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Spent Fuel Calculation With Image Processing In Rod Bundle Nuclear Reactor Core

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Abstract: Rod bundle in the nuclear reactor core which exist in the nuclear plant must be continuously monitored for spent fuel rods. Digital cameras continuously obtain videos of the core from which images can be obtained of the rod matrices, we have processed these images with digital image processing techniques and through iteration algorithm initially those images were de-blurred to get precise images and then through correlation techniques it was found that how many rods are spent because each rod spent shows a hole in the image apart from other control holes.

Keywords: IMAGE PROCESSING, REGRESSION ALGORITHM, DE-BLURRING, CORRELATION, NUCLEAR ROD BUNDLE

I. INTRODUCTION

Nuclear power plant consist of fuel handling building, containment building where reactor core exist, steam generators in containment building, turbo-generator building which contains turbines then turbines runs the electrical generators to generate electrical energy as shown in Fig. 1 [1]. Inside the reactor core there is a large pressurized water reactor as shown in Fig.2 which also shows the bar matrix [2]. Bar matrix has also some control holes which has poison bars which captures neutrons for controlled neutron fission reaction as shown in Fig.3 [3].

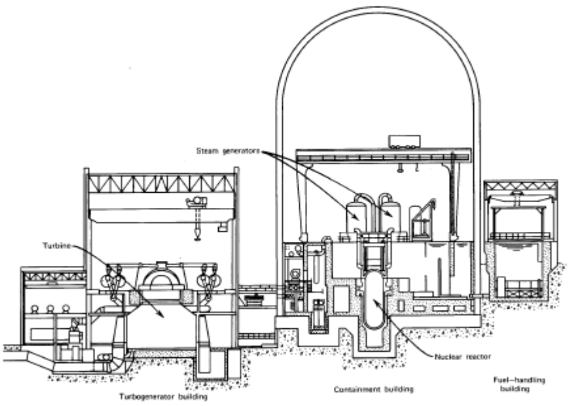

Fig.1 Design of nuclear power plant

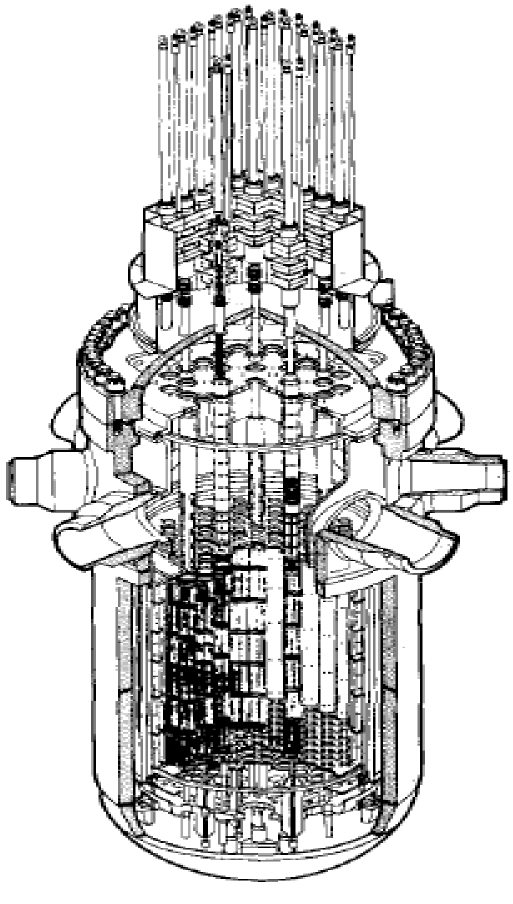

Fig.2 Large Pressurized Water Reactor

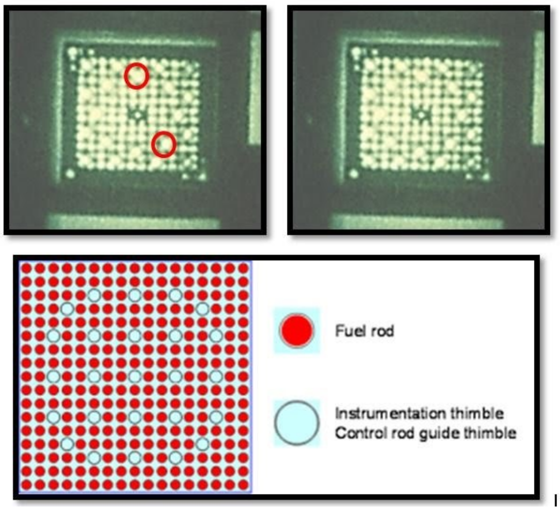

Fig.3 Instrumentation thimble Control rod guide thimble

II. **Regression Algorithm**

For the de-blurring of images regression algorithm has to be used which is an iteration algorithm as shown in the point spread function and following derivation.

Point Spread Function

Point spread function describes the response of an imaging system to a point source or a point object.

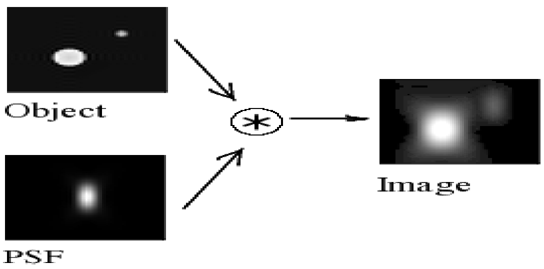

Fig.4 Example of Point Spread Function

Suppose,
Y : Degraded Image,
Λ : Original Image,
P : Point Spread Function,
*: Operation of Convolution.
Then

$$Y = \Lambda * P \ldots\ldots\ldots\ldots\ldots(1)$$

Numerical values of Y, Λ and P can be considered as a measure of frequency at that point.

In the model (1),

$P = ((\ p(i,j)\ ))$, $p(i, j)$ = P[Photon emitted at i is seen at j]

$\Lambda = (\lambda_1, \ldots\ldots, \lambda_n)'$ λ_i= True pixel value at the *ith* point.

$Y = (y_1, \ldots\ldots, y_d)'$

y_j= Observed pixel value at the j^{th} point.

Distribution of Observed Pixels

Notice that yj is nothing but the count of the photon seen at j. So yj has a Poisson distribution. In fact,

$$yj \sim \text{Poisson}(\mu j)$$

Where

$$\mu j = \sum_{i=1}^{n} \lambda i \ \ p(i,j) \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Distribution of Spread Function

The distribution of spread function varies from problem to problem. In our problem we have taken the Gaussian spread function which is given by:

$$p(i,j) = \exp\left(-\frac{d(i,j)2}{\sigma 2}\right) \ldots\ldots\ldots\ldots..(3)$$

Where $d(i, j)$ = Distance between i and j

Explanation of Regression Algorithm

Define the contribution of λ_i and y_j as

$$z(i,j) \sim \text{Poisson}(\lambda i \ p(i,j)) \ldots\ldots.(4)$$

then,

$$yj = \sum_{i=1}^{n} z(i,j) \ldots\ldots\ldots..(5)$$

and $\frac{\lambda i \ p(i,j)}{\sum_k \lambda k \ p(k,j)} \ldots\ldots\ldots\ldots(6)$

is the proportion of yj emitted by i

If we know Λ then z(i,j) is emitted by

$$\dot{z}(i,j) = \frac{yj \ \lambda i \ p(i,j)}{\sum_k \lambda k \ p(k,j)} \ldots\ldots\ldots(7)$$

Given z(i,j), λi is estimated by

$$\lambda i = \sum_{j=1}^{d} z(i,j) \ldots\ldots\ldots(8)$$

So ultimately it gives an iterative procedure [4]

$$\lambda i(t+1) = \lambda i(t) \sum_{j=1}^{d} \frac{yj\ p(i,j)}{\sum_k \lambda k\ p(k,j)} \quad ...(9)$$

III. High Resolution Image captured through Improved Cerenkov Viewing Device

High resolution image captured through Improved Cerenkov Viewing Device and it is shown in Figure 5

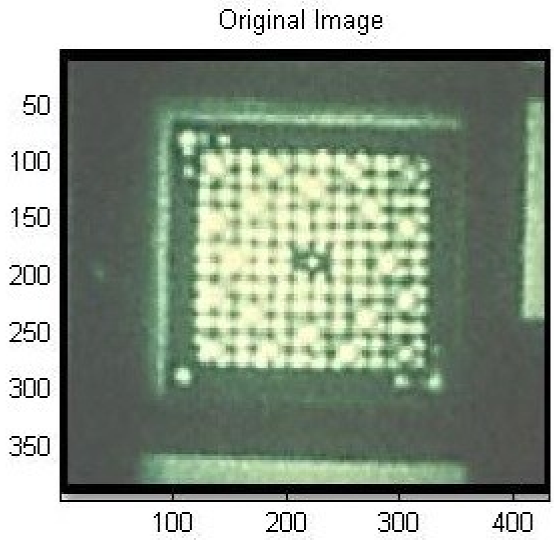

Fig. 5 High resolution image captured through Improved Cerenkov Viewing Device

Blurred image was de-blurred through iteration algorithm after 5 iterations, correlation was calculated and it is as shown in Figure 6

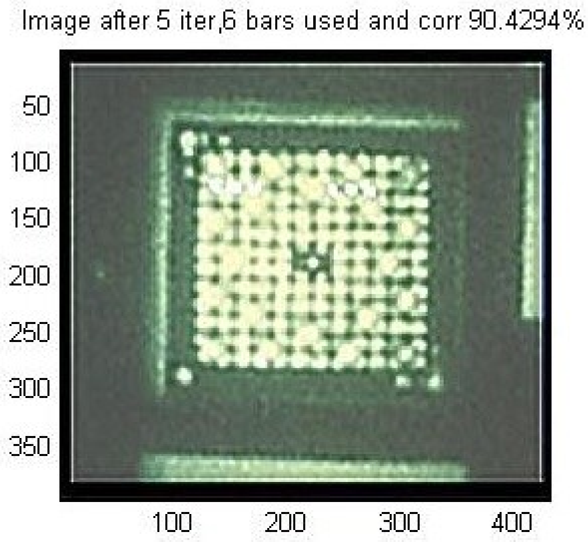

Fig. 6 De-blurred image after 5 iterations, 6 bars used and correlation with original image is 90.4294%.

Blurred image was de-blurred through iteration algorithm after 5 iterations, 12 bars used and correlation was calculated and it is as shown in Figure 7

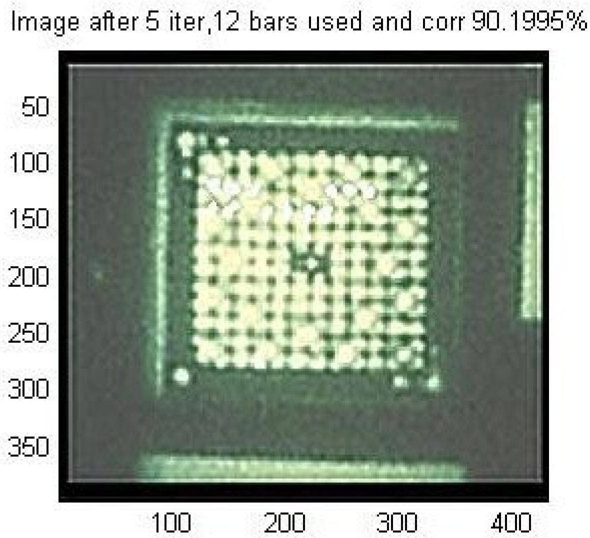

Fig. 7 De-blurred image after 5 iterations, 12 bars used and correlation with original image is 90.1995%.

Blurred image was de-blurred through iteration algorithm after 5 iterations, 18 bars used and correlation was calculated and it is as shown in Figure 8

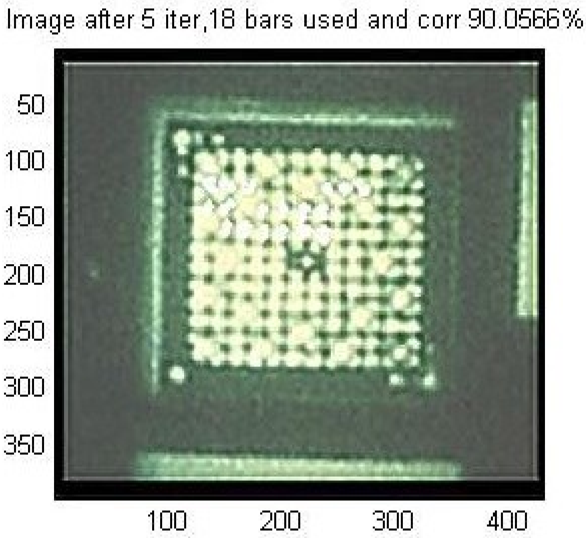

Fig. 8 De-blurred image after 5 iterations, 18 bars used and correlation with original image is 90.0566%.

Blurred image was de-blurred through iteration algorithm after 5 iterations, 24 bars used correlation was calculated and it is as shown in Figure 9

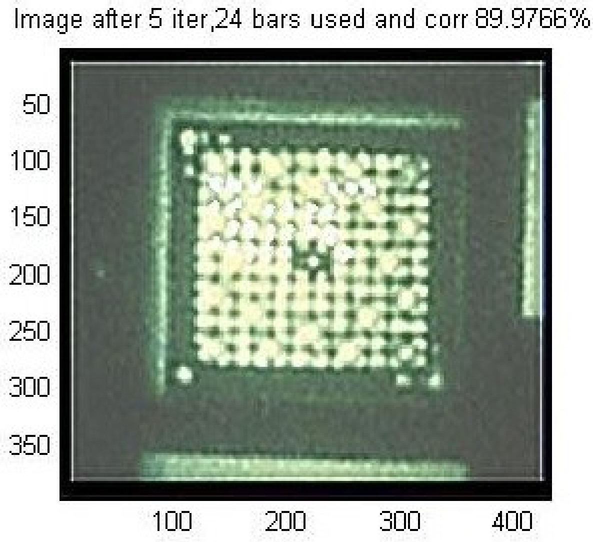

Fig. 9 De-blurred image after 5 iterations, 24 bars used and correlation with original image is 89.9766%.

Blurred image was de-blurred through iteration algorithm after 5 iterations, 30 bars used and correlation was calculated and it is as shown in Figure 10

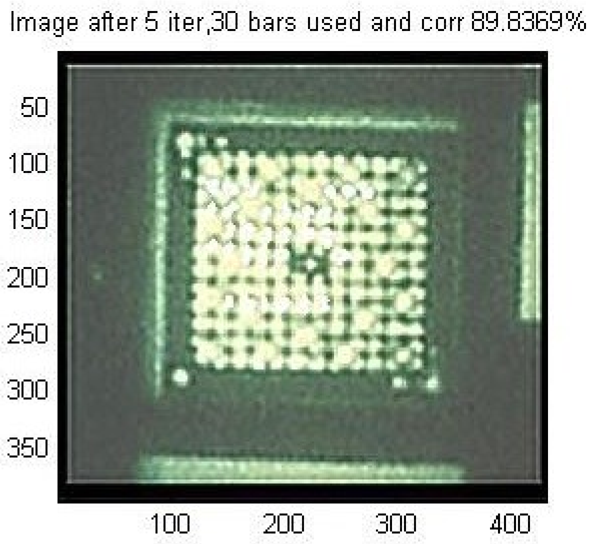

Fig. 10 De-blurred image after 5 iterations, 30

bars used and correlation with original image is 89.8369%.

Five iterations are enough for the de-blurring and graph drawn between the bars used and correlation with the original image was as shown below

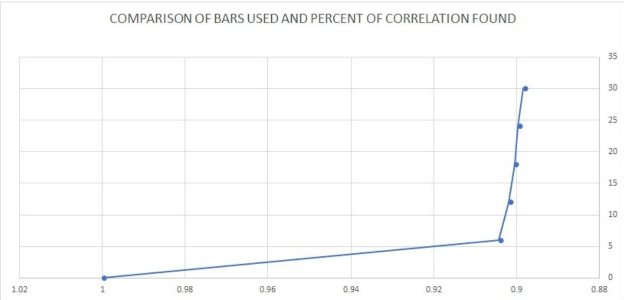

Fig. 11 Comparison of bars used and percent of correlation found

V. CONCLUSION

Improved Cerenkov Viewing device used for capturing images of rod bundle of the nuclear reactor core and images has been processed through advanced image processing techniques like de-blurring regression algorithm for the improvement of images so much more accurate bars used have been measured. Correlation finding technique is used to see that how many bars used. Higher resolution and many filtering techniques can be applied for future enhancement in the image processing of much unseen spots.

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