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Development of Automatic Nuclear Fuel Rod Character Recognition System Based on Image Processing Technique

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영상처리기술을 이용한 핵연료봉 문자 자동인식시스템 개발

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Abstract

Numeric characters are printed at the end part of nuclear fuel rod containing nuclear pellets. Fuel rods are discriminated and managed systematically by these characters in the process of producing fuel assembly. The characters are also used to examine manufacturing process of fuel rods in the survey of burnup efficiency as well as in inspection of irradiated fuel rod. Therefore automatic character recognition is one of the most important technologies in automatic manufacture of fuel assembly. In this study, character recognition system is developed. In the developed system, mesh feature extracted from each character written in the fuel rod has been compared with reference feature value stored in database, and the character is thus identified. In the result of experiment, 95.83 percent recognition rate is achievable.

요 약

핵연료 소결체가 장전되는 핵연료봉의 끝 부분에는 각각의 핵연료봉을 구분해주는 고유의 문자가 인쇄되어 있다. 핵연료 집합체 제조 과정에서 각각의 핵연료봉은 고유 문자에 의해 구분되어 체계적으로 관리되고 있으며 아울러 핵연료 연소 이상상태 감시 및 사용후 핵연료 검사 분야에서 핵연료봉 제조과정 추적에 이용되고 있다. 핵연료봉 문자 자동인식은 핵연료 집합체 제조과정의 자동화를 위한 핵심 기술이다. 본 연구에서는 핵연료봉 문자인식 시스템을 개발하여, 핵연료봉단에 기록된 각 문자로 부터 추출한 메쉬 특징값을 데이타베이스에 저장된 특정 문자의 특징값과 비교

하여 자동으로 문자인식을 수행하도록 하였다. 실험 결과, 95.83 퍼센트의 양호한 인식률을 기록하였다.

1. Introduction

When the characters are read and recorded by a man in the process of recognizing characters in fuel rod, it is difficult to manage data promptly and systematically. In order to manage data efficiently, to reduce the job quantity of workers, and to increase productivity, it is necessary to develop automatic recognition system for identifying fuel rod characters[1]. In this study, the characters in the fuel rod are acquired by CCD camera, and the acquired data are processed by image processing technique. After mesh features of a character are extracted, the character can be recognized.

2. Construction of Fuel Rod Character Recognition System

The schematic diagram of fuel rod character recognition system is shown in Fig. 1. The fuel rod image is relayed to image processing board(AT-100) by CCD camera, and the input image is processed by host computer. Then, the input image as well as the processed result is displayed on RGB monitor.

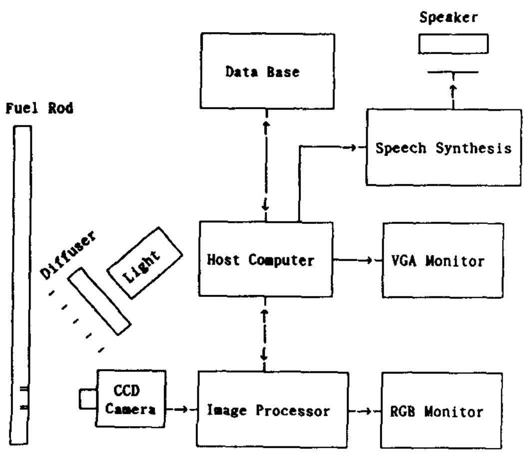


Fig. 1. Block Diagram of Fuel Rod Character Recognition System

3. Algorithm of Character Recognition

There are two regions, character region and the remaining region, in the acquired image from CCD camera. In order to extract character region only, the first order differential operator is used. The character region is divided into three areas and binarized in each area. Then feature vector is extracted by making use of mesh feature. The character is recognized by comparing the extracted feature vector with reference feature vectors stored in database. Fig. 2 shows the procedure for recognizing characters in fuel rod.

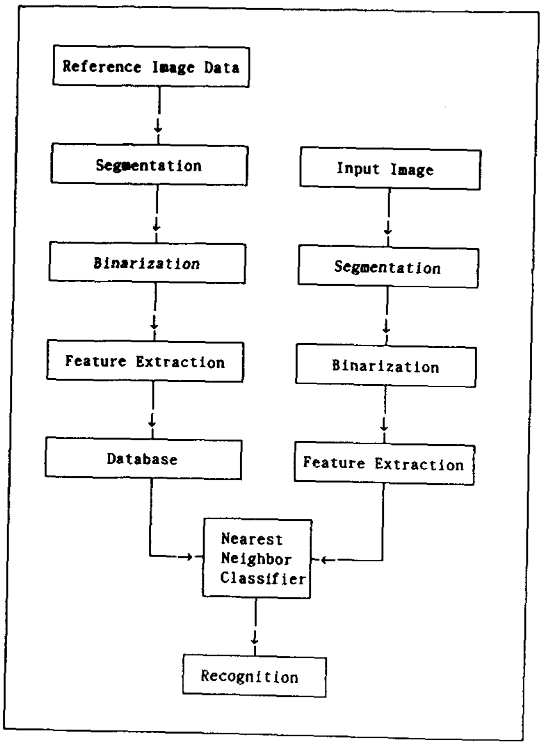


Fig. 2. Flow Chart of Character Recognition

3.1. Segmentation

Fuel rod image is composed of eight numbers and two hyphens as shown in Fig. 3. Image segmentation is divided into horizontal and vertical direction. In this study, the one-dimensional first order differential operator is used to segment image as shown in Fig. 4[2-4].

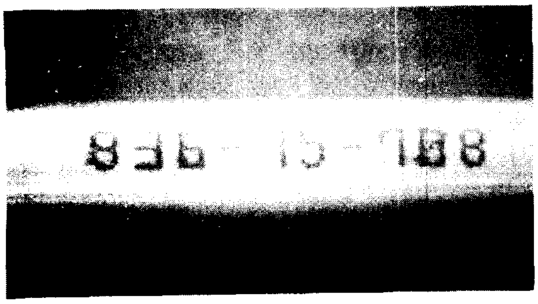


Fig. 3. Original Image of Fuel Rod

-1	-2	0	2	1

Fig. 4. The First Order Differential Operator

3.1.1. Horizontal Segmentation

The first order differential operator is adopted for detecting the boundary region in the horizontal direction, and then the absolute value is projected to each horizontal line. The projected value is smoothed by an average filter of size 5. Here, the values of character region are larger than those of the other region. The character region is horizontally segmented out by these different levels. The procedure is shown in Fig. 5.

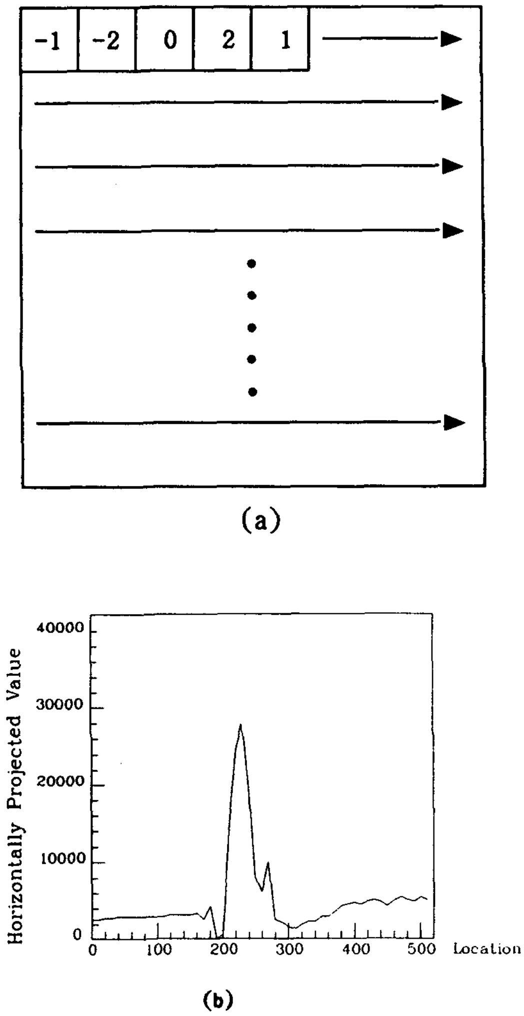
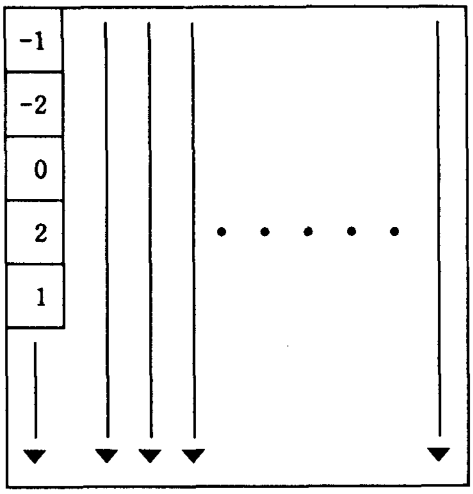


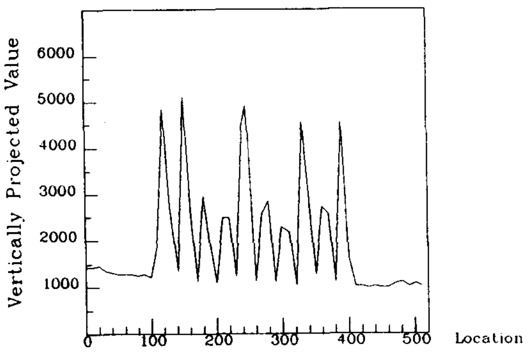
Fig. 5. (a) The First Order Differential Operation Procedure for Horizontal Image Data
(b) Projection Values Smoothed After Average Filtering

3.1.2. Vertical Segmentation

The first order differential operator as well as an average filter is used vertically for image segmentation in the same way. The procedure is shown in Fig. 6. Rod characters are composed of eight numbers and two hyphens, so ten peaks are represented in the result. The choice of eight peaks from ten peaks are needed for segmentation. After the threshold level is found, vertical segmentation is completed.



(a)



(b)

Fig. 6. (a) The First Order Differential Operation Procedure for Vertical Image Data
(b) Projection Values Smoothed After Average Filtering

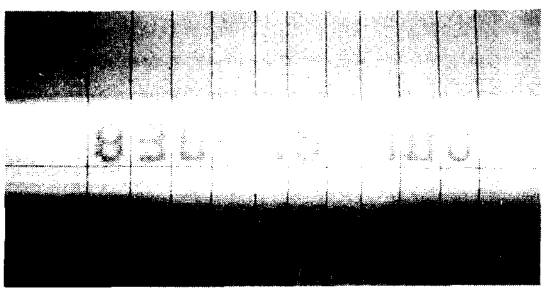


Fig. 7. Segmented Image

3.1.3. Binarization using variable threshold

Real images are affected by not only irradiation conditions but camera characteristics. Since fuel rod is round, brightness level is not uniform in the locations of character region. In order to overcome this restriction, character region is divided into three areas as shown in Fig. 8. The threshold level is defined in each area. Fig. 9 shows the resultant binarized image. Note that the brightness level of character and boundary are reversed for darity of display.

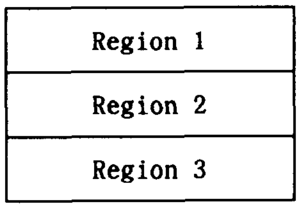


Fig. 8. Character Area Divided Into Three Regions to be Binarized

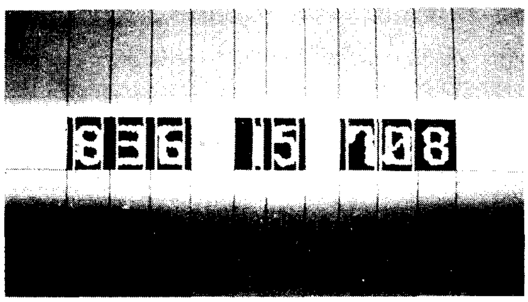


Fig. 9. Binarized Image

3.1.4. Recognition

Mesh features are used to recognize characters. Mesh feature means the number of white pixels in each defined mesh. In this experiment, the character region is divided into $8 \times 5 (=40)$ meshes. Each mesh contains about $5 \times 5 (=25)$ pixels. Nearest neighbor classifier is used as recognizer. The distance between feature vector and reference feature vector is computed. When the distance is smaller than any other distances, we define that the class of feature vector equals that of reference feature vector. The Euclidean distance in Eq.(1) is used for our case nearest neighbor classifier as shown in the following equation (1) [5,6].

$$\text{Distance} = \sqrt{\sum_{i=1}^{N} (f(i) - rf(i))^2} \qquad (1)$$

Here, f(i) and rf(i) are i–th components of the input feature vector and the reference feature vector, respectively, and N is the dimension of the vector and N equals 40 in this case. The recognition result is shown in Fig. 10.

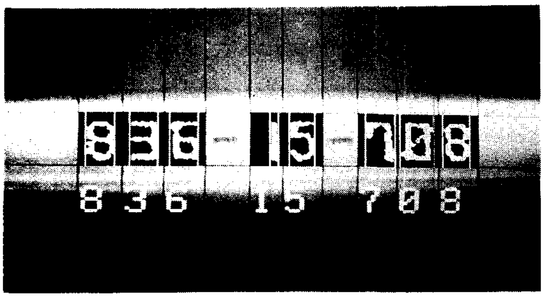


Fig. 10. Recognized Characters

4. Experiment

In this study, six fuel rods are tested. The specifications of fuel rods are shown in Table 1. The results of experiments are represented in Table 2.

Table 1. Specifications of Fuel Rods

ITEMS	SPECIFICATIONS
Manufacturer	Westinghouse
Material	Zircaloy–4
Inner diameter	8.2mm(±0.04mm)
Outer diameter	9.5mm(±0.05mm)
Length	384.7mm (+0.2mm, −0.6mm)
Width of character	2mm(±0.5mm)
Hight of character	3mm(±0.5mm)
Construction of character	NO N1 N2–N3 N4 –N5 N6 N7

Table 2. Results of Experiments

INPUT IMAGE	RESULT
836–15–708	836–15–708
818–28–244	818–28–244
8$\bar{3}$3–1$\bar{0}$–002	8$\bar{9}$3–1$\bar{8}$–002
827–13–281	827–13–281
837–24–163	837–24–163
837–24–073	837–24–073

As can be seen in Table 2, forty–six characters out of forty–eight characters are recognized correctly. Therefore, the recognition rate reaches 95.83 percent. Some of characters, like "3", and "0" are recognized incorrectly. Due to the similarity in feature vector, "3" is regarded as "9", and "0" as "8", respectively.

5. Conclusion

In this study, image processing and recognition technique for recognizing characters written in fuel rod are suggested. Fuel rod image is segmented by horizontal and vertical segmentations using the first order differential operator. Each character is segmented and binarized in its region. Mesh features are extracted from each character. Nearest neighbor classifier is introduced to recognize feature vectors. In this study, 95.83 percent recognition rate is obtained. In the future, not only new binarization technique considering nonlinearity of fuel rod surface but the enhancement of reference feature data will improve recognition rate to some degree. It is also expected that complete recognition will be able to be achieved by adapting neural network to noise affected or damaged characters.

References

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