEN,J)=32767
0037      32 CONTINUE
0038      IF(LNCT.GT.JORG+2) GO TO 33
0039      IF(LNCT.LT.JORG-2) GO TO 33
0040      PIC(IORG,J)=32767
0041      33 CONTINUE
0042      40 CONTINUE
0043      WRITE(3,NBK) BUF
0044      50 CONTINUE
0045      RETURN
0046      END

```