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Identification and Segmentation of Impurities Accumulated in a Cold-Trap Device by Using Radiographic Images

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ABSTRACT

Accumulation of impurities within cold trap device results in degradation of efficient performance in a nuclear reactor systems. The impurities have to be identified and the device has to be replaced periodically based on the accumulation level. Though there are a few techniques available to identify these impurities from the cold trap device, there are certain limitations in these techniques. In order to overcome these constraints, a new harmless and easy approach for identifying and separating the impurities using the radiographic images of cold traps is proposed in this paper. It includes a new segmentation algorithm to segregate the deposited impurities from the images of the cold trap device after sodium experiment. The experiment begins with thresholding and segmenting of impurities by using transformations onto the radiographic images of the cold trap device. The procedure is experimented on two section of the cold trap's image and it yields far better results on comparison with other segmentation techniques. The results are verified and approved by the scientists working with Fast Breeder Test Reactors. Implementation of the proposed algorithm with the simulation results are presented in this paper.

Keywords: Intensity value, Fast Breeder Test Reactor (FBTR), K-means clustering. Region growing, Threshold

1 INTRODUCTION

IN fast nuclear reactors, liquid sodium is used as the primary coolant. Being non-corrosive to steel and having high heat capacity, Liquid Sodium is highly preferred as a coolant in nuclear reactors than water. Though it is extensively used, there are a few problems that arise due to the high chemical reactivity of Sodium. Sodium metal can react easily with Hydrogen and Oxygen resulting in the formation of compounds like sodium oxides and hydrides. These compounds deposit in the reactor parts as impurities, reducing the performance of the reactor. As a performance improvement measure, the cold trap device is used in fast reactors for the elimination of premature plugging and for the reduction of metal corrosion. The cold trap's job is to purify the coolant and maintain the level of oxygen and hydrogen content in liquid sodium (Bloom G R, et al.(1978)). It finds its application in the regulation of the concentration of impurities in liquid-sodium systems. However, for the consistency in performance of the device, it is vital that the concentration of the impurities must be identified periodically and if need be the cold trap device should be replaced subsequently. As there exists only a slight variation in density of steel and the impurities such as sodium oxide, the detection of impurities is difficult. In this paper, the radiographic images of the cold trap device are analysed and a procedure has been put forth for identifying the concentration of impurities deposited within the device. The radiographic images help in identifying the various components present in the images and hence these images have been widely used in different applications (Thamotharan B, et al. (2012)). Here, the impurities that are formed in the cold trap are segmented out from the radiographic images of different sections of the device (Karthikeyan B, et al.(2012)).

Cold traps are devices that are used in sodium systems of the Fast Breeder Test Reactors (FBTR) in the atomic areas for controlling and maintaining the level of oxygen or hydrogen in sodium systems within

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the tolerable amount (Hemanath M G, et al. (2010)). The cold trap devices are made of stainless steel and they comprise of cylindrical tanks with hollow ends. They are operated to reduce the solubility of impurities in sodium. They work on the principle that hydrides and oxides of sodium crystallise and precipitate inside the wire mesh when the temperature is reduced below the saturation level (Ashton Action Q, et al(2011)).

Figures 1- 4 are radiographic images of the cold trap device. These are the inputs considered for the process of segregation of the impurities. By the experts, the portions marked by green line in the above figures are the areas where the impurities are deposited which marks the required area to be processed.

1.1 Image Segmentation

Many enhancements must be made in the radiographic images to accomplish the task of sorting out sodium oxide and other impurities formed in the cold trap. The image segmentation approach provides efficient results in identifying the impurities. The basic idea of segmentation is to fence off an image in order to achieve a set of disjoint regions based on various properties like texture, intensity, colour, etc. and this helps in the precise analysis of different regions of an image. Image segmentation finds its application in image compression, object detection, machine vision and many other fields (Rafael C Gonzalez, et al.(2005)). Various approaches such as thresholding split and merge, region growing, etc., are available for segmentation and based on the input images, an appropriate method must be opted for obtaining effective results. The selection of segmentation technique depends on the requirements of the images. In this paper, existing methods have been applied to the radiographic images. The results obtained from individually applying the methods does not provide an efficient segmentation that is required for detecting the impurities in the cold trap and hence we propose a new technique to achieve the precise results.

2 CONVENTIONAL SEGMENTATION METHODS

THRESHOLDING, K-means clustering and region growing are some of the conventional segmentation methods and they are applied to the input image shown in Figure 4. A brief description of these methods are as follows:

2.1 Thresholding

Thresholding aims at segregation of an input image into pixel intensities of two or more values. This is done by comparing the pixel intensity values with the predefined threshold value individually. The pixel value above the threshold is marked as foreground while that below the threshold is marked background. This method transforms a gray-scale image into a binary image. The technique is based on the idea that regions can be separated by applying a function on the intensities of image pixels. The primary parameter is the threshold value selected. Generally, thresholding is of two types: Global and Local. In global thresholding, an image will be partitioned into two regions and the threshold value for the entire image remains constant. In local thresholding the image will be split into sub images with different local threshold values. Local thresholding is also referred to as Adaptive or Variable thresholding.

Figure 1. **Original radiographic image of cold trap (Bottom middle)**

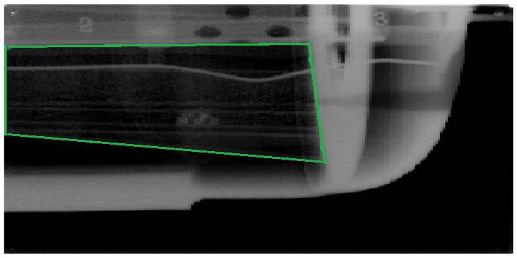

Figure 2. **Original radiographic image of cold trap (Bottom right)**

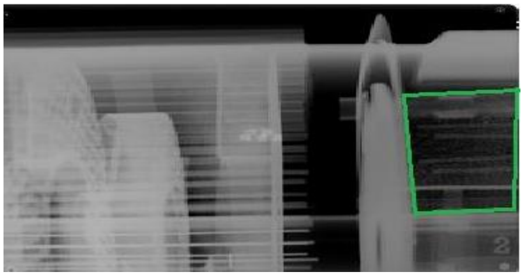

Figure 3. **Original radiographic image of cold trap (Top middle)**

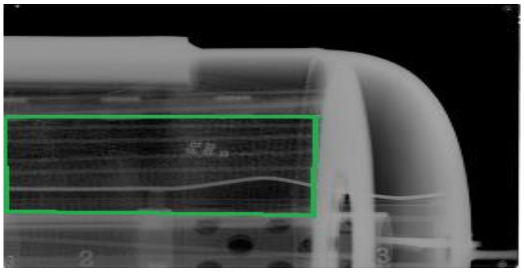

Figure 4. **Original radiographic image of cold trap (top right)**

Determination of threshold value can be done in various ways. It can be manual or computed through specific algorithms. The most preferable and simple choice would be to select the mean or median value7. The selection of mean or median value produces good results for noiseless images, possessing uniform object and background values. Another way of choosing the threshold is through the Otsu's method. This method is based on the histogram of images. Representing the pixel intensities in a histogram and selecting the valley point as the threshold yields good results if there exist average values for both the object and background pixels (Firas A Jassim, (2012)).Easy implementation and reduced computational delay makes this technique advantageous over other techniques. On applying thresholding on to the radiographic images of the cold trap, only the outer part of the device was detected and the impurities remained unidentified. The result produced under segmentation using thresholding is given in Figure 5. From the above results, it can be concluded that thresholding by itself is not a good choice for the identification and segmentation of impurities.

2.2 K-means clustering

Clustering is a segmentation process that partitions the given image into disjoint clusters. The image patterns are assigned to a cluster such that no two clusters possess the same pattern. Several algorithms have been proposed under the category of clustering and among them, K-means serves as a simple, yet effective segmentation method. It is being widely applied in various practical fields. In K-means clustering, an integer k and a set of n data points are determined. Here k represents the number of clusters for image segmentation.

Each pixel point must be assigned to any one of the clusters of the image. The allocation of the pixels to the clusters is based on the distance criteria that are measured between the pixel point and the cluster centre. The pixel is assigned to the cluster that possesses minimum mean square distance value. The K-means algorithm tries to find the lowest possible value of the sum of the squares of the distances between each point in the cluster and the cluster centre. The computation of the cluster centres is done iteratively and the process of assigning the pixels to the clusters continues until convergence criterion is satisfied. K-means algorithm is very fast in converging results and this feature makes it advantageous over other methods (Siddeheswar Ray, et al. (1999)). The problem with this clustering algorithm is the pre-requisite of specifying the number of clusters needed for the segmentation of the image. When k-means was opted for segmenting impurities in our process, it produced over-segmentation as shown in Figure 6. It detected the impurities but it also detected the device externals which were not required and hence K-means by itself is not useful.

2.3 Region growing

Region growing belongs to the class of region-based segmentation. This method begins with the selection of a seed point, which serves as the basis for the segmentation. After selecting the seed point, the region possessing the same criteria as that of the seed point has to be grown. A single seed or a set of seeds can be chosen. Giving single seed as input results in growing of a region in the image whereas, multiple seeds results in different regions each possessing different properties. The regions are iteratively pixels and the pixel possessing the least difference value is allocated to the respective region.

The benefit of using region growing is that it provides good results for the images possessing sharp edges (Raja Sekar Reddy, et al. (2012)). However, the selection of seed is based on the problem domain and it proves to be a major difficulty. The difficulty arises because different seed pixels results in different segmentation. The time consuming computations adds to the drawback of region growing segmentation (Ghule A G, et al. (2012)). These drawbacks can be overcome by performing simultaneous techniques of region growing. The process can be implemented on parallel computers for efficient results (David A Bader, et al. (1996)).

Though region growing provides efficient results, it did not segment out the impurities in this process. It produced a similar under-segmentation result shown in Figure 7 which is similar to that of thresholding. So region growing is also not suitable for segmentation of impurities.

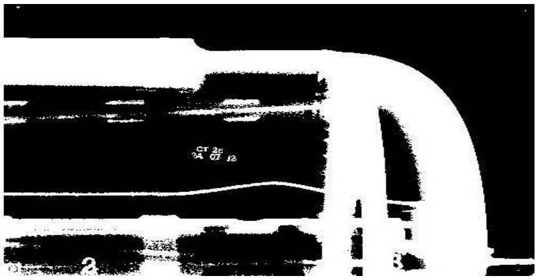

Figure 5. **Output image of Thresholding method for Figure 4**

Figure 6. **Output image of K-means clustering method for figure 4**

Figure 7. Output image of region growing method for Figure 4

3 PROPOSED METHOD

THE proposed method for identifying and segregating impurities in the radiographic images is discussed in this section. As the initial step, the thresholding technique is applied. The boundaries of the cold trap, which are not required, are removed using various image transformations. Then, by pre-fixing a value of intensity, the impurities part of the cold trap device is identified.

3.1 Algorithm

Input: The radiographic image of a cold trap device with impurity deposits.

Output: The image containing only the impurities.

Step 1: Let us consider the input image as “A”. Calculate the global threshold value of the input image using Otsu’s method. The threshold value is chosen such that it reduces intra-class variance of white and black pixels.

Step 2**:** Using the obtained threshold value from step 1, convert the gray scale image to binary image format. Let this image be “B”.

Step 3: If holes exist in the binary image obtained in step 2, fill the holes in the binary image by making use of 4-connectivity to cover the outer portions of the device in the image. Let this image be “C”.

Step 4: a. If holes are absent, then get the image “D” by performing a flood-fill morphological operation on specified locations of the binary image obtained in step 2 to fill the region where impurities are deposited.

b. Transform “B” and “D” into original image type by performing element wise multiplication. Let the image obtained be “E” and “F” respectively.

Step 5: Mask the outer portions of the device leaving behind the necessary impurities area by subtracting “C” from “A” (if step 3 is executed) or “E” from “F” (if step 4 is executed).

Step 6: Fix a value of intensity that enables us to identify the impurities in the input images. The selection of intensity is based on expert’s opinion on segmentation results

The radiographic images that are taken as input belong to two different sections of the cold trap device. The impurities are formed at different regions in these sections. The presence of holes in the image depends on the section of the cold trap device. The application of basic morphological operations and transformations make the proposed method differ from the conventional techniques discussed.

In addition to identifying the impurities, the area of the impurities is also determined. It is measured based on the radiographic images of cold trap device in the nuclear reactor. The impurities are first identified and then the area is calculated from each of the images. Initially, the area of the device was calculated in pixels and then converted to it corresponding values in units of cm2. The proposed algorithm not only identifies the concentration of impurities in the cold trap but also finds the area of these impurities occupy.

For this process, an equivalent of pixels in terms of centimetres must be determined. According to the dimensions of the cold trap device mentioned, the area of the device is identified. The area of impurities is in centimetre square. Also from different parts of the device, the length and breadth is found in terms of pixels. When the radiographic images are observed cautiously along with the inputs from the experts, it is obvious that only four parts of the device contain impurities. Hence, the concentration of impurities is identified from these images using the proposed algorithm and then the area is calculated.

4 RESULTS AND DISCUSSION

AS conventional segmentation algorithms do not provide efficient and accurate results, the given technique for the identification and segmentation of impurities present inside a cold trap device was proposed. The intensity value in step 6 of the algorithm is chosen to be 35 after executing for different intensity values. This value was chosen as it provides results that satisfy the expert’s opinion. The table below provides the different intensity values chosen and their results

Table 1: Segmentation result for different intensity value

Intensity value	**Result/Remarks**
<30	Under Segmentation
≈35	Impurities best identified
>40	Over Segmentation

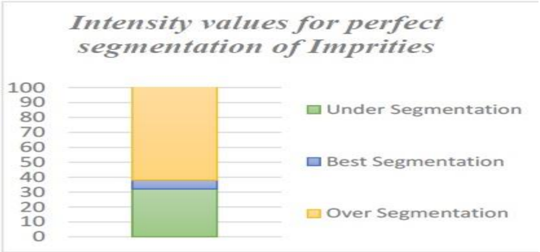

Figure 8. Intensity vs Segmentation level graph

From the cold trap images the length of the device is found out to be 23400 pixels and the width is 9534 pixels. The area of the device is calculated to be 223095600 pixels. From the calculations made as mentioned above, it is measured that one pixel is equal to 0.001294 cm2. Based on the dimensions of the cold trap device, its area is found to be 288750 cm2 with its length and breadth measures to be 825 and 350 cm respectively. The output of the proposed segmentation technique is the images containing impurities. Figures 9-12 show the impurities formed in the cold traps of the fast reactors.

Figure 9. **Output image of cold trap (Bottom middle)**

Figure 10. **Output image of cold trap (Bottom right)**

Figure 11. **Output Image of cold trap (Top middle)**

Figure 12. **Output image of cold trap (Top right)**

In horizontal view, the cold trap device has six parts aligned at top left, top right, top middle, bottom middle, bottom left, and bottom right. In regards with the facts suggested by the scientist who works with Fast Breeder Test Reactor's (FBTR) cold trap devices, the top left and bottom left part of radiographic images of cold trap device are eliminated from discussion as it does not contain any impurities. Therefore, the corresponding images are not taken for the segmentation process. Finally, the area of the impurities in the cold trap device is calculated for each part individually. The total area of impurities is measured to be 14529 cm2, which comes up to 5% of the total area of the cold trap device. The calculation of area of the impurities helps in calculating the concentration of impurities accumulated inside the cold trap device. The results obtained from the proposed segmentation process technique have been verified by the experts of the Fast Breeder Test Reactor (FBTR) cold trap device. The percentage of impurities is calculated and once the concentration of the impurities reaches a specified level, upgrading or new cold trap-device is suggested. The images are verified by the scientists working with FBTRs and the identification of impurities was found to be optimal.

5 CONCLUSION

THE problem of identifying and segmenting the impurities from the cold trap, plays a crucial role in efficient performance of a nuclear reactor. Any flaws in identification of deposits can lead to disastrous results. The proposed technique provides a better solution to this problem when compared to that of the conventional techniques. Moreover, the implementation of these algorithms is simple. This technique is found to generate acceptable results from the radiographic images of the cold trap in fast nuclear reactor by identifying the impurities present in different sections of the cold trap device and informing about their concentration. Thus, this process of segmentation identifies the impurities formed in the cold trap device and helps in analysing the efficiency of the fast reactors and determining when the cold trap device needs to be replaced. These qualities are highly essential for any automated monitoring systems in order to prevent any unwanted happenings.

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7 DISCLOSURE STATEMENT

NO potential conflict of interest was reported by the authors.

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9 NOTES ON CONTRIBUTORS

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