# MORPHOLOGICAL SKELETON ALGORITHM FOR PDP PRODUCTION LINE INSPECTION

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## ABSTRACT

Morphological skeletonization is an image processing technique that reduces complex, thick-lined images to a series of single pixel lines that accurately represent the original shapes. This procedure is especially useful to simplify automated applications requiring simple shape analysis and continuity checking by reducing the amount of redundant image data. In the semiconductor inspection field, skeletonization is a process that can be used to detect defects during plasma display panel (PDP) inspection. This paper will introduce a novel morphological skeletonization algorithm developed for electrode pattern inspection of PDPs. This algorithm has been successfully integrated within a commercial machine vision system.

## 1. INTRODUCTION

Skeletonization is a process designed to reduce objects in any binary image to a set of single pixel lines that are an accurate representation of the overall original shape. Research has been conducted in the field of image processing to determine various methods to efficiently perform skeletonization.

Various optical inspection systems developed at V Technology (a Japanese-based high technology company) utilize skeletonization as a key process in the computerized detection of manufacturing defects. By reducing complex images to a simple set of basic features, including intersections and endpoints, defect analysis can be performed more easily.

The purpose of this investigation is to research the development of a new skeletonization algorithm. It was prompted by the shortcomings of the existing skeletonization procedure which prevented it from correctly skeletonizing circles. The goal of this research is to provide a new technique that properly reduces circles to dots and more accurately maintains the shapes of objects during the skeletonization process. The new algorithm is designed to overcome the problems with the traditional method.

This paper first explains the concept of skeletonization. It describes the design criteria for a new skeletonization algorithm, its development, and the outline of some application-specific modifications which can be made to deal with various input and output requirements. Also, the feature point classification and its direction code based matching method for defect inspection are introduced and demonstrated with PDP images.

## 2. BACKGROUND

### 2.1. Skeletonization Overview

A skeleton can be defined as a connected set of medial lines along the limbs of a figure [1]. Skeletonization describes a thinning process designed to operate on binary images and reduce them to this set of single pixel lines. To obtain a skeleton of the original image, successive passes of a skeletonization algorithm are applied until the output from this operation does not change from the input.

The ideal skeleton is intuitively pleasing, but a direct implementation is very difficult and computationally intensive [2]. Instead, an iterative or recursive technique is often implemented which simplifies the process but only approximates the skeleton. Many such implementations are possible, but typically they work by repeatedly stripping layers off the outside of shapes in a binary image until a skeleton is obtained. Though most iterative or recursive methods do not yield ideal skeletons, for most purposes, the results are still useful and describe the original images quite well.

Skeletonization eliminates redundant information while retaining only the topological information about the shape of the form [1]. This is ideal when a machine must process the image. The information that is removed is often not necessary to the analysis and eliminates confusion and complexities in the original image.

In a large number of applications, such as PDP inspections, analysis of every pixel of the skeleton is not necessary. As a result, the skeletonization engine actually eliminates the majority of the data and returns only those "features" of the skeleton which are needed for processing.

### 2.2 Traditional Method

There are two algorithms which have been implemented and tested for comparing with our new method. The first is the Zhang and Suen Two Step Approach [4] and the second is the Davies' Four Step Approach [1]. Both of these are commonly used skeletonization algorithms that have been implemented directly from their textbook descriptions. Each works by examining the image, one 3x3 region at a time, and mathematically determining whether to keep or remove the centre pixel.

The Zhang and Suen Approach strips pixels from the outside of a binary object - first from the northwest and then from the southeast. Gonzalez and Wintz give a full development of this approach [2].

The advantages of this approach is that since this algorithm requires only two cycles to strip an entire set of pixels from the outside of an object, it is considered quite fast. The problem with this approach is that it works well only with non-rotated rectangular based shapes which are approximately aligned with the pixel axes. This is sufficient for maintaining the shape of square lines, but other shapes are not preserved nearly as well through this skeletonization process. Another problem found, experimentally, with this algorithm is the complete erosion of 2x2 squares. This means that any object which starts as a 2x2 square or becomes a 2x2 square during the skeletonization process will disappear completely from the image. This presents a significant problem for the final PDP defect image analysis stages.

The four step approach, which Davies describes in [1], is the algorithm usually used for skeletonization. This algorithm has fewer problems than the Zhang and Suen approach. Some of the details of this process must be described because they are the basis for the new approach.

The *crossing number* $\chi$ (chi) is a quantity used by the thinning algorithm when determining pixel deletion. The crossing number of any particular 3x3 neighbourhood is defined as the total number of 0-to-1 and 1-to-0 transitions encountered while travelling once around the 8 bits bordering the neighbourhood. In essence, it is a measurement of twice the number of possible connections joining this 3x3 region to the surrounding ones. Davies presents a discussion of various methods for determining $\chi$.

The *neighbourhood sum* $\sigma$ (sigma) is another quantity used in the thinning algorithm to determine if a given pixel should be removed. $\sigma$ is the sum of the eight pixels around the outside of the current 3x3 neighbourhood. If this value is equal to 1, the current pixel is the endpoint of a line. If endpoints are to be preserved, a pixel cannot be deleted if $\sigma=1$.

Davies' approach is based on the two quantities defined above. A pixel will be removed only if $\sigma\neq1$ and $\chi = 2$. These criteria ensure that endpoints of lines are preserved and that the pixel being examined is not a vital connecting point between two parts of the object.

The advantages of this approach is that i works relatively well with all kinds of shapes, although not perfectly. It does not consume 2x2 objects like the Zhang and Suen algorithm does. It can be configured to absorb or leave endpoints depending upon the requirements of the application. The problems with this approach is that circles do not skeletonize to dots. They do not remain circular during the skeletonization process. Instead, they become diamond shaped. These diamonds then skeletonize to crosses. Figure 1 depicts the results of skeletonizing a circle with Davies' algorithm.

The Zhang and Suen approach can completely skeletonize circuit traces of width $n+1$ pixels or less in $n$ passes. This process has half that efficiency and requires $2n$ to accomplish the same amount of skeletonization.

## 3. NEW MORPHOLOGICAL SKELETON ALGORITHM

### 3.1 Design Criteria

There are three main criteria that the new algorithm must meet. This algorithm must (1) be at least as fast as the traditional algorithm, (2) skeletonize circles to dots, and (3) not have the

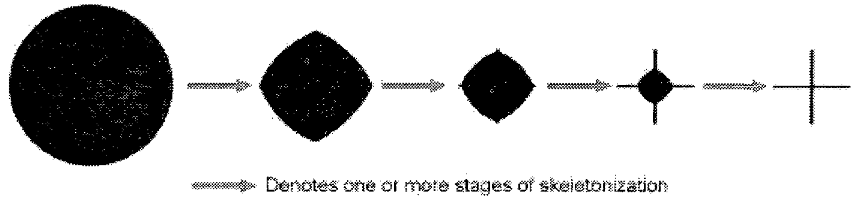


Figure 1: Skeletonization Problem with Davies' Algorithm

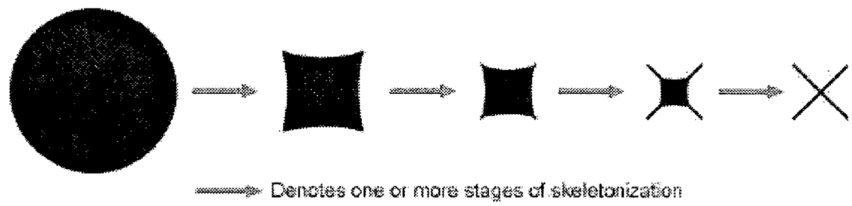


Figure 2: Skeletonization with Strict Directional Points

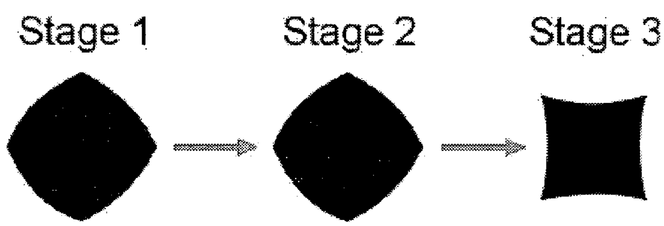


Figure 3: The Three Stage Approach

disadvantages of either the Zhang and Suen approach in [4] or Davies' approach in [1].

### 3.2. The Modified Four Step Algorithm

To produce an unbiased skeleton and obtain a set of truly medial lines, it is critical that pixels be removed as evenly as is possible from the outside of objects [1]. Research was conducted using Davies' approach in [1]. An attempt was made to improve upon the existing algorithm rather than developing an entirely new procedure.

A modification was made to the definition of a directional point. Instead of defining the directional points to include the diagonals, as Davies' did, only the horizontal and vertical points were included. Tests were done using these newly defined strict direction points. Now, instead of consuming diagonals in two of the four cycles, they were not consumed at all. This yielded an output as depicted in Figure 2. This output was then compared to that of the original algorithm as seen in Figure 1.

These outputs appear to be geometric opposites of one another. One consumes diagonals quickly while the other consumes horizontal and vertical directions quickly. This was the motivation behind the development of the final algorithm. If these algorithms are combined, each can cancel out the negative effect of the other - in essence, preserving the overall shape of the image.

Experimentally, it was determined that the best results were obtained if these two techniques were combined in a 2:1 ratio. This yielded a three stage approach which is shown in Figure 3. Stages 1 and 2 are both Davies' existing algorithm, and stage 3 is the modified approach.

This leads to a twelve step procedure. Figures 5 and 6 (placed on the last two pages of the paper) illustrates a series of real-world test images as well as their skeletonized results. It contains both the outputs obtained using the original skeletonization from Davies' approach [1] and the modified algorithm.

## 4. FEATURE POINT CLASSIFICATION

The final skeletonized image is often processed in order to perform some form of analysis. For PDP inspection systems, the skeletonization itself is performed on hardware module. The final stage of the inspection is an analysis of this skeletonized image. Since this step is computationally difficult it is performed on a host computer, so the skeletonization output must be transferred to the host for analysis.

Instead of transferring the entire skeletonized image, which would be time consuming due to the size of image and the bandwidth available, the final stage of the skeletonization process performs feature classification. Since the analysis of these features only requires the knowledge of a given 3x3 neighbourhood, this can be performed in the existing skeletonization architecture. This stage reduces the image to a set of feature codes. For example, in the analysis of circuits, the only points of interest are the endpoints or intersections of traces. These main defect categories permit the detection of circuit breaks or shorts and solder splashes. All other skeleton pixels can be eliminated, reducing the image to feature codes consisting of endpoints, T-junctions and cross or X-like intersections. Examples of these are shown in Figure 4.

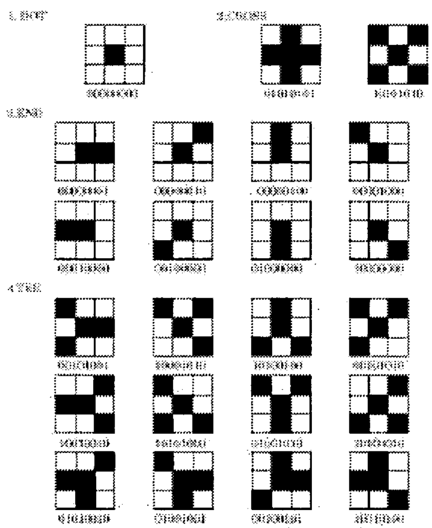

Figure 4. Examples of feature codes used for classification of PDP defects.

## 5. DIRECTION CODE BASED FEATURE POINT MATCHING

Defect inspection is performed in a simple manner. For every feature point, with the help of their feature type and feature directions, the surround feature points are searched. If targets are found, the direction code may or may not be matched by one of the codes in Figure 4. In this manner, several types of defects can be identified eg. OPEN, SHORT. This methodology is designed especially to detect electrode defects in PDPs.

## 6. SUMMARY

The new skeletonization algorithm has been demonstrated to be an improvement over existing techniques. The algorithm has been successfully implemented within a PDP inspection machine in use by popular PDP manufacturers eg. Panasonic, NEC, Pioneer, etc.

## References


[1] Davies, E. R. *Machine Vision: Theory, Algorithms, Practicalities*, (Second Edition) San Diego: Academic Press, 1997. pp. 151-163.

[2] Gonzalez, Rafael C. and Wintz, Paul. *Digital Image Processing*, (Second Edition) Massachusetts: Addison-Wesley Publishing, 1987. pp. 398-403.

[3] Belanger, Richard P. "Morphological Processing System," United States Patent. Massachusetts, 15 September 1992. Sections 1-10.

[4] Zhang, T.Y. and Suen, C.Y. "A Fast Parallel Algorithm for Thinning Digital Patterns." *Communication of the ACM*, vol. 27, no. 3. 1984. pp. 236-239.

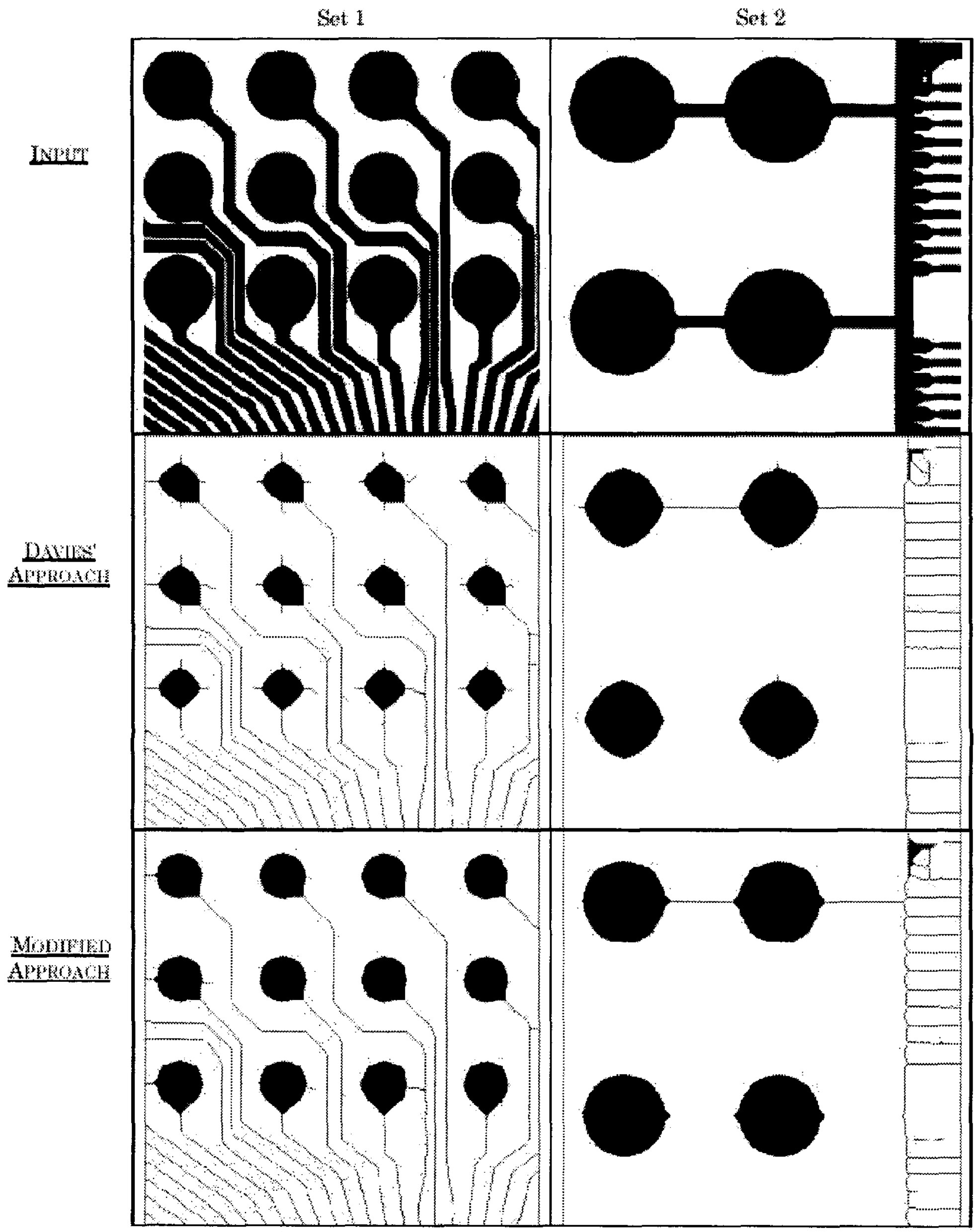


Figure 5: Comparing results

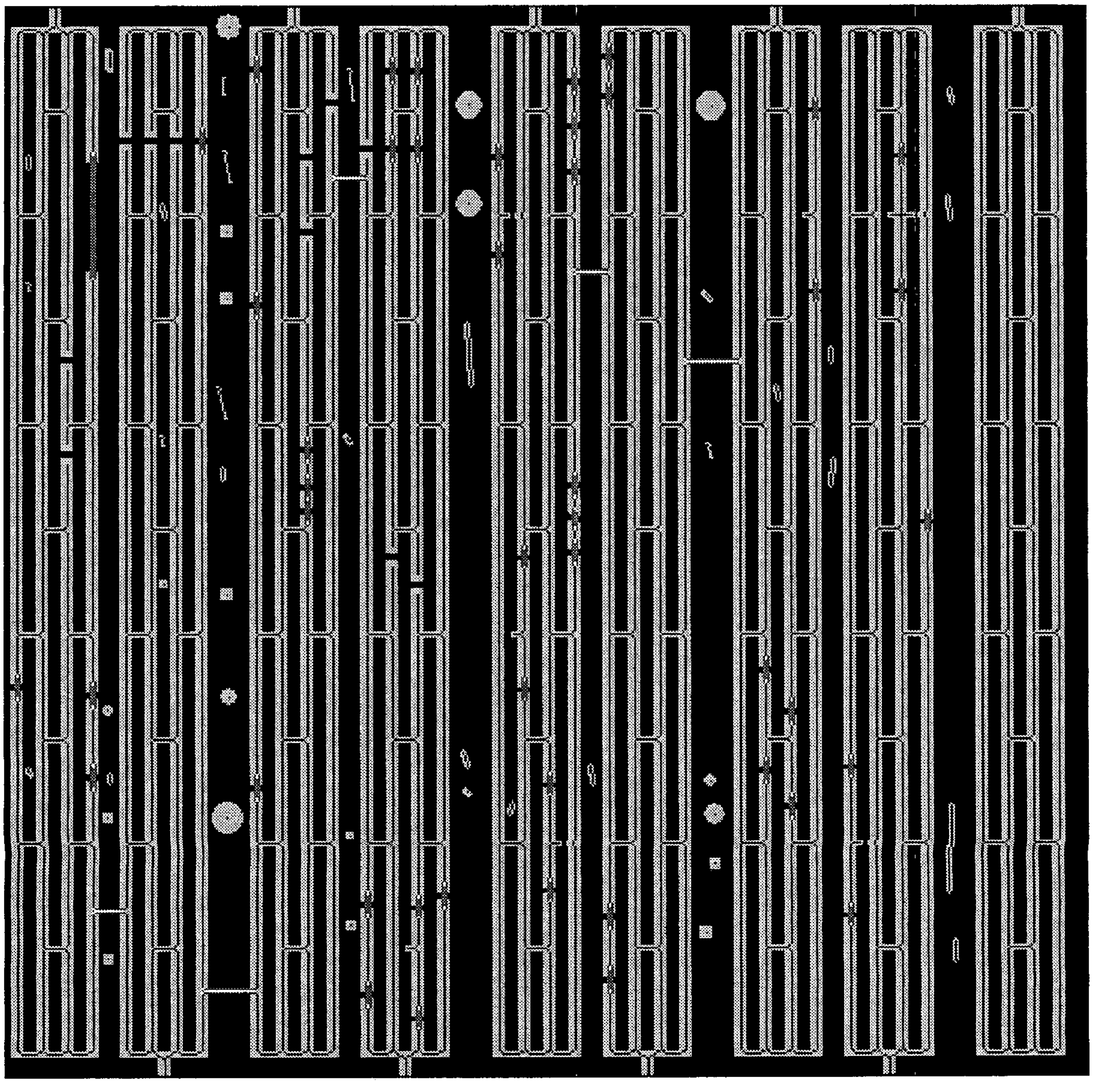

Figure 6: Example of Direction code based feature point matching for defect inspection of PDP.
( Note that red indicated defects.)