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Industrial Parts Recognition and Inspection by Image Morphology

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ABSTRACT

Mathematical morphology applied to image processing which deals directly with shape is a more direct and robust approach to feature measurements than traditional techniques. This paper focuses on application algorithms for industrial parts and tool recognition and inspection by image morphology techniques. A recursive adaptive thresholding algorithm transforms a gray level image into a set of multiple level regions of objects. This algorithm uses a morphological erosion with a large size symmetrical concave structuring element. A distance transformation algorithm transforms these binary image regions into the minimum distance from each object point to the boundary of the object. This algorithm uses a morphological erosion. From the distance transform, we can compute a shape number and extract the skeleton which is useful for generic pattern recognition and feature extraction. We can identify, locate, and estimate the angle of corners, and identify, locate, and estimate the radius of circular holes by using morphological openings and erosions. These algorithms allow robust tool and parts recognition and inspection.

1. INTRODUCTION

Mathematical morphology, which is based on set-theoretic concepts, extracts object features by choosing a suitable structuring shape as a probe. It was first investigated by G. Matheron [1] at the Paris School of Mines and extended by F. Meyer [2], J. Serra [3], and S. Sternberg [4]. A tutorial on mathematical morphology was written by R. Haralick and S. Sternberg in 1987 [5].

Most morphological hardware architecture implementations are limited to a fixed structuring element size. Hence, the capability of decomposing large non-linear structuring element operations into smaller morphological operations is extremely important and is discussed in [6]. Gray scale dilation and erosion can be computed very fast by using the architecture of threshold decomposition of gray scale morphology into binary morphology [7].

The paper is divided into three parts. Section 2 analyzes a recursive adaptive thresholding algorithm which uses an adaptive symmetrical concave structuring element. Section 3 introduces a distance transformation algorithm and a shape number. Section 4 discusses feature extraction for corners and circular holes.

2. RECURSIVE ADAPTIVE THRESHOLDING

Industrial parts, made from different material with various surface texture, may reflect different gray values. Gray values also vary with lighting conditions. Lighting from different angles produces different shadows. The recursive adaptive thresholding algorithm described here can separate different level regions of the object. The algorithm is especially effective when edges are narrow and have suitable gray level change. In order to keep the gray level change at the edges at a consistent level with variable lighting, the preprocessing used first maps the gray levels with a logarithm function look-up table. (The lighting changes have a multiplicative effect.)

We select a symmetrical, concave structuring element which is shown in Fig. 1. The high slope region of the structuring element is used to locate significant edges. The low slope region of the structuring element allows the region gray level to vary slowly without causing a new region to be identified. The slopes can be adaptively adjusted depending on the lighting conditions and object texture. The size of the concave structuring element is determined by the largest expected object size in the image.

Fig. 1. The symmetrical concave structuring element used for adaptive thresholding. Only one dimension is shown for simplicity.

The adaptive thresholding algorithm is described as follows:

1. A gray level image is eroded with a large size symmetrical, concave structuring element as shown in Fig. 2. (The background is assumed dark and the output will equal the input over the background until an edge is encountered.)

2. Compare each pixel value of the eroded result and the original image. If two values are the same, then set the pixel to be a high value (255). Also mark those pixels as region 0. If two values are different, then pass the gray value of the original image.

3. The output of (2) is dilated with the center (5x5) region of the symmetrical, concave structuring ele-
ment. Thick edges in the image give a non-zero residue after this operation.

(4) Compare each pixel value of the dilated result and the output of (2). If two values are different, then set the pixel to be the high value (255). Mark those pixels as region 1. If two values are the same, then pass the gray value of the output of (2).

(5) Repeat (1)-(4) procedures using different region labels until all the pixels are marked.

(6) Region merging: If the size of the smallest region expected is known a priori, then region merging rules may be applied at this point.

(7) Opening and closing with a suitable size disk structuring element. This step makes the regions smooth and complete.

Fig. 2. Example of the adaptive thresholding algorithm in a one-dimensional single video scan line. The algorithm is actually implemented in two dimensions.

An example of the adaptive thresholding algorithm operating on image data is shown in Fig. 3.

The large size concave structuring element can be decomposed into the maximum selection of two results of operations with two small size structuring elements. Decomposition of a large size structuring element allows it to be implemented using hardware designed for small structuring elements. A detailed discussion of decomposition of linear, convex, and concave structuring elements can be found in [6].

3. DISTANCE TRANSFORM AND SHAPE NUMBER

After the binary regions are extracted using the recursive adaptive thresholding, features are extracted from these regions. The distance transformation transforms a binary image into a gray level image whose values reflect the minimum distance from each object point to the boundary of the object. A detailed discussion can be found in [8].

Distance Transformation Algorithm:
(1) Represent a binary image with +∞ (or a large number) for each object pixel and 0 for background pixels.
(2) Do f = k.
(3) Repeat (2) until the result doesn’t change any more or until all "+∞" are removed.

The distance transformation can be useful in image analysis. One of applications is to compute a shape number [9]. Another is to obtain the medial axis (skeleton) and use for feature extraction [10]-[12].

3.1. Shape Number from the Distance Transform ---

The shape number is computed from the total distance and the total number of all object points [9]. It is a measure of the compactness of the shape. Let N be the total number of pixels which belong to the object and Xi be the distance transform value for pixel i. The shape number is expressed as follows:

\[
\text{Shape Number} = \frac{N^3}{9\pi \sum_{i=1}^{N} X_i^2}
\]  

Fig. 3. A recursive adaptive thresholding example. (a) Original gray level image; (b) after step (1); (c) after step (2); (d) after step (4); (e) region labels after steps (1)-(4) are done twice; (f) region labels after step (7).
4. FEATURE EXTRACTION

Since image morphology directly deals with shape, specific industrial parts features can be easily and quickly extracted. Some feature extraction techniques have been developed [13-14]. Two common features to be recognized are corners and circles. This section will discuss the algorithms which deal with corner and circle detection. It is assumed that binary regions are available as such as are generated by the adaptive thresholding algorithm discussed earlier.

4.1 Corner Detection --- Opening with a large disk structuring element rounds sharp corners. The residue area found by subtracting this opening from the original varies with the angle of the corner. The residue area can be determined using morphological techniques. One can either use a shape bandpass filter approach if the angle of the corner is known or use the distance transform if the angle and residue area are unknown.

**Corner Detection Algorithm:**

1. A binary image is dilated with a suitable size of disk structuring element. The size is determined by the largest area which can fit inside the opening residue corner (output of (3)). This is to make the location estimate of the corner more accurate by correcting for the bias introduced by the erosion in Step (4).
2. The output of (1) is opened with a large-size of disk structuring element.
3. Subtract the output of (2) from the output of (1).
4. The output of (3) is eroded with two disk structuring elements. The size of one structuring element is used in (1) and the other size is a little bit larger.
5. Subtract the two eroded outputs of (4). This is a shape band-pass filter. The remaining points are the corner points.

An example of corner detection is shown in Fig. 4.

4.2 Circle Extraction --- The distance transform followed by shape number calculation can be used to conclude whether each region is a circle or not. If it is a circle, the maximum distance is the radius and the location of that value is the center.

**Circle Detection Algorithm:**

1. A gray level image is thresholded into multiple regions by the recursive adaptive thresholding algorithm.
2. Do the distance transformation algorithm on each region.
3. Use shape number computation to determine whether each region is a circle or not.
4. If the region is a circle, detect the maximum distance value in the region and its coordinates.
5. If there is more than one point with the maximum distance value, then select the average of the coordinates as the center and add 0.5 to the maximum distance value as the radius.

5. CONCLUSIONS

Image morphology applied to industrial vision applications can be a very effective technique. A recursive adaptive thresholding algorithm, a distance transformation algorithm, a corner detection algorithm, and a circle detection algorithm have been described. There are obviously many more applications to be developed.

6. REFERENCES