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Automatic thresholding for defect detection by background histogram mode extents

Masoumeh Aminzadeh*, Thomas Kurfess

The George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, 771 Ferst Drive, NW, Love Bldg., Room 105, Atlanta, GA 30332, USA

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ABSTRACT

Automatic thresholding is a popular segmentation technique that is widely used for automated visual inspection of defects. Many methods have been proposed for appropriate selection of the threshold value. However, most of these methods perform well for images where defects and background have distinguishable histogram modes and select a threshold close to a valley between the two modes which is usually very hard to locate except for the clearly bi-modal histograms. Additionally, where defect detection requires bi-level segmentation, these methods require a prior knowledge of the number of thresholding levels. In this paper, a new approach for threshold selection is taken that aims to find the threshold value at the boundary of the intensity ranges of defects (object) and background by comparing the histogram modes of the background and defective regions. The proposed method automatically detects defective regions as well as defect-free regions or background. By study of the histogram of the background region, appropriate threshold values are automatically selected at the extents of the background histogram mode. The proposed method proved very effective on several standard images of surface defects. The significance of the method's efficiency is well seen in successfully segmenting defects in images with non-uniform background and with no visible bi- or multi-modal behavior. Another significance of the technique is segmentation of defects comprising of two intensity regions (such as bumps and pits) without specifying the number of threshold levels.

1. Introduction

Thresholding is an important image segmentation technique in various applications of computer vision such as inspection of manufactured parts, sheets, and surfaces for detection of defects. The basic idea of thresholding is to select an appropriate intensity value as threshold to segment objects of interest from the background based on their intensity distributions. If done manually, appropriate threshold values can be selected either by trial and error to reach the satisfactory segmentations or by observing the histogram of the image and selecting a value that lies between the histogram modes (if any) that usually appears as a flat minimum called valley. However, many industrial applications, such as automated visual inspection and machine vision, require the threshold selection to be automated. Several methods have been proposed that automatically locate the valleys in the histogram and set as threshold [1,2]. These methods assume that the boundary between the background and defect histogram modes occurs at a valley. These methods were found susceptible to signal noise. Aoki et al. [3] assumed the background histogram mode shows a linear variation at the outer regions of the mode and fit a line to the linear variation of the histogram and selected the zero-crossing of this line as an approximation of the boundary between the background mode and defect mode. Another automatic thresholding approach is to select the threshold value as the average intensity of the pixels on the boundary of the object and background where the boundary could be found with the aid of edge detection techniques [4].

A large variety of other automated thresholding techniques especially histogram-based methods have been proposed [5–11], among which the Otsu method has been recognized as one of the most efficient and widely-used thresholding techniques. Otsu [12] took an optimal approach for selection of the threshold by maximizing the between-class variances of the histogram [12]. The Otsu method, however, is optimal for segmenting large objects from the background. In other words, Otsu performs well when the image consists of two or several clear modes of similar size and distribution shapes. In many applications of defect detection, however, there are several defects on a large surface (background) such that the dominant area of the image is covered by background, and therefore Otsu method will not be effective in identifying the

* Corresponding author. Tel.: +1 404 385 1507.
E-mail address: m.aminzadeh@gatech.edu (M. Aminzadeh).

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true modes of defect and background. Ng [13], followed by other researchers [14,15], improved the Otsu method by modifying the weights in the cost function. They were able to segment small objects such as defects from a large background. Their method was able to find a threshold at the flat valley between the large mode of the background and a small mode of defect in the histogram. One assumption of this method was that the threshold is present in a local valley where the probability is locally low, which may not be the case in many images where background shows rather large intensity variations. These methods perform satisfactorily for images that consist of two or several visible histogram modes (not necessarily of similar shape and size) and with a visible flat region or low-probable region between two modes that is recognized as a valley. For images with strong overlap between modes with no observable valleys, these methods may not provide satisfactory results.

In some applications of defect detection such as bumps and pits with both elevations and corrosions, unlike scratches or contaminations, defects' intensity does not belong to a single gray level range and may appear both darker and brighter than the background. Without this prior knowledge, number of threshold levels is not known for certain. To use the Otsu method as well as its modified versions for defect segmentation, however, whether a single-level threshold or bi-level thresholding would be appropriate should be specified.

Considering the basic idea of thresholding, (global) thresholding is a possible segmentation technique only if the image contains an object which occupies a different range of gray levels than that of the background. The objective of all aforementioned thresholding techniques is to find a value that best separated background gray values from that of defect. This idea is conveniently used in this paper to propose a new method for automatic threshold selection for defect detection applications. Unlike the methods using assumptions such as valley-based thresholds or that background histogram mode can be fit by a curve, the proposed method efficiently determines the gray level ranges of the background and defects whether the defect itself has a single mode comprising a single range of intensity or two modes covering both darker and brighter regions in the image.

In the proposed method in this paper, background (defect-free regions) as well as defective regions (regions containing defects) are automatically found. By study of the difference between the background and defective regions' histograms, appropriate threshold values are automatically selected at the extents of the background histogram mode. For better estimation of the histogram extents for unclear background histogram mode, a percentage of accumulative probability can efficiently be incorporated. The proposed method proved very effective on several standard images of surface defects. The significance of the method's efficiency is well seen in successfully segmenting defects in images with non-uniform backgrounds and images with no visible bi- or multi-modal behavior and with no visible flat region or low-probable region between two modes that can be considered as a valley. Both small and large defects can be segmented effectively, using the proposed method, from a large background. Additionally, the background can even contain texture and patterns of low contrast and sharpness that the Otsu method may mistakenly segment as defects. Another significance of the technique is segmentation of defects comprising of two intensity regions (such as bumps and pits) without specifying the number of threshold levels.

2. Threshold selection by histogram comparison

The objective of many automated thresholding methods [1,2,13–16], is to find the valley in the histogram that separates the objects from the background. The proposed thresholding method, however, most efficiently seeks the solution to the basic idea of thresholding. A defect can be segmented by global thresholding if it occupies a different range of gray levels than that of the background and the best threshold values lie at the boundary of the gray level ranges associated with defects and background. If the histogram distributions of the background be known as well as the intensity distribution of defective regions, it is possible to compare the two histograms and clearly see what intensity values are more dominantly occupied by defects.

To find the background intensity distribution, regions that are very unlikely to have defects can be found and chosen as background. Similarly, regions that are very likely to have defects can be marked as defective regions. Study of histogram of several background regions and comparing with the distribution of defective regions reveal what intensity ranges are most dominated by background and defects separately and select threshold values at the boundary of background-dominated gray levels and defect-dominated gray levels.

Fig. 1. Image of a defective surface; the three large defects can clearly be recognized.

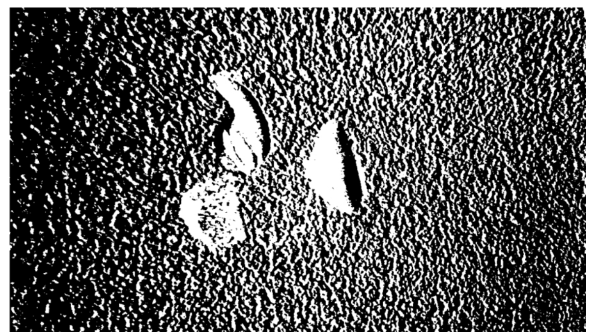

Fig. 2. Result of Otsu thresholding.

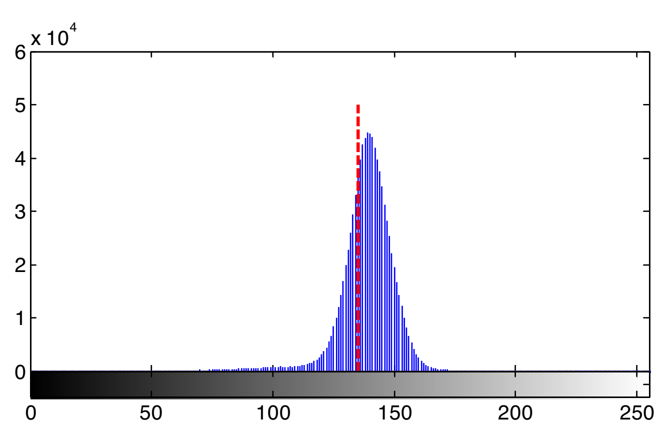

Fig. 3. Histogram of the image with the Otsu threshold marked.