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Two-stage high-precision visual inspection of surface mount devices

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Abstract. *A two-stage high-precision algorithm for detecting the orientation and position of the surface mount device (SMD) is described. In the preprocessing step, a coarse orientation of the SMD is obtained by line fitting. A high-precision fuzzy Hough transform (FHT) is applied to the corner points to estimate precisely the orientation of the device, with its position determined by using four detected corner points. The FHT employed has a real-valued accumulator over the limited range of angles that is determined in the preprocessing step. Computer simulation with a number of test images shows that the parameters obtained by the presented algorithm are more accurate than those by conventional methods such as the moment method, projection method, and Hough transform methods. It can be applied to fast and accurate automatic inspection and placement systems.* © *1997 SPIE and IS&T.*
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1 Introduction

With the development of industrial electronic technology, various surface mount devices (SMDs) used in many electronic goods have been highly functional and integrated, and they have become smaller and lighter. Recently by using robots, productivity has been dramatically increased and computers can easily control a robot for mounting SMDs on a printed circuit board (PCB) automatically, precisely, and flexibly. It is reported that the pitch between SMD leads is getting smaller, for example, less than 0.5 mm,[1] the number of leads are getting larger, and the size of the devices is becoming smaller. So one of the most important things for a mounting system is to employ fast and high-precision vision algorithms for detecting the orientation and position of SMDs. If position or orientation error occurs, it is necessary to pass the detected parameters over to a robot control system to compensate for misalignment. Examples of vision based industrial applications[2] are found in several areas such as a die bonding system,[3] VLSI mask inspection,[4] PCB inspection,[5] and SMD inspection and position alignment system under special illumination.[6,7] This paper presents a fuzzy Hough transform (FHT) based algorithm for precisely detecting the orientation and position of the SMD. This algorithm can be applied to a fast and high-precision visual inspection system.

Conventional algorithms for detecting the orientation and position of the SMD are briefly reviewed. A moment method[8] which finds the line passing through the principal axis of an object can be used to detect the orientation and position of the device by calculating the first and second moments. Horn obtained the information of orientation and position from data projected along horizontal, vertical, and diagonal directions.[8] This projection method is faster than the moment method, however, for multiple objects overlapped in the projection space, it cannot detect each object correctly. In the conventional Hough transform (HT) method, each edge point was transformed by a given parametric equation, and the cell having the maximum value in the parameter space was detected to determine the final orientation. This HT based method is robust to noise, but it requires complex computations. To reduce the computation time required for the HT, only corner points were used which were detected by a contour following and corner finding algorithm.[9] Also the algorithm with subpixel accuracy using morphology[10] was presented for accurate inspection.

The HT technique is effective in finding several pieces of lines in an image with low sensitivity to noise, but it requires high computational complexity when parameters in a Hough domain require high precision. Compared to conventional methods, the proposed two-stage algorithm requires much less computation, and detects the orientation and position more precisely. In the preprocessing step, corner points are detected based on the chain codes of edge contours of SMD leads. Then the extracted corner points are separated into two groups with each group existing in opposite sides to the principal axis of the SMD. Then the coarse angle of the principal axis is obtained by averaging two angles detected by a moment line fitting algorithm with two groups of corner points.

The FHT is applied to the detected corner points of SMD leads over the limited angle range that is determined in the preprocessing step. The FHT used is different from the conventional HT techniques in accumulating the vote.

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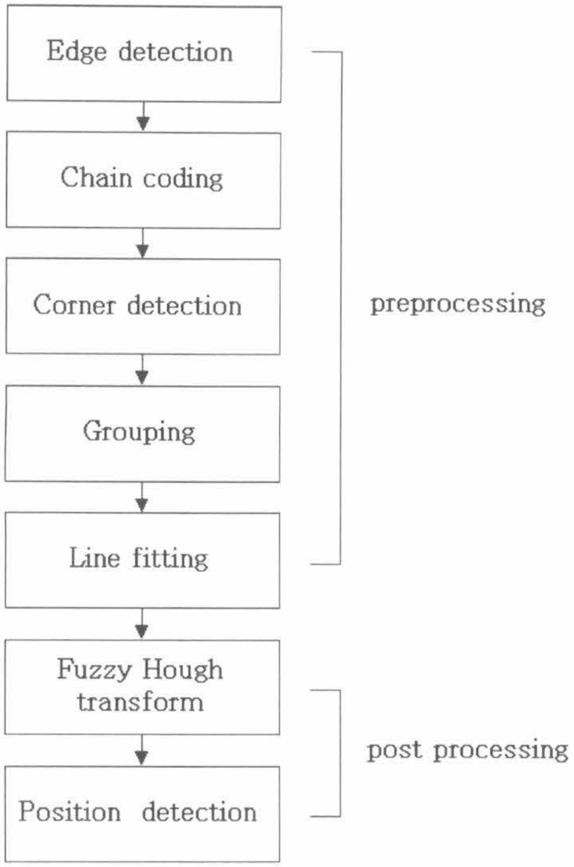


Fig. 1 Flowchart of the proposed detection algorithm of orientation and position of the SMDs.

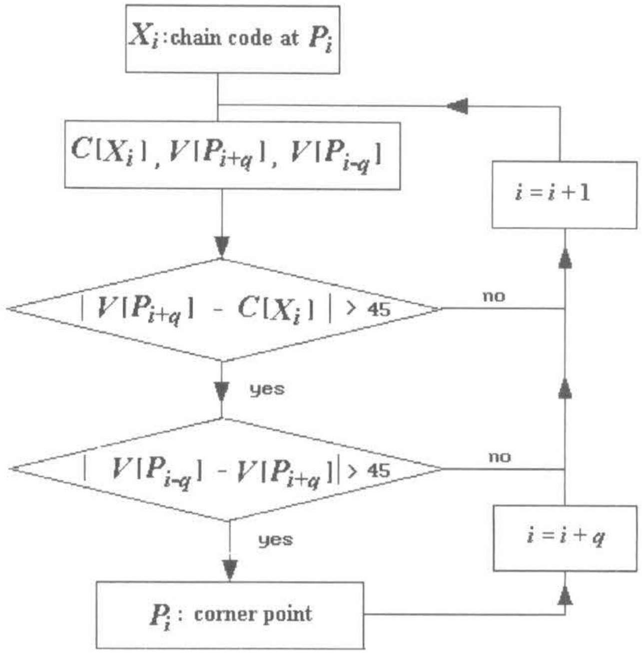


Fig. 2 Flowchart of the corner detection algorithm.

The FHT uses a real-valued accumulator to employ a real membership function that is centered at a parameter value computed. The results of the FHT are better than those of the conventional HT. The limited angle range in the HT is determined by the coarse angle obtained in the previous step. Thus the orientation of the SMD can be detected more precisely with much finer resolution of the Hough array. The SMD position may also be determined by using the detected orientation and its four corner points.

2 Detection of the Orientation and Position of the SMD

A two-stage algorithm that detects the orientation and position of the SMD based on the FHT is proposed in this paper. A preliminary version of this paper was presented in Ref. 11. It consists of preprocessing and post processing steps, as shown in Fig. 1. Each unit is briefly described in the following.

2.1 *Preprocessing Step*

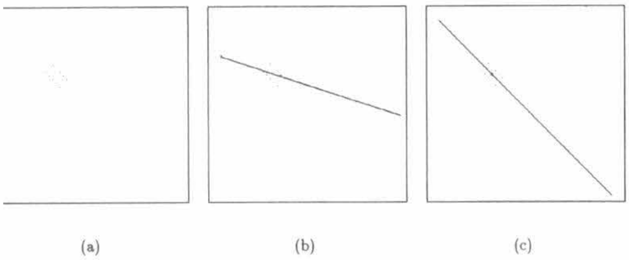
The detection algorithm analyzes a gray level image of the SMD. In a preprocessing step, its boundary points as well as corner points are detected. Based on coordinate values of extracted corner points, two groups are formed with each group existing in the opposite side with respect to the principal axis of the SMD. Then the coarse orientation of the principal axis is obtained by averaging two angles detected by a moment line fitting algorithm.

First, the gray level image is smoothed for noise reduction and the smoothed image is converted to a binary image by thresholding. Then boundary points are detected and represented by chain codes,[12] in which an initial point and a set of successive 8-directional vectors are specified. Corner points of the SMD are feature points describing its boundaries. There are several methods[13] to detect them from the given chain codes. In this research, we extract them by tracing directional vectors which are represented by the difference chain codes.

The flowchart of the corner extraction algorithm is shown in Fig. 2. Let X_i represent the chain code at point P_i, and $C[X_i]$ denote the chain code value at point P_i represented as an integer multiple of 45 (degrees). For example, $C[X_i]$ is equal to 90 (degrees) if the chain code X_i is equal to 2.

If two conditions $|V[P_{i+q}]-C[X_i]|>45$ (degrees) and $|V[P_{i-q}]-V[P_{i+q}]|>45$ (degrees) are satisfied, the point P_i is determined as an edge point, where $V[P_{i-q}]$ represents the angle in degree between the horizontal line and a line connecting two points P_{i-q} and P_i. The angle $V[P_{i+q}]$ is similarly defined. We select q experimentally, ranging 4 to 12, depending on the noise level of an input image and the type of the SMD.

Next, detected corner points are separated into two groups that are located in the opposite sides with respect to the principal axis of the SMD. Then each group is fitted to a line and the fitted line is used to detect the coarse orientation. Let c_i denote the detected corner point, $1 \leq i \leq I$, where I signifies the number of corner points, and $V(c_{i+1})$ represent the angle in degree between the horizontal line and a line connecting current corner point c_i and the next



ig. 3 Extracted corner points and the detected principal axis. (a) xtracted corner points. (b) Line fitting by the least-squares method. c) Line fitting by the moment method.

ne c_{i+1}, then a grouping algorithm is described as fol- ows:

1. Initialize i.
2. Calculate $V(c_{i+1})$.
3. If $V(c_{i+1})$ is different from the angle of grouping vectors previously detected and stored in memory, c_{i+1} is determined as a new starting corner point and it forms a new group.

Each group of corner points extracted in the previous tep forms two parallel lines. Figure 3(a) shows an example f detected corner points. Detection of the coarse orienta- ion may be performed by the line fitting method. However, ote that we may obtain the incorrect orientation with the east-squares line fitting method, as illustrated in Fig. 3(b). The line fitting method is somewhat sensitive to noise, thus he final detection of orientation is achieved by the high- recision HT that is robust to noise.

To obtain the exact orientation, we use the moments of nertia[14] of edge points forming two parallel lines. Let M_{ij} lenote the $(i+j)$'th moment as given by

$$M_{ij}=\sum_x \sum_y (x-x_0)^i(y-y_0)^j f(x,y), \quad (1)$$

vhere $f(x,y)$ represents the gray level at (x,y), and $x_0,y_0)$ denotes its centroid as defined by

$$x_0=\frac{\Sigma_x\Sigma_y x f(x,y)}{\Sigma_x\Sigma_y f(x,y)}, \quad (2)$$

$$y_0=\frac{\Sigma_x\Sigma_y y f(x,y)}{\Sigma_x\Sigma_y f(x,y)}. \quad (3)$$

Ve determine the orientation α of the SMD by minimizing he cost function E defined by

$$E=\sum_x \sum_y d^2(x,y) f(x,y), \quad (4)$$

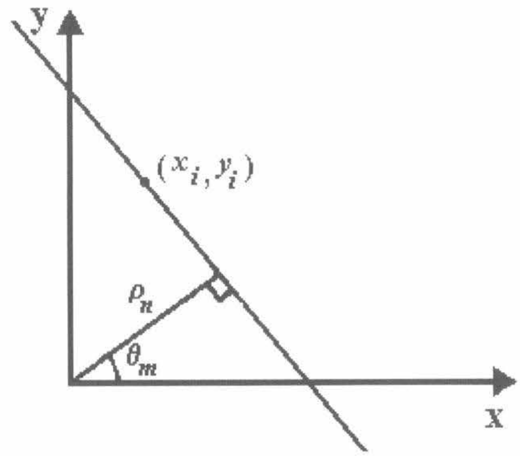


Fig. 4 Hough transformation to the ρ-θ parameter space.

where $d(x,y)$ denotes the distance to the fitted line from a point (x,y).[8] The orientation α is calculated by

$$\alpha=\frac{1}{2}\tan^{-1}\frac{2M_{11}}{M_{20}-M_{02}}, \quad (5)$$

where α represents the angle between the fitted line and the x axis. As shown in Fig. 3(c), the moment line fitting gives better results than the least-squares line fitting method.

2.2 *Post Processing Step*

In the post processing step, the final orientation of the SMD is determined. In this paper, an FHT is applied to the detected corner points over the limited angle range centered at the coarse orientation value computed in the preprocessing step. Also its position is detected by using the four corner points.

The HT[15] is a well-known method for extracting line segments in an image. Dominant line segments are detected by finding the peak parameter values in the HT domain. The line equation passing through a point (x_i,y_i) can be expressed as

$$\rho_n=x_i \cos\theta_m+y_i \sin\theta_m, \quad (6)$$

where ρ_n denotes the distance to the line from the origin and θ_m signifies the angle between the x axis and the line perpendicular to the detected line. Figure 4 shows a line and its Hough transformation to the ρ-θ parameter space. The coordinate value (x_i,y_i) in a $D_x\times D_y$ image plane is transformed into the parameter space (ρ,θ). Then the parameter indices n and m satisfy the inequalities as given by

$$-\frac{\sqrt{D_x^2+D_y^2}}{\rho_q}\leqslant n\leqslant\frac{\sqrt{D_x^2+D_y^2}}{\rho_q}, \quad 0\leqslant m\leqslant\frac{180}{\theta_q}, \quad (7)$$

where ρ_q and θ_q denote the quantization step sizes of ρ and θ, respectively. The angle is assumed to be in the range of 0 and 180 degrees.

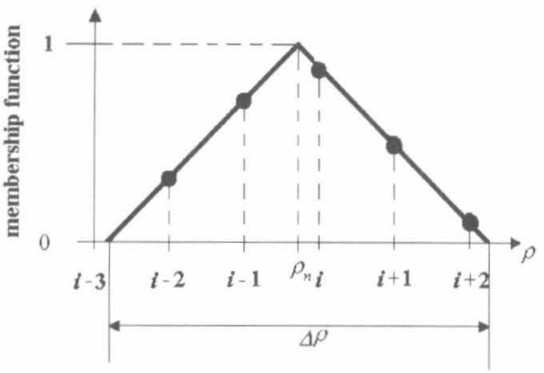


Fig. 5 FHT accumulator.

In the conventional HT, though ρ is real, the paramete space (ρ,θ) is incremented by one. But in the FHT en ployed, the parameter space (ρ,θ) accumulates the rea value. Figure 5 shows an example of the real-valued acc mulation process of the FHT using a triangular membershi function, where ρ_n is located between the $(i-1)$'st and i't cells. The point ρ_n calculated by Eq. (6) has a weight fact of one, and adjacent integer points have real weight valu specified by a membership function centered at ρ_n. In th case of noisy images, the FHT gives better results than th conventional HT. The membership functions considered i our experiments are shown in Fig. 6. Two-dimensional e ponential, circular, and triangular membership function

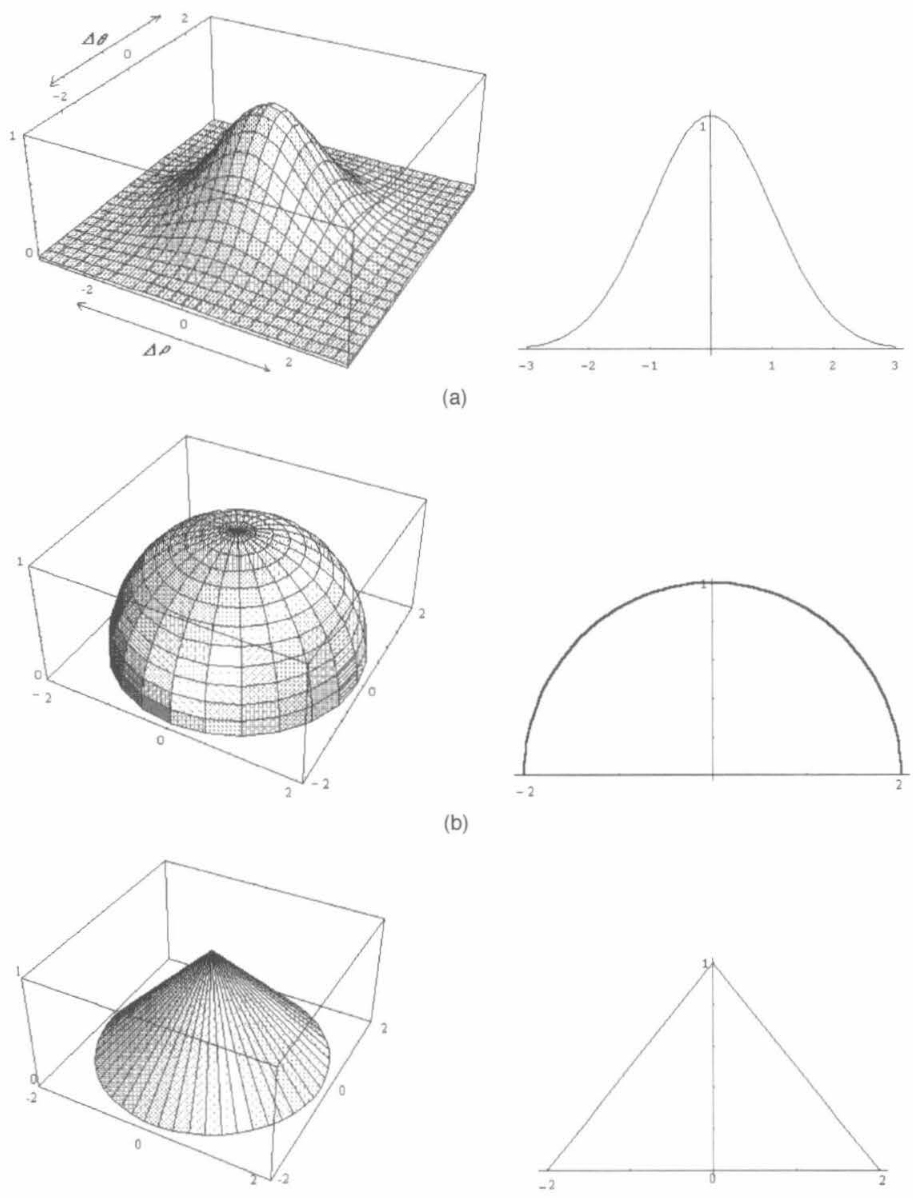


Fig. 6 Membership functions employed in FHT. (a) Exponential membership function. (b) Circular membership function. (c) Triangular membership function.

along with their 1-D profiles are shown in Figs. 6(a), 6(b), and 6(c), respectively. The proposed algorithm was simulated with several fuzzy membership functions: 2-D membership functions applied to the ρ and θ axes, and 1-D membership functions applied only to the ρ axis. In our experiments, both the width $\Delta\rho$ and $\Delta\theta$ are selected experimentally and set to 5.

After transformation, the cell having the highest vote is selected. The accuracy of orientation detection depends on the quantization step size of an angle. In the post processing step, detection of orientation is performed over the limited range centered at the angle detected roughly in the preprocessing step. Note that we use only corner points of SMD leads and detect precisely its orientation using by the high-precision FHT.

The position of the SMD may also be determined using a grouping algorithm in the preprocessing step. After extracting four corner points, its position is determined as an intersecting point determined by two diagonal lines.

The presented algorithm requires a high-quality image for good performance, in which binarization is employed. The threshold value for binarization is a critical value for good performance of the algorithm. So a perfect backlighted image without impulse noise is required. If the detected edge is blurred or not reliable, the algorithm might yield the angle or position different from the accurate one.

3 Experimental Results and Discussions

Computer simulation is performed on a MIPS workstation using C language. Each input image is 512×512 and it is uniformly quantized to eight bits. Figure 7 shows eight test images which are used in experiments. The whole test images were captured by a camera with backlighting. Test images in Figs. 7(a), 7(b), 7(c), and 7(d) are rectangular-type SMDs with 14 pins. Their orientations are 0, 5, −6, and 7 degrees with their positions being (226, 253), (238, 241), (202, 274), and (249, 268), respectively. Note that the position is defined by the center coordinate of the device, with (0,0) representing the top left point of an image. The orientation is represented by an angle between the principal axis of the SMD and the horizontal x axis. The test images in Figs. 7(e), 7(f), 7(g), and 7(h) are the square quad flat package (QFP) type SMDs with 80 pins. Their orientations are 3, −1, 1, and −4 degrees with their positions being (274, 281), (272, 240), (251, 281), and (266, 283), respectively.

Figure 8 illustrates extracted corner points of test images shown in Fig. 7, where the symbol × shows grouping points. Blunt leads of the SMD cause slight positional error in detecting orientation. Table 1 lists the preprocessing results, where the detected angle is obtained by averaging two angles computed from two lead groups. Table 1 shows that the preprocessing step gives coarse orientations of the devices and a small amount of error exists due to noise.

A performance comparison of various orientation detection methods is listed in Table 2. Also Fig. 7 shows the final results with detected center position represented by a white dot and orientation by a line. Orientation detection by the HT is equivalent to selecting a peak in the Hough array cell. If the maximum value occurs at multiple cells which are adjacent, the final orientation is determined by averaging their orientation angles. The original HT method using all the edge points detected requires high computational complexity. In computer simulations, the θ-resolution of the proposed technique in the HT is set to 0.01, 0.02, and 0.05 degree, and the search angle range is set to ±2 degrees from the coarse orientation detected in the preprocessing step.[11] In the proposed two-stage algorithm, high precision in orientation and position is accomplished by small parameter resolution whereas reduction in computation time is achieved by small search angle range, which is possible by coarse detection of orientation in the preprocessing step. Note that moment and projection methods cannot be applied to QFP types, because the moment of inertia is diagonal for perfectly symmetric QFP types. For example, for test images in Figs. 7(e) through 7(h), the moment and projection methods detect the orientation incorrectly while the proposed algorithm can detect it correctly (see Table 2). The presented algorithm employs a 2-D exponential fuzzy membership function that produces better results than any other membership functions shown in Fig. 6. Note that the polarity of the SMD is not considered; in other words, the orientation of a rectangular SMD has a periodicity of 180 degrees and that of a QFP type SMD has a periodicity of 90 degrees. Thus the orientation of a rectangular SMD ranges from −90 to 90 degrees and that of a QFP type SMD ranges from 0 to 90 degrees.

A performance comparison of various position detection methods is listed in Table 3. In terms of the accuracy of position detection, the performance of the presented algorithm is better than that of the conventional algorithms. Note that the accuracy of the detected position by the presented algorithm is higher than that of the conventional algorithms.

A comparison of the computation time is illustrated in Table 4. As observed in Table 4, the computational complexity of the presented algorithm is greatly reduced by the preprocessing step, compared with that of the conventional HT method. The search angle range is set to ±2 degrees from the coarse orientation. If the search angle range is further decreased, it can further reduce the computation time.

4 Conclusions

This paper presents a two-stage high-precision algorithm using the FHT for detecting the orientation and position of the SMD. The presented algorithm consists of two steps: a preprocessing step and post processing step, in which corner points of the SMD are detected and the FHT is applied to only corner points over the limited range of angles determined by the preprocessing step. Note that high precision in orientation and position detection, and reduction in computation time are achieved by the coarse detection of orientation in the preprocessing step. Computer simulation shows that the presented algorithm gives better performance than other conventional algorithms with lower computational complexity and higher precision in orientation. Further research will focus on the development of the faster and more precise visual inspection algorithm, and on investigation of its hardware implementation.

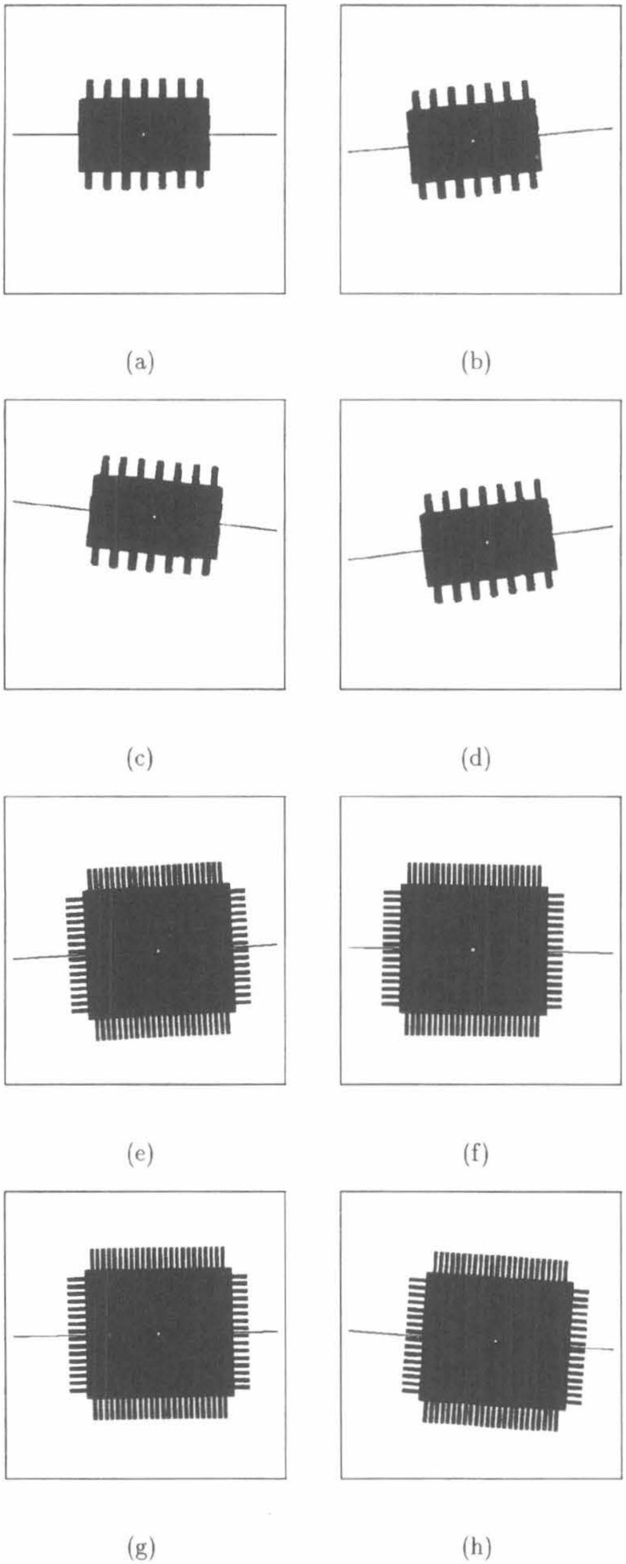


Fig. 7 Test images.

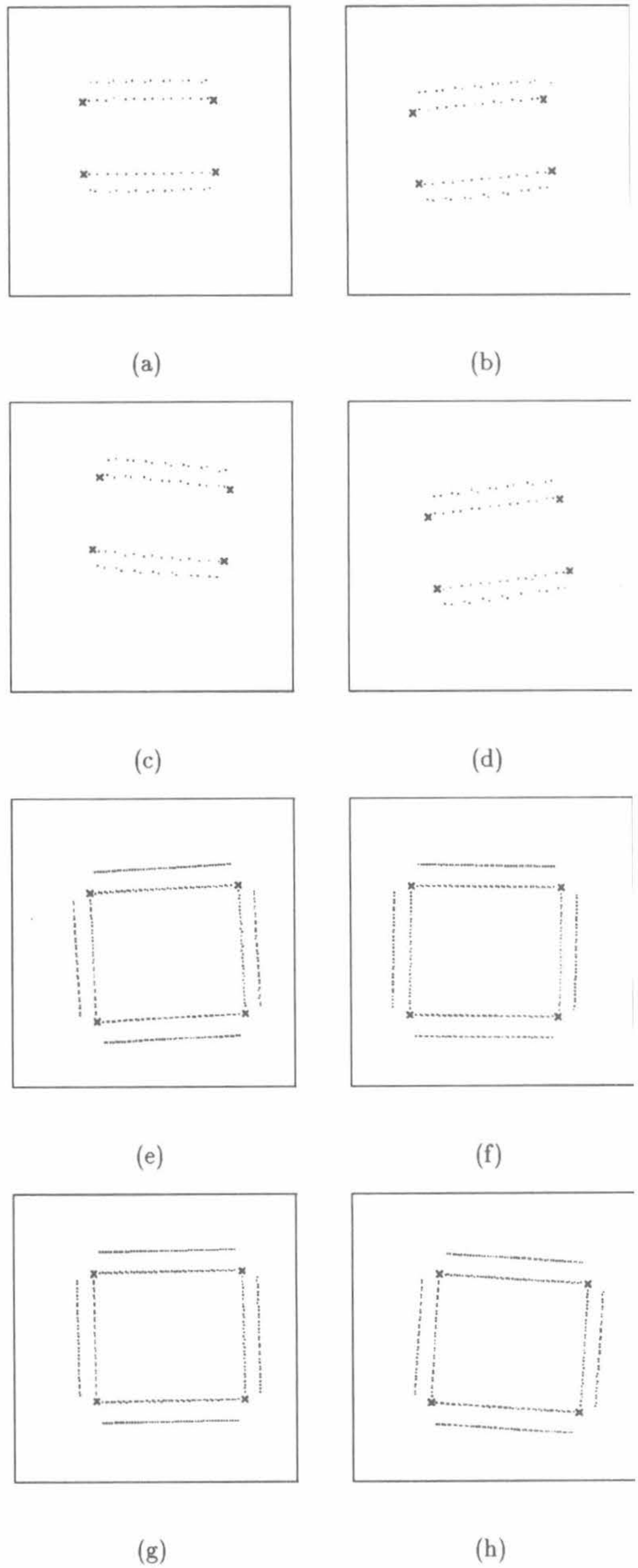


Fig. 8 Extracted corner points of Fig. 7.

Table 1 Line fitting results in the preprocessing step (unit: degree).

test images	orientation: detected	orientation: correct
Fig. 7(a)	0.682	0
Fig. 7(b)	5.349	5
Fig. 7(c)	−5.349	−6
Fig. 7(d)	7.519	7
Fig. 7(e)	3.023	3
Fig. 7(f)	−0.912	−1
Fig. 7(g)	0.806	1
Fig. 7(h)	0.445	−4

Table 2 Results of orientation detection (unit: degree).

methods				test images: Fig. 7(a)	Fig. 7(b)	Fig. 7(c)	Fig. 7(d)	Fig. 7(e)	Fig. 7(f)	Fig. 7(g)	Fig. 7(h)
moment[8]				0.738	5.702	−5.264	7.696	2.912	−5.273	−0.779	−3.772
projection[8]				0.098	5.094	−6.056	7.119	−0.953	−5.279	−3.146	−7.528
Hough	edge		1	1.000	5.750	−5.250	8.000	3.500	−1.250	1.250	−4.125
Hough	corner		1	1.000	6.000	−6.500	7.725	3.500	−1.250	−1.500	−4.000
Hough	Proposed	non fuzzy	0.01	0.190	5.040	−5.780	7.340	3.030	−1.175	1.010	−4.030
Hough	Proposed	non fuzzy	0.02	0.124	5.040	−5.770	7.340	3.040	−1.180	1.020	−4.030
Hough	Proposed	non fuzzy	0.05	0.125	5.250	−5.750	7.200	3.100	−1.175	1.050	−4.025
Hough	Proposed	2-D Exponential Fuzzy	0.01	0.005	5.000	−5.991	7.005	3.000	−1.010	1.000	−4.000
Hough	Proposed	2-D Exponential Fuzzy	0.02	0.030	5.032	−5.974	7.014	3.010	−1.030	1.000	−4.000
Hough	Proposed	2-D Exponential Fuzzy	0.05	0.085	5.070	−5.985	7.075	3.040	−1.050	0.995	−4.010
correct orientation				0.0	5.0	−6.0	7.0	3.0	−1.0	1.0	−4.0

Table 3 Results of position detection.

test images	methods: moment[8]	projection[8]	proposed method (fuzzy)	correct position
Fig. 7(a)	(225, 252)	(225, 253)	(226.88, 253.14)	(226, 253)
Fig. 7(b)	(239, 241)	(239, 241)	(238.10, 241.02)	(238, 241)
Fig. 7(c)	(201, 274)	(201, 274)	(202.01, 274.00)	(202, 274)
Fig. 7(d)	(249, 268)	(249, 268)	(249.01, 268.05)	(249, 268)
Fig. 7(e)	(120, 136)	(120, 136)	(120.20, 136.00)	(120, 136)
Fig. 7(f)	(272, 241)	(272, 241)	(272.02, 240.01)	(272, 240)
Fig. 7(g)	(251, 281)	(251, 281)	(251.00, 281.03)	(251, 281)
Fig. 7(h)	(265, 283)	(266, 283)	(266.01, 283.03)	(266, 283)

Table 4 Comparison of the computation time.

methods	moment[8]	projection[8]	Hough transform (edge points)	Hough transform[9] (corner points)	proposed methods: non fuzzy	proposed methods: fuzzy
time (sec)	0.32	0.29	8.02	2.10	0.17	0.42

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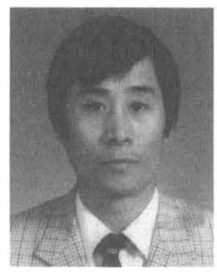

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BOOK REVIEWS

Computer Visualization

Richard S. Gallagher, Ed. 352 pages. ISBN 0-8493-9050-8. CRC Press, Boca Raton, Florida (1994) $79.95.

Reviewed by Lawrence A. Ray, Eastman Kodak Company, Transaction Imaging, Rochester, New York 14650-0312.

Anyone who has ever used a graph as a means of understanding data and mathematical concepts has already stepped into the realm of scientific visualization. However, this step is but the first of a longer journey into the potential of viewing data, and the insights that can be achieved when the power of computer graphics is applied. While it seems quite natural to view data in terms of graphs and charts, the use of computer visualization via computer graphics is a relatively recent phenomenon. The purpose of this book is to expose the scientific community to the techniques and methods of computer visualization.

This book is an edited collection of chapters, and as many such books, suffers from an irregular presentation and depth of content. On the whole it is a fair treatment of the subject and is a reasonable introduction to the topic. A natural use of scientific visualization is for computer-aided engineering, as the depiction of data sets on some engineering part. The use of false color-coded data across the surface representing some quantity, such as heat or stress, is obvious. What is not so obvious are the methods of conveying dynamic motions, flows, and time-dependent phenomena in an easy to understand manner. Finding the right paradigm to display data which simplifies the viewers' insight into a phenomenon is an art. One good aspect of this book is that it presents many instances where this occurs.

Richard S. Gallagher, the editor, is the head of computer graphics at Swanson Analysis Systems, a producer of CAD software. This is perhaps one reason the book seems largely written from the perspective of engineering. My objection to this is that the book advertises itself to be scientific visualization, not strictly engineering visualization. The methods and approaches to other areas of visualization, such as molecular modeling, turbulence, and mathematics, are not presented as well as one would hope.

The book is segmented into three sections, with a total of ten chapters. The sections are introductory material, techniques, and application issues. The first chapter is the required introduction to the material, which is heavily weighted in terms of engineering applications, followed by a chapter that contains a brief description of computer graphics. Since a single chapter can hardly begin to encompass the field of computer graphics, the chapter is a high level overview of some of the most basic concepts. If one is already familiar with computer graphics, then the chapter can be omitted.

The most substantive material is in the section on techniques. Among the chapters of this section, the best chapters describe a unified framework for flow visualization and continuum volume displays. Both of these chapters break away from strict engineering methods and look at more general methods. In particular the use of flow fields, vector traces, and icons to represent data in a coherent manner are explored. Visual exploration of volumetric data brings a host of new problems. Being able to query the interior of volumetric data and methods of how to extract data in an efficient manner are described. The "Marching Cubes" algorithm is also touched on. Extracting isosurfaces within a volume is not a simple operation and one that if not done properly results in an unsatisfying visual result.

The chapter on producing animations is rather shallow. It is, at best, hints for the novice. Most of the information will become immediately apparent to anyone attempting to produce an animation and then have it recorded into a video format. Since it is unlikely that someone will purchase the equipment to perform this task without first gaining some experience by working with a knowledgeable person, the value of the chapter is limited.

Despite some of its shortcomings, this book is still worthwhile to one interested in computer visualization. A potential reader should be aware of its bias toward mechanical engineering. While it is not adefinitive treatment of the subject, it provides a valuable appreciation of what can be gained and what is required.

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1997 AUTHOR INDEX

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