Detection of missing rods of 4-directional carbon preform from images

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Abstract. Poor quality of the carbon preform including missing rods can affect the desired properties of the tailored composite. The carbon preform is currently manufactured manually and therefore, an effective solution for guaranteeing the quality of carbon preform is needed. This paper proposes new inspection method that can detect the missing rods of carbon preform by just taking a picture of it. The new method found all missing rods and marked missing place with red circle. By wide use of smart devices, it becomes very easy to take a picture nowadays and the picture quality has improved dramatically. Moreover, the inspection method suggested in this paper can be easily converted into a form of android application and it is expected to be applied effectively to the fields of manufacture of the carbon preform.

1. Introduction

Carbon/carbon (C/C) composite consists of carbon preform and carbon matrix. Therefore, its specific strength and stiffness hardly change with environmental temperature, even when the temperature goes up extremely high compared to the normal temperature. Additionally, C/C composite has several other outstanding properties, including great ablation resistance, low thermal expansion coefficient and high thermal shock resistance. Because of these superior engineering properties, C/C composite has become one of the essential materials in the field of aerospace engineering. However, C/C composite also has some drawbacks. The most critical drawback is its high cost. In addition, another drawback is the fact that C/C composite is anisotropic. 1-D (unidirectional) and 2-D (two-directional) C/C composites are really anisotropic, and show weakness in bearing some forces acting in certain directions. This is why multi-directional C/C composite is often used in the structure of aerospace engineering. For example, the multi-directional C/C composite can be used for a rocket nozzle, leading edge and nose cap of a space shuttle. Two most frequently used structures of multi-directional C/C composite are 3-D (three-directional) and 4-D (four-directional). The 4-D structure is commonly known to be more isotropic and efficient structure than the 3-D structure. This is because 4-D structure has one more radial axis of carbon rods. As a result, 4-D structure consists of one axial direction and three radial directions. This is well displayed in Figure 1, which is rendering result from a three-dimensional sketch program.

The type of structure for the C/C composite is determined at the manufacturing stage of the carbon preform. The carbon preform is an essential framework of tailored composite. However, the carbon preform is manually manufactured now, hence many mistakes can occur in its manufacturing stage. In particular, a common mistake is the omission of carbon rod. A poor quality of carbon preform affects some of the desired properties like superior strength and good ablation performance for the tailored composite. Thus an effective solution for guaranteeing the quality of the carbon preform is needed.
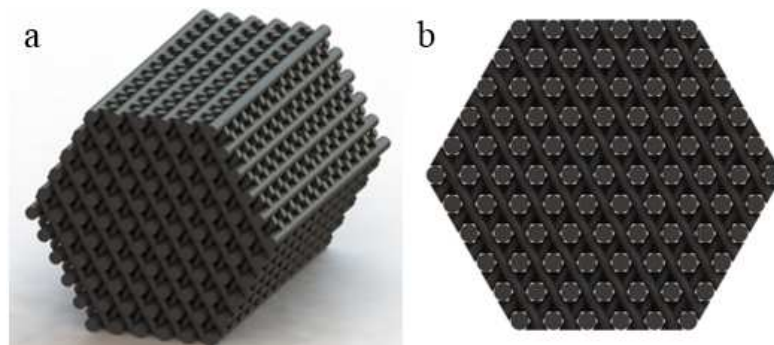
Figure 1. The four-directional structure: (a) overall view and (b) top view

The goal of this paper is to propose and show that by just taking a picture of the carbon preform, it can be a powerful method of quality inspection. For convenience, in this paper, the mistakes stated above are restricted to the omission or missing of carbon rods only. The carbon preform pictures used in this paper are supplied by DACC. There are so many carbon rods in the picture and their diameter is 1.7mm, so they are almost fibre. In order to detect missing carbon rods that are very thin, some image processing techniques are utilized. The typically used technique is binarization, which is a mid-process that makes the picture much simpler.

2. Image processing technique
First of all, the carbon preform picture should be converted into a gray scale image to reduce the size of data. In the RGB image, there are three values at each pixel but in the gray scale image, there is only intensity value at each pixel. This makes the gray scale image is much simpler to handle than the original image. In addition, if the picture is high-definition, the run time will be very long. Therefore, it is necessary to convert the RGB image into the gray scale image in the case of high-definition.

2.1. Binarization by adaptive thresholding
The main goal of image processing is to separate the object from the background. To do that, it needs a clear criterion. In the binarization, the criterion is threshold value of the intensity. A bright pixel with high intensity value gets 1 whereas a dark pixel with low intensity value gets 0. Generally, the object is brighter than the background such as it is possible to classify the pixels into the object group and the background group theoretically.

There are two types of threshold. The first type is global threshold, which is calculated once and applied to all pixels at a time. If the picture is quite simple, this type of threshold is very effective and efficient to classify the pixels. Another type is local threshold that is calculated at every pixel using the information of surrounding pixels. Because this type of threshold is calculated adaptively, it is possible to cope with a change of brightness and illuminance. The carbon preform pictures can be taken under various environments, hence the second type of threshold is adopted for binarization in this study. This can be expressed in Equation 1 and it is called adaptive thresholding method.

$$b(i,j) = \begin{cases} 1, & f(i,j) \geq t(i,j) \\ 0, & other \ wise \end{cases} \tag{1}$$

The $b(i,j)$ means i-th row and j-th column element of the binary image. In similar manner, the $f(i,j)$ means i-th row and j-th column element of the original image. The value $t(i,j)$ is locally computed threshold of i-th row and j-th column pixel.

2.2. Integral image
Unfortunately, the adaptive thresholding method has a big problem. It takes too long time because the threshold has to be computed at every pixel using the information of surrounding pixels. Therefore, it

is necessary to reduce the run time using an integral image method. The integral image is defined as Equation 2.

$$I(x,y) = \sum_{i=1}^{x}\sum_{j=1}^{y} f(i,j) \tag{2}$$

The $I(x,y)$ is x-th row and y-th column element of integral image and it means a simple summation of all left and upper values of (x, y) pixel of the original image. Using Equation (2), these three following Equation 3, Equation 4 and Equation 5 can be easily derived and they help the integral image to be computed fast.

$$I(1,y) = f(1,y) + I(1,y-1) \tag{3}$$

$$I(x,1) = f(x,1) + I(x-1,1) \tag{4}$$

$$I(x,y) = f(x,y) + I(x,y-1) + I(x-1,y) - I(x-1,y-1) \tag{5}$$

2.3. Local sum
After getting the integral image, it is possible to calculate the local sum, s(x, y) using Equation (6). The local sum refers to a simple summation of certain area of the original image. In image processing, the area is called window. Equation 6 implies that the local sum value can be computed using only four elements of the integral image. This is depicted as Figure 3.
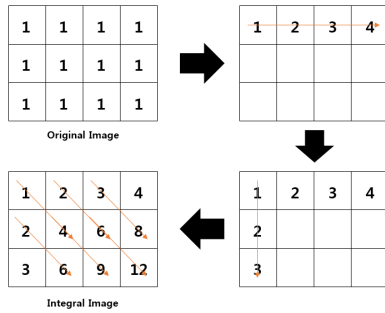

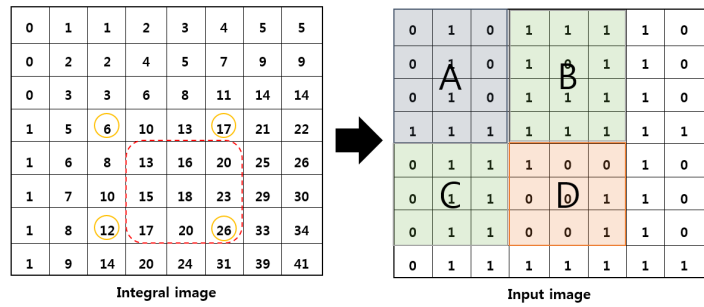**Figure 2.** Calculation of integral image

Figure 3. Calculation of local sum

$$s(x,y) = \sum_{x=x_1}^{x_2}\sum_{y=y_1}^{y_2} f(x,y) \tag{6}$$
$$= I(x_2,y_2) - I(x_2,y_1-1) - I(x_1-1,y_2) + I(x_1-1,y_1-1)$$

Finally, using the local sum, s(x, y), the threshold, t(i, j) can be computed by Equation 7. The first fraction of Equation 7 is average value of intensity of surrounding pixels while the second fraction of is a kind of margin. If *p* is positive, the threshold becomes lower than the average of the surrounding pixels. On the other hand, the threshold becomes higher than the average when *p* is negative. So it is possible to control the local threshold level by changing the value *p*.

$$t(i,j) = \frac{s(i,j)}{w^2}\frac{100-p}{100} \tag{7}$$

It is very simple to calculate the local threshold because the local sum already has the information of surrounding pixels in the form of a simple summation. If the integral image and local sum are not utilized for getting the local threshold, it will take extremely long time because the process of getting the local threshold is a kind of 2-dimensional convolution or image convolution.

3. Results

In order to create a circumstance of missing rods to evaluate the proposed method, several rods are randomly chosen and covered by neighboring background color. After erasing some rods, the size of picture is adjusted. The size of the original carbon preform picture is 4032 by 3024. It means that the original picture has about 12 million pixels. However, most smart devices have a much lower display resolution and thus the size of the picture is adjusted to 2048 by 1536, which is about 3 million pixels.

Figure 4 is the resultant picture of the detection and it is composed of only zeros and ones because it is binary image. There are many red circles but only two of them are located inside of the carbon preform. The other red circles are located at the outside and also at the boundary of the carbon preform. Therefore, the two red circles are real detection result and the other red circles are errors. Figure 5 is an enlarged image of Figure 4. In Figure 5, there are many white circles and there is also one red circle. The white circles are real carbon rods while the red circle signifies missing carbon rod. The red circle is located at the exact position of the missing carbon rod.

4. Conclusion

In this paper, a new detection method for missing rods of carbon preform is proposed. In the result of the detection, red circles mark all missing rods without omission. In addition, all errors are located at the outside and boundary of the carbon preform, so they do not interfere in finding the missing carbon rods. Furthermore, this new method to detect the missing rods can be converted into a form of android application that can be used to find the missing carbon rod during manufacturing phase. All in all, this method is good at detecting missing rods and it is really expected to be applied to the manufacturing site of the carbon preform such that it can be produced much faster and more accurate than before.
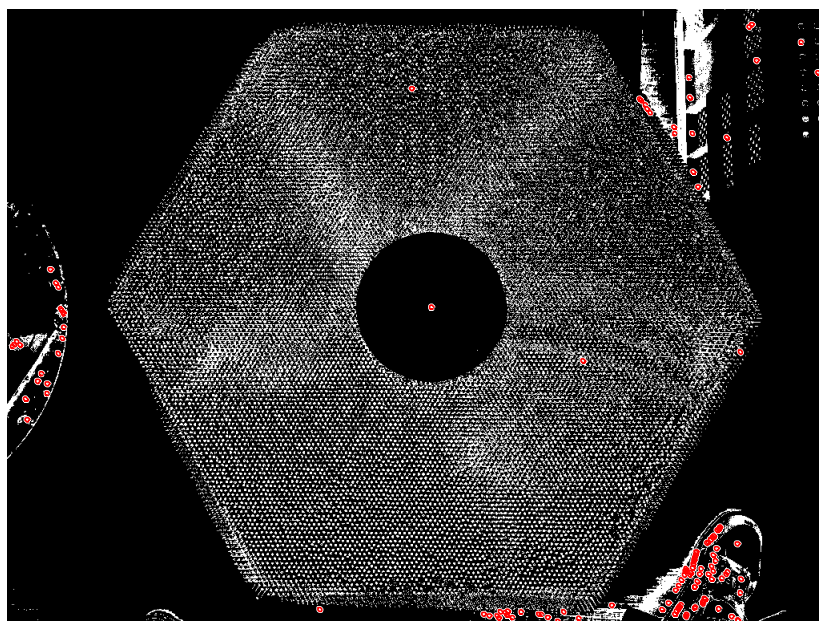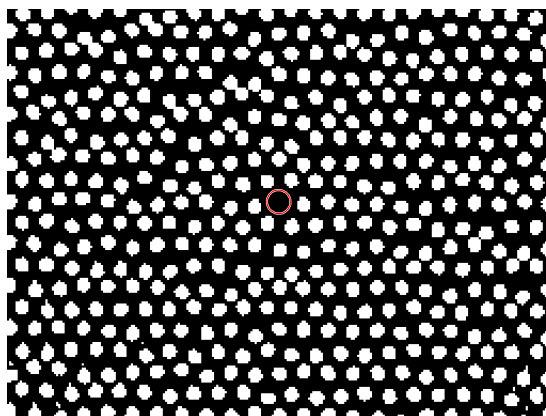

Figure 4. Detection result of the carbon preform

Figure 5. Enlarged result of detection

References
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[3]   Venkatesh S, Mohan V M and Karthikeyan T V 2014 *International Journal of Advancements in Mechanical and Aeronautical Engineering* **1** 1-5