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Segmentation of Casting Defects in X-Ray Images Based on Fractal Dimension

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Abstract

Considering defect segmentation is the most important and hardest issue for various defects recognition and classification in the X-ray image, a segmentation algorithm based on fractal dimension which is calculated by differential box-counting is investigated to locate defects in the gray-level images. The results indicate that fractal dimension can be a good alternative in defect-segmentation. Some comparative experiments are done and the results demonstrate that the algorithm is simple, and adapt to precisely segmenting casting defects in X-ray images.

Keywords: Casting Defects, X-Ray, Fractal Dimension, NDT

1 Introduction

In the casting process, shrinking processes occur during the cooling of molten metal and they may lead to inhomogeneous regions within the workpiece such as cavity, cracks, gas, inclusion[1]. In order to insure the safety of conductions, especially those parts relevant to vehicle safety like railway casts, wheel rims, a control of their quality is required. Among several nondestructive testing (NDT) methods used to detect and estimate quality-level, X-ray inspection is an established technique for identification and evaluation of internal defects, which has been applied to a wide range of industries such as casting, welded seams and heavy steel structures that are more than 100 mm thick.

Unfortunately, the visual result evaluation of X-ray images is adopted by most X-ray inspection systems. The inspection quality depends on operator experience, and the inspection process itself is time-consuming and inefficient. Moreover, human inspector is not able to make quantitive analysis for the size and classes of defects. With the development of modern production technology, more complicated workpieces need to be tested and much more X-ray images need to be evaluated, such manual inspection method has lagged behind modern production. In order to make the inspection efficient and all testing results objectivity and reproducibility, the research of automatic detection of casting defects has become more and more valuable.

An automated X-ray inspection system is typically composed of five parts: a manipulator, an X-ray source, an image sensors, a CCD camera and an image processor for the automatic classification of the test piece as satisfactory or defective by digital image processing[2,8,10]. And an image processor is consist of four parts: image preprocessing which includes noise reduction and enhancement, defect extraction, defect classification, the statistic result output and defect display, and defect-segmentation is the most important and difficult part.

Different methods for extraction of casting defects using image processing can be found in literature within the past twenty years. And generally these methods can be classified two classes: one is direct extraction, and the other is indirect[3]. The indirect class of approaches generally proceeds by identifying the significant difference between a test image and the reference image to classify the test piece as defective[2]. In order to use reference image, the distribution of gray values in the image must correlate to the current image. This requires a very precise positioning of the piece as well as very strict fabrication tolerances and the reproducibility of the X-ray parameters during imaging indispensable. Small variations in these variables may lead to great differences between the two images[2]. In additionally, the reference image of workpiece which is not given previously may be too difficult to get when workpiece is too complex and the controlling of manipulator is not precise enough. Thus the direct extraction of defects is applied in our context. Yet simple process or specific filtering can not segment defects with any size and shape from complex images. In this paper, a method of defect segmentation using fractal dimension (FD) is proposed.

2 Fractal theory

2 .1Fractal dimension

The fractal dimension is an important characteristic of fractal because it contains information about their geometric structure. Usually we think that the dimension of a point is zero; the dimension of a line is one; the dimension of a surface is two; and the body's is three, and that the dimension of the object wouldn't change whatever the object does any transformation. This kind of dimension called as: topology dimension, defined as: d. Mandelbrot, who introduce the concept of fractal and self-similarity to describe realistic objects, believe that, in the fractal world, the dimension needn't be integer number. The dimension of fractal geometric object (defined as D) is bigger than its topology dimension, so $D \geq d$. Fractal dimension presents the irregular degree which equals an object’s ability to occupy the space and then it can reflect the roughness degree of the object[4]. So we use fractal dimension as a parameter to segment defects from X-ray images.

A basic principle to estimate fractal dimension is based on the concept of self-similarity which can be explained as follows. Consider a bounded set A in Euclidean n-space. The set is said to be self-similar when A is the union of N_r distinct (nonoverlapping) copies of itself each of which is similar to A scaled down by a ratio r. Fractal dimension D of A can be derived from the relation[5]

$$1 = N_r r^D \quad \text{or} \quad D = \frac{\log(N_r)}{\log(1/r)} \tag{1}$$

However, natural scenes practically do not exhibit deterministic self-similarity. Instead, they exhibit some statistical self-similarity. Thus, if a scene is scaled down by a ratio r in all n dimensions, then it becomes statistically identical to the origin one, so that (1) is satisfied.

2.2 Calculation of Gray Image Fractal Dimension[5-7]

There are many different methods to implement the fractal dimension, and in which box-counting dimension or box dimension proposed by N.Sarkar is one of the most widely used dimension. Its popularity is largely due to its relative ease of mathematical calculation and empirical estimation.

First of all, the image is “scanned ”by the window having the size M×M pixels with the step a (if a=1 the window will be “gliding”, if a>1 it will be “jumping”). Afterwards each step should be calculated and put into the matrix $D_{i,j}$, which is called fractal dimension field(FDF) [9]. The calculation of fractal dimension of every sub-image is shown as follows.

Consider that the sub-image of size M×M pixels has been scaled down to a size s×s where $M/2 \geq s > 1$ and s is an integer. Then we have an estimate of $r = s / M$. Now, as in previous techniques, consider the image as a 3-D space where two coordinates (x, y) represent 2-D position and the third (z) coordinate represents gray level. N_r is counted as the following procedure:

1) The (x, y) space is partitioned into grids of size s×s. On each grid there is a column of boxes of size $s \times s \times s'$. If the total number of gray levels is G then $[G/s'] = [M/s]$. For example, see Fig. 1, where $s = s' = 3$.

2) Assign numbers 1, 2, …to the boxes as shown in Fig. 1. Let the minimum and maximum

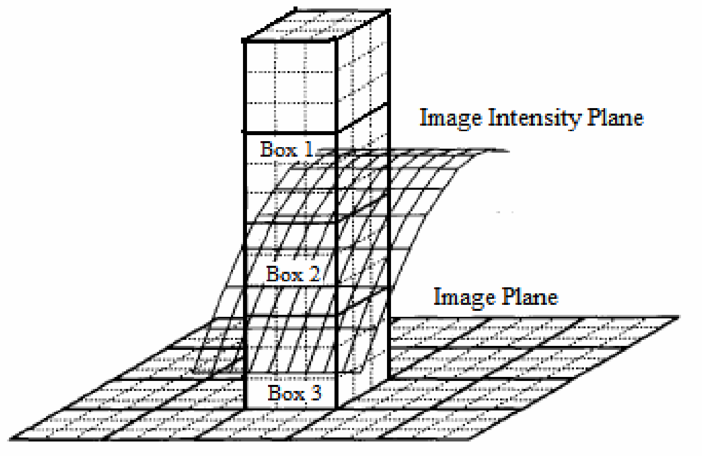


Fig. 1 Determination of N_r

gray level of the image in the (i, j)th grid fall in box number k and l, respectively.

Then

$$n_r(i, j) = l - k + 1 \tag{2}$$

is the contribution of N_r, in (i, j)th grid.

3) Taking contributions from all grids, we have

$$N_r = \sum_{i,j} n_r(i, j) \tag{3}$$

N_r is counted for different values of r, i.e., different values of s. Then using (1), we can estimate D, the fractal dimension, from the least square linear fit of log (N_r) against log (1 / r).

Let y = mx + c be the fitted straight line, where y denotes log (N_r) and x denotes log (1 / r). Then error of fit E can be expressed as the root mean-square distance of the points from the fitted line.

$$E = \frac{\sqrt{\sum_{i=1}^{n} \frac{(mx_i + c - y_i)^2}{(1+m^2)}}}{n} \tag{4}$$

The error provides a measure of fit so that the lower the value of E, the better is the fit.

2.3 The Character of Gray Image Fractal Dimension

A. The fractal dimension of the gray image has something to do with the size of the scanning window M, also have something to do with the box size s. The smaller s is, the more precise fractal dimension is. In our defect-segmentation system, M equals defect size.

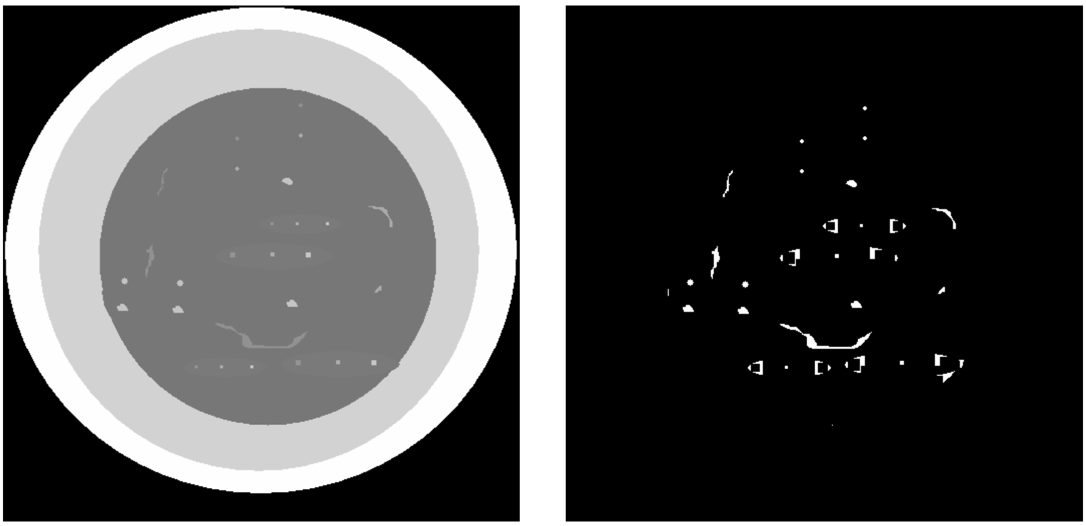
B. The fractal dimension has nothing to do with which kind of logarithm we have taken in (1).

3 Experiment Results

In this section, we present the results of defect segmentation using the proposed method and the other two methods: viener filter & edge-detection, median filter & edge-detection. These results demonstrate the effectiveness of our proposed method.

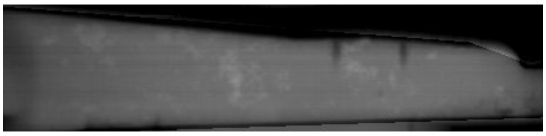
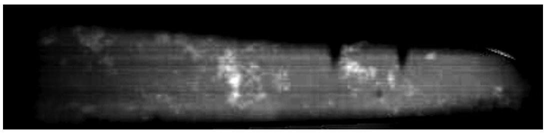
We use 5×5 pixels scanning window, namely, M=5 and box counting algorithm for FD calculation. In order to save time for building FDF, we make some changes to the box-counting method described in section 2.2. For a sub-image with size of M×M pixels at the position (i, j) in a wordpiece image, if its gray level is single, we set 0 to the corresponding position in FDF[9], namely $D_{i,j}=0$. That is to say, if each pixel of the sub-image has the same gray value, we think that these areas include nothing useful information about the structure of workpiece and do nothing to it. So, we can use a threshold which equals to 0 to eliminate the background, and sometimes it may implement defect-segmentation at the same time. As Fig.2 show, Fig. (a) is a simulated image and Fig.(b) is the segmentation result using fractal dimension with threshold 0.

For the same workpiece image, different areas of fractal dimension distinguish different area of the image, and which reflect different structure information of wokpiece. For images of different workpieces, the same value-area of fractal dimension presents different information. So, we should adjust threshold-area of defects to different workpieces. Additionally, since there are too much noise and artifact except defects in the real industrial X-ray image, preprocessing is required before defect extraction. In fig. 3, Fig. (a) to Fig. (e) show the original image, the preprocessing result, the defect-extraction using the proposed method, the result using viener filter & edge-detection, and the result using median filter & edge-detection respectively.



(a) (b)

Fig.2 simulating image with defects and its segmentation result

(a) (b)


(c) (d)

(e)

Fig.3 (a) the original image. (b) preprocessing result. (c) result using FD. (d) result using viener filter & edge-detection (e) result using median filter & edge-detection

From Fig. 3(c), we can see all defects in Fig. (b) are located based on fractal dimension and little artifact is included in the result, although there is a problem: the edge of defects is not close, and that is solved by defect-track. From Fig. 3(c) and (d), it seems that using filter& edge-extraction also achieve this goal, but then you will find the results include almost all edge: the edge of defects, the edge of workpiece and too much edge of artifact, and no doubt that will make defect-track too difficult to carry out. In a word, the proposed method using fractal dimension is effective to detect defects from X-ray image.

4 Conclusion and future work

In this paper, fractal dimension is introduced to defect-inspection and the results demonstrate that fractal dimension can be a good parameter in defect-segmentation. In the future, how to implement defect-track with great performance and how to design a classifier to identify the various defects will be the next important tasks to be tackled.

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