Multi-voltage X-ray image sequence fusion based on selection of valid region

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Abstract: A key step is to extract valid information region in the fusion of multi-voltage X-ray image sequence for complicated components. To improve the self-adaption of extraction, a method is presented in this paper. In this paper, the valid information region is selected by the grey level interval, which is computed by the optimization of image quality evaluation model. The model is based on the histogram equalization and the grey level interval. Then, every valid region of images at different voltages is extracted and they are fused according their grey level transformation function. The fusion image contains completed structure information of the component. The fusion experiment of a cylinder head shows the effectiveness of the presented method.

Key words: multi-voltage; X-ray image; fusion; valid region

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0 Introduction

There are some complex structures or multi-material components in the industrial X-ray imaging. Since they have a wide range of equivalent thickness and the detector has a limited dynamic range, it can not accomplish X-ray imaging with a single fixed voltage for overexposure in the thin thickness region and underexposure in the large thickness region[1]. Only a part of structures of the component can be seen in every image with different voltages. The local region of every image with good quality is regarded as the valid region. So the problem can be solved by multi-voltage X-ray imaging[1]. A X-ray image with completed structure information can be achieved by the fusion of different voltage X-ray images' valid regions[2-3].

The fusion method can be classified into two groups. One is without extracting valid region and the entire image is taken in fusion[4-7]. The fusion image's quality is reduced since overexposure and underexposure regions have low quality. For example, the overexposure region may make fake edge in the fusion image. Another one is that it only fuses the valid region of different images[1-3,8-10]. The extraction of valid region is got a very important step for the fusion. The fusion image is got by stitching the valid region according to the grey level transformation function of images at different voltages[1-3,8-10]. Then the fusion image's grey level is matched to the equivalent thickness, so the fusion image can be better applied. So far, the extraction of valid region is got by selecting a grey level interval and the selecting needs much experience or data, which can be got from many pre-experiments. This method has not self-adaption and its application is limited.

In order to improve the self-adaption of fusion, this paper presents a method to extract the valid region depending on the local image quality. The remainder of this paper is organized as follows. In sec-

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tion 1, the local image quality evaluation model is introduced and the grey level transformation function of images at different voltages are presented. In section 2, the presented method is applied to the fusion of a cylinder head's image squence. Finally, the conclusions are presented at the end.

1 Selection and fusion of valid region

The signal-to-noise ratio, peak signal-to-noise ratio and contrast are the usually X-ray image quality evaluation methods. If these methods are used in the local image quality is evaluation, an existing local image is the premise. However, the valid region is unknown before the local image quality evaluated, and all the local images need to be evaluated, which are not practical. So these evaluation methods can not be used to extract the valid region.

All information of the tested object is showed by grey level of X-ray images. The valid region should not be too bright or too dark. By referring to the traditional methods, the presented method also extracts the valid region by selecting a grey level interval. Different from the traditional methods, the grey level interval selection is according to the quality of local image itself. In the X-ray image, the thickness resolution is higher as the grey level interval is larger for the same thickness difference. The larger grey level interval can show more detailed information of the tested object. This indicates that the grey level interval of valid region should be as larger as possible. On the other hand, the histogram equalization is usually used to improve image quality, which shows that a better quality image has a higher equalization histogram to some extent[11-13]. From the analysis of image information entropy, the entropy is the maximum if the number of pixels at every grey level is equal[11]. Considering the two sides, the extracting model of valid region is presented based on the interval span of grey level and the histogram equalization.

The image histogram is noted as $G_i = G(H_i)$. The equalization of H_i is evaluated with the standard deviation of S_i at the grey level interval $[H_i - \delta, H_i + \delta]$ and it is noted as $\sigma(H_i)$. The δ is a positive integer. The equalization of H_i is better as the $\sigma(H_i)$ is smaller. The average equalization of $[H_{i_1}, H_{i_2}]$ is defined as

$$\frac{\sum_{i=i_1}^{i_2} \sigma(H_i)}{H_{i_2} - H_{i_1}}. \tag{1}$$

Considering the interval span of grey level and the histogram equalization, the grey level interval $[H_{i_1}, H_{i_2}]$ of the valid region is determined as the optimization model

$$\min \left(\frac{\sum_{i=i_1}^{i_2} \sigma(H_i)}{H_{i_2} - H_{i_1}} \right)^{\alpha} \left(\frac{1}{H_{i_2} - H_{i_1}} \right)^{\beta}. \tag{2}$$

The α and β are positive real number and their relative sizes determine the relative importance of the grey level interval's span and histogram equalization. Since $\frac{\sum_{i=i_1}^{i_2} \sigma(H_i)}{H_{i_2} - H_{i_1}} \geqslant 0$, $\frac{1}{H_{i_2} - H_{i_1}} > 0$, $\alpha > 0$ and $\beta > 0$, there is $\gamma = 1 + \frac{\beta}{\alpha}$, and then Eq. (2) can be rewritten as

$$\min \frac{\sum_{i=i_1}^{i_2} \sigma(H_i)}{(H_{i_2} - H_{i_1})^{\gamma}}. \tag{3}$$

Solving Eq. (3) could get the grey level interval $[H_{i_1}, H_{i_2}]$ of valid region.

If the $\sigma(H_i)$ is seen as continuous function, then the partial derivatives of Eq. (3) for H_{i_1} and H_{i_2} can be taken. The extreme value condition is $\sigma(H_{i_1}) = \sigma(H_{i_2})$, which is got by making the partial derivatives equal to 0. Considering that the $\sigma(H_i)$ is actually discrete function, the solution can be got by traversing all the H_{i_1} and H_{i_2} conforming to $\sigma(H_{i_1}) \approx \sigma(H_{i_2})$. Also, the solution can be got by traversing all the grey level when the grey level interval is not large.

The different valid region is extracted from different images at different voltages, then they need to transform to equivalent grey at the identical voltage by the grey level transformation function. The transformation function is solved according to the different grey levels of the same region at different voltages.

According to the references[8,14-15], when the voltage increases small, the transformation function can be replaced by linear function

$$I_2 = aI_1 + b, \tag{4}$$

where I_1 and I_2 are respective gray of low voltage image and high voltage image. The a and b can be got by gray data fitting[8,14]. Then the different valid regions can be fusion one by one from low voltage to high voltage according to the grey level transformation function.

2 Result

A engine's cylinder head is used in the multi-voltage X-ray imaging experiment, as shown in Fig. 1.

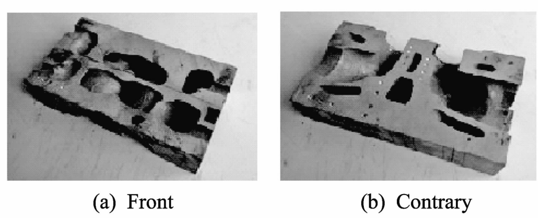

Fig. 1 Engine's cylinder head

During the experiment, the X-ray source (ISOVOLT TITAN 4503PH with 450/5 tube housing) is operated at a tube current of 1.5 mA. The tube voltages is 65—185 kV and it collects one image every 5 kV. The applied flat panel detector (VARIAN PaxScan 2520) has 1 536 × 1 920 cells that its size is 0.127 mm, and only a part are used for imaging. The program of image collection is developed by our own laboratory. The cylinder head's X-ray images has much stripe noise in the overexposure region and part of the denoised images are shown in Fig. 2.

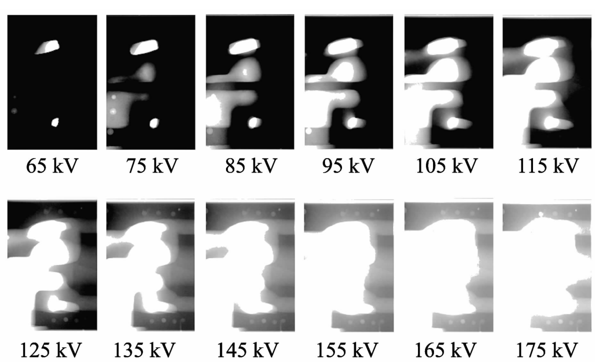

Fig. 2 X-ray images of cylinder head at different voltages

Only the cylinder head's lower left and around holes region can be seen in the X-ray images at lower voltage. The right region and the up and down of the top gradually appear as the voltage becomes higher. At the same time, the lower left and around holes region disappear in the images and they are overexposure.

The valid region of every X-ray image is extracted according to the Eq. (3) and a part of the valid region sequences are shown in Fig. 3. The values of γ and δ are selected according to experience, where $\gamma=5$ and $\delta=15$.

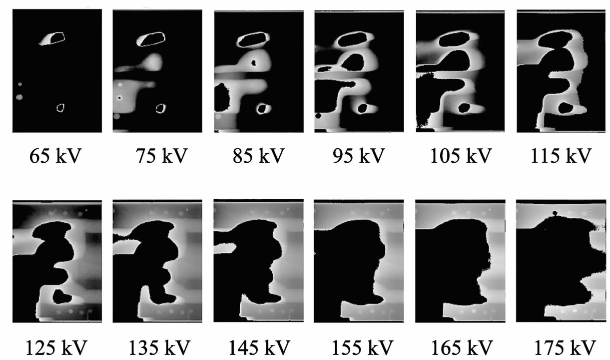

Fig. 3 A part of valid region sequences

The gray transformation of images between low voltage and high voltage is computed with linear fitting of the valid region's gray. The parameters and errors of the linear fitting are shown in Table 1. The error can be acceptable and then the replace of gray transformation with linear function is feasible in the fusion.

Table 1 Parameters and errors of valid region's gray fitting

Image	a	b	Mean absolute error	Mean relative error
70—75 kV	1.105 0	35.004 1	19.068 7	1.69%
115—120 kV	1.119 0	36.037 7	26.728 9	1.25%

The fusion is from the valid region of 65 kV, and then one by one. The gradual variation of fusion image is shown in Fig. 4. The structure information of cylinder head is complete after the valid region of 125 kV is fused. Since the gray dynamic range of the fusion image is large, only the high gray region can be seen. Then the enhanced images of the images in Fig. 4 are shown in Fig. 5.

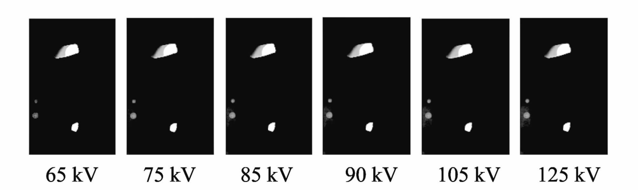

Fig. 4 Gradual variation of fusion image

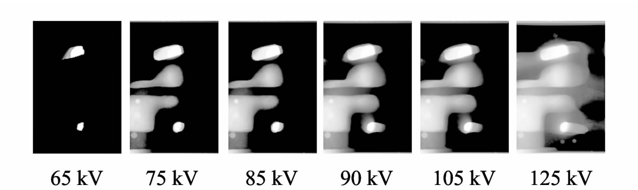

Fig. 5 Enhancement of every image in Fig. 4

Compared to traditional methods, the method presented in this paper improves the self-adaption. The method does not need to design the check block of special shape or material to collect experiment data, which is used for prior analysis. This enhances the flexibility of the fusion method in engineering application.

However, the presented method is not perfect. It improves the self-adaption of fusion, but does not accomplish the complete self-adaption. The selections of γ and δ in the image quality evaluation model still need manual intervention. This is the disadvantage to accomplish the complete self-adaption. The further work is to research the relationship between the variation of valid region and the variation of model parameters γ and δ for the complete self-adaption of multi-voltage X-ray image sequence fusion.

3 Conclusion

To improve the self-adaption of extracting X-ray image's valid region, this paper presents a method to extract the valid region according to the image quality evaluation model. The gray level interval is selected through the optimization of image quality evaluation model, which completely depends on experiments in the traditional methods. The multi-voltage X-ray image sequence fusion experiment of cylinder head shows the effectiveness of the presented method. The future work is to accomplish the self-adaption selection of the model parameters.

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基于有效区域选取的变电压 X-射线图像融合

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摘 要： 针对变电压 X-射线图像序列融合有效区域的提取问题，本文提出了一种依据图像质量来判断有效区域灰度区间的方法，提高了提取的自适应性。首先，考虑图像直方图均衡性和灰度区间宽度，建立图像质量评价模型。然后求解模型，并依据所得灰度区间提取有效区域。最后，利用灰度变换函数融合各有效区域，获取被检测对象完整结构信息的图像。本文以缸盖为实验对象，验证了该方法的有效性。

关键词： 变电压；X-射线图像；融合；有效区域

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