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Evaluating the Performance of Various Segmentation Techniques in Industrial Radiographs

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Abstract: *At present, image processing concepts are widely used in different fields, such as remote sensing, communication, medical imaging, forensics and industrial inspection. Image segmentation is one of the key processes in image processing key stages. Segmentation is a process of extracting various features of the image which can be merged or split to build the object of interest, on which image analysis and interpretation can be performed. Many researchers have proposed various segmentation algorithms to extract the region of interest from an image in various domains. Each segmentation algorithm has its own pros and cons based on the nature of the image and its quality. Especially, extracting a region of interest from a gray scale image is incredibly complex compared to colour images. This paper attempts to perform a study of various widely used segmentation techniques in gray scale images, mostly in industrial radiographic images that would help the process of defects detection in non-destructive testing.*

Keywords: *Segmentation techniques, weld radio graphic images, image analysis.*

1. Introduction

In a manufacturing process, non-destructive testing is widely used to categorize the defects in industrial radiographic images. Most of the researchers have contributed their works towards proposing new techniques or enhancement of existing segmentation techniques in image processing [2, 3, 5, 6, 10, 11, 13, 15, 16, 17, 21]. Some of the pioneers have proposed a system to extract the region of interest and identify the types of defects in different fields, such as weld radiographic images [8, 14, 23, 24], wood images [3, 19], ceramic tiles images [18, 26], under water images [12] and satellite images [1]. When performing such a process, it must be noted that a domain expertise is needed to identify and determine the accuracy of defects. Without manual intervention it is a very difficult task to accomplish. In fact, it is a very subjective process leading to a lot of misinterpretations also.

Hence, a study is performed to find out the suitability of the segmentation techniques in identifying an acceptable Region Of Interest (ROI). To demonstrate the study, industrial radiographic images, containing weld defects are considered.

2. Related works

Image segmentation represents the first step in image analysis and pattern recognition. It refers to the process of partitioning the image into groups or pixels that are homogenous with respect to some criterion. In general, segmentation techniques involve edge detection, thresholding and clustering for segmenting the region/boundary or detection of the edges in an image.

The purpose of edge detection is to identify the areas in the image where a large change in intensity occurs. Edge detection is usually done using local linear gradient operators, such as sobel, canny, zero cross edge detection and roberts cross edge detection methods. Thresholding is another approach used for segmentation in various images processing applications. An object having homogenous intensity and a background with different intensity levels could easily be differentiated with this approach. Different types of existing thresholding techniques are global thresholding, adaptive thresholding, histogram equalization and otsu thresholding. The segmented image out of these methods contains more useful information for subsequent key processes. Clustering is yet another technique that attempts to access the relationships among patterns of the data set by organizing the patterns into groups or clusters. K-means clustering and Fuzzy C-means clustering are the widely used clustering techniques. Similarly, region based segmentation is carried out to segregate a group of connected pixels with similar properties called a region. In region based segmentation an image is partitioned into regions that correspond to objects or parts of an object .Watershed segmentation, salient region detection and single seeded region growing are the most applied region based segmentation techniques. Some of the work carried out in the past towards segmentation of images are outlined in the subsequent paragraphs. Verma et al. [11] have presented a method for colour image segmentation using a simple single seeded region growing algorithm and adaptive thresholding. The methods applied only to Berkley segmentation database images and the results were analyzed based on Liu's F-factor. Though the results obtained were satisfactory, it failed to segment the images present in the other image databases. Kaushal et al. [7] used adaptive thresholding approach on gray scale images to extract true edges and tried to reduce the false edges. On the other hand, Kekre et al. [5] discussed an approach for enhancing the tumor area in mammography images. The approach used extended sobel operator to perform 2-D spatial gradient measurement on a mammography image. The technique was able to find the approximate absolute edges at each point in an input grayscale image. Further to add, Padmavathi et al. [12] demonstrated segmentation of underwater images by applying fuzzy c-means clustering using a nonlinear assessment. The system achieved desirable results. Zhang et al. [20] aimed to explore the zero-crossing edge detection method based on the scale-space theory. By applying this operator, the edges were obtained with one pixel width image border. The results were compared with other edge detection methods and the results have shown more precise edges than the other methods.

Kekre and Wadhwa [6] introduced a novel image retrieval method based on shape features extraction using gradient operators. The shape features were extracted using the slope magnitude method by using roberts, sobel, prewitt and canny gradient operators. Based on the performance ranking it was concluded that the Robert-Mask-Shape-block truncation coding method was able to retrieve relevant information. Zheng et al. [25] applied a salient region detection technique for both colour and gray scale images. The accuracy of extracting the region of interest from a colour image was highly considerable. But the accuracy of extracting the region of interest from a grey scale image was not so good when compared to colour images. Wang et al. [24] proposed an improved histogram equalization technique to enhance the aircraft digital radiographic images. The classification of enhanced images results was desirable. Hocenski et al. [26] developed a system to detect the defects in ceramic tiles. Canny edge detection technique was used to detect the edges. This technique was able to detect the edges with higher rate of accuracy.

Tatiraju and Mehta [16] discussed an approach for image segmentation using k-means clustering, Expectation Maximization (EM) and normalized cuts on gray-scaled images. The proposed *k*-means clustering algorithm was applicable only to the images which have smaller values of *k*. When images have larger values of *k*, the clusters were formed in discrete places. This was observed to be the drawback of the proposed approach. Zarqa [9] introduced two different segmentation approaches for gray scale images. In the first approach, *k*-means clustering was used for the initial stage and a next stage watershed technique was applied. The accuracy of the segmented regions was highly acceptable. At the initial stage, the image was segmented as a region by applying *k*-means and for the next stage the edge strength was applied. In the validation process, the first approach was able to give a better result compared to the second approach. Funck et al. [3] analyzed the results obtained by using a variety of algorithms for wood surface feature detection and defined several measures for examining the algorithm performance. The performance analysis of segmentation algorithms on images of Douglas-fir veneer showed that region-based algorithms have the best performance. For image enhancement, otsu thresholding method provided better results. Salih et al. [21] discussed the image segmentation methods for edge based and region based segmentation. Experiments of segmentations resulting from edge-based methods and region growing methods were not the same. From the results it was concluded that the region growing techniques were generally better in noisy images, where edges were extremely difficult to detect. Liao et al. [13] proposed an algorithm for multilevel thresholding which reduces the ostu thresholding technique execution time at its best.

Zhu et al. [10] applied ostu thresholding technique for shape-based image segmentation in gray scale image and the images were segmented with higher rate of accuracy. As per the literature survey, it is clear that the significance of the segmentation process is larger when compared to other early image processing key stages. Alnihoud and Bayt [4] proposed an efficient approach for object recognition. Mathematical morphological technique was applied to correlate and retrieve the objects. The Laplacian of Gaussian technique was applied for detecting the edges. Bing Fei Wu et al. [2] have proposed a new region-based segmentation method for resolving issues associated with the complexity of the backgrounds of complex document images. The method proposed processes the document image regionally and adaptively according to the local features using two stages. An automatic localized multilevel thresholding method was utilized to recursively segment a specified block region into several layered image sub-blocks. Then a multi-layer region-based clustering was performed to aggregate the layered image sub-blocks with homogeneous features into associated object layers. The experimental results on text extraction from complex document images demonstrated the efficiency of the proposed method. According to Thacker [22], using image shape descriptions based on pair wise geometric relationship has resulted in the extraction of smooth arbitrary con-complete curves from gray scale images. The system has a disadvantage of changes due to translation and rotation. From the survey performed, it is clear that image segmentation has a major role to play in the process of object detection and identification. Also, it is noted that the performance of the various segmentation techniques can vary from an image to an image depending on the nature and the modality of images. Motivated by these changes, an effort is made towards applying the widely used segmentation techniques in industrial radiographic images.

3. Methodology

A set of images containing welding defects, such as tungsten inclusion, porosity and crack are considered for the study. Initially, a ground truth image is created. Different image segmentation techniques, such as boundary based, edge based and threshold based segmentations are applied and tested. *Ground Truth Image*: A Ground truth Image (GI) is created for the radiographic image, containing a weld defect using the hand segmentation tool *Microsoft paint*. After creating the GI, the original source image (SI) is subjected to various existing segmentation techniques.

The following procedure is adopted to perform the process.

1. Read the original image –OI(x, y) where x, y are spatial coordinates

2. Construct the ground truth image GI(x, y).

3. Perform enhancement of OI(x, y) by suppressing the noise without blurring the sharp edge. To obtain the noise suppressed image, a median filter is applied.

4. Convert the filtered image into black and white (binary) image. The filter image converted to a black and white image by a thersholding operation. The output

black and white image replaces all pixels in the input image with luminance greater than a level with the value of 1 (white) and replaces all other pixels with the value 0 (black). Specify the level within the range [0, 1]. This range is relative to the signal levels possible for the image's class. Therefore, a level value of 0.5 is a midway between black and white, regardless of the class.

5. Apply all the segmentation techniques and segment the edges of the image. After completion of filtering and conversion of the binary image, the meaningful region of the image has to be extracted/identified for the further process, such as recognition/classifying the image. In this procedure, determination of identifying the best suitable segmentation technique for industrial radiographic images is carried out. With this intension, as per the related work edge based, boundary based, threshold based segmentation techniques are applied to segment the edges of the industrial radiographic images. The results of applying various segmentation techniques are discussed in Table 1.

6. To assess the accuracy of the segmentation techniques, the meaningful segmented image is required. To obtain the meaningful segment of the image, a manual segment is performed. For carrying out such a task, the grabbed original image is converted to a ground truth image using MS-paint. The boundary of the ROI is marked manually using the grid facility of the paint tool and the same is used to obtain the efficiency of the segmentation methods. Using (1) the threshold value of the Ground truth Image (GI_T) and the threshold value of various Segmentations truth Image (SI_T) is computed for further processing. The implementation of this is discussed through Table 2 up to Table 7. Compute the threshold of GI_T and SI_T

A threshold is obtained using

$$T(\mathrm{OI}) = \left\{ \begin{array}{cc} 0 & 0 \le \mathrm{OI} < a \\ \propto \mathrm{OI} & a \le \mathrm{OI} \le b \\ L & \mathrm{OI} \ge l \end{array} \right\}, \tag{1}$$

where, OI is the original image; a, b define the valley between the peaks of the histogram; T is the threshold value; L is the intensity.

7. Compare the threshold value of the ground truth image with the threshold value of the segmented image to get the difference as $D_T = GI_T - SI_T$.

Hence, the percentage of difference is obtained as $((D_T/GI_T)100)$.

Radiographic images containing defects, such as Tungsten inclusion, porosity and crack are taken as a sample. Sample selection is made based on the aspects, such as similar and dissimilar geometrical features. In an industrial radiographic image, based on defect detection, it is very difficult to differentiate the tungsten inclusion from porosity due to their similarities in the geometrical features. Therefore, to find out the significance of segmentation algorithms in detecting these defects, they are considered in the study. On the other hand, to show the efficiency of the segmentation process in discriminating the circular and elongated defects, an image, containing a crack is considered in the study. The result of applying various segmentation techniques are tabulated in Table 1.

4. Results and discussion

From Table 1 it is evident that the segmentation process plays an important role in defects detection process. The results of various segmentation techniques are analyzed and the percentage of mismatching segmentation between ground truth images with all the segmentation techniques is computed. The details are given below.

Table 1. Results obtained from various segmentation techniques

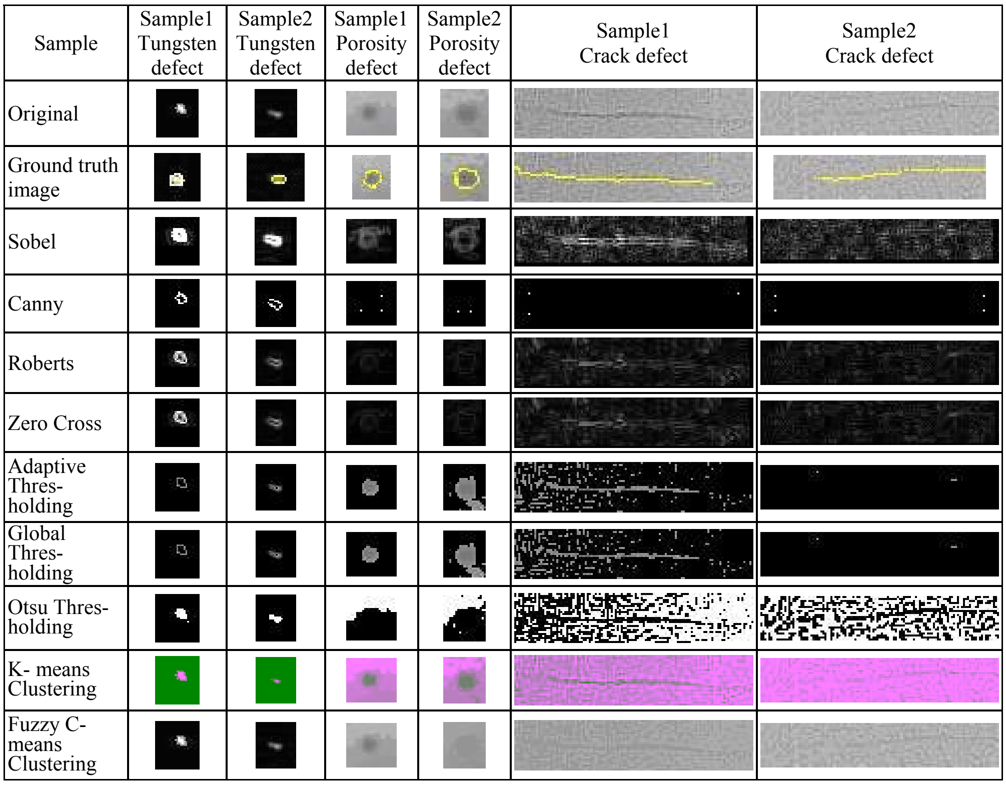

Table 2. The percentage of mismatch between the ground truth image and segmented image – Tungsten (Sample 1)

Tungsten Sample 1 Ground truth image(GI_T) Threshold Value: 32			
Segmentation Technique	SI_T	D_T	D_T, %
Sobel	10	22	69.81
Canny	20	12	37.50
Roberts	18	14	42.86
Zerocross	18	14	42.86
Adaptive Thresholding	18	14	43.75
Global Thresholding	18	14	43.75
Otsu Thresholding	15	17	52.94
K-Means Clustering	31	1	3.13
Fuzzy –C means Clustering	29	3	8.57

Table 3. The percentage of mismatch between the ground truth image and the segmented image – Tungsten (Sample 2)

Tungsten Sample 2 Ground truth image(GI_T) Threshold Value: 33			
Segmentation Technique	SI_T	D_T	D_T, %
Sobel	12	21	62.92
Canny	22	11	33.33
Roberts	22	11	32.65
Zero cross	22	11	32.65
Adaptive Thresholding	29	4	12.12
Global Thresholding	29	4	12.12
Otsu Thresholding	19	14	43.10
K-Means Clustering	32	1	2.94
Fuzzy –C means Clustering	33	0	0.00

According to the study made (Tables 2 and 3), with Tungsten inclusion, the total number of pixels within the ground truth is found to be 32 and 33 respectively. By comparing the number of pixels obtained after applying the standard segmentation techniques, it is clear that the efficiency of the edge based, region based algorithms is less compared to the clustering techniques, whereas the rest of the techniques are found appropriate over segmented images only.

Table 4. The percentage of mismatch between the ground truth image and segmented image – Porosity (Sample 1)

Porosity Sample 1 Ground truth image(GI_T) Threshold Value : 483			
Segmentation Technique	SI_T	D_T	D_T, %
Sobel	194	289	59.83
Canny	2	481	99.59
Roberts	6	477	98.76
Zerocross	6	477	98.76
Adaptive Thresholding	137	346	71.64
Global Thresholding	137	346	71.64
Otsu Thresholding	224	259	53.62
K-Means Clustering	483	0	0.00
Fuzzy –C means Clustering	483	0	0.00

Table 5. The percentage of mismatch between ground truth image and segmented image – Porosity (sample2)

Porosity Sample 2 Ground truth image(GI_T) Threshold Value : 550			
Segmentation Technique	SI_T	D_T	D_T, %
Sobel	152	398	72.36
Canny	4	546	99.27
Roberts	7	543	98.73
Zerocross	7	543	98.73
Adaptive Thresholding	51	499	90.73
Global Thresholding	51	499	90.73
Otsu Thresholding	229	321	58.36
K-Means Clustering	550	0	0.00
Fuzzy –C means Clustering	550	0	0.00

Similarly, for defect porosity, the study proved (Tables 4 and 5) that the performance of clustering techniques is better than the other edge based and region based segmentation.

Table 6. The percentage of mismatch between the ground truth image and segmented image – Crack (Sample 1)

Crack Sample 1 Ground truth image (GI_T) Threshold Value: 1700			
Segmentation Technique	SI_T	D_T	D_T , %
Sobel	1497	203	11.96
Canny	3	1697	99.84
Roberts	539	1161	68.31
Zerocross	539	1161	68.31
Adaptive Thresholding	371	1329	78.15
Global Thresholding	371	1329	78.15
Otsu Thresholding	1491	209	12.31
K-Means Clustering	1114	586	34.49
Fuzzy –Cmeans Clustering	1456	244	14.34

Table 7. The percentage of mismatch between the ground truth image and segmented image – Crack (Sample 2)

Crack Sample 2 (Ground truth image (GI_T) Threshold Value pixel Count): 1637			
Segmentation Technique	SI_T	D_T	D_T, %
Sobel	209	1428	12.77
Canny	1633	4	99.76
Roberts	1354	283	82.71
Zero Cross	1354	283	82.71
Adaptive	1633	4	99.76
Global	1633	4	99.76
Otsu	263	1374	16.09
K-means	613	1024	37.47
Fuzzy –C means	613	1024	37.47

Considering the defect crack (Tables 6 and 7), all the identified segmentation techniques were applied. From the experimentation carried out, it is found that the Sobel based edge detection and Otsu thresholding based region detection performed well than the other methods.

Table 8. Performance analysis of percentage of mismatch of between ground truth image and segmented image – Tungsten, Porosity and Crack

Defect Type	Tungsten		Porosity		Crack	
Segmentation Technique	Sample1	Sample2	Sample1	Sample2	Sample1	Sample2
Sobel	69.81	62.92	59.83	72.36	11.96	12.77
Canny	37.50	33.33	99.59	99.27	99.84	99.76
Roberts	42.86	32.65	98.76	98.73	68.31	82.71
Zero cross	42.86	32.65	98.76	98.73	68.31	82.71
Adaptive Thresholding	43.75	12.12	71.64	90.73	78.15	99.76
Global Thresholding	43.75	12.12	71.64	90.73	78.15	99.76
Otsu Thresholding	52.94	43.10	53.62	58.36	12.31	16.09
K-means Clustering	3.13	2.94	0.00	0.00	34.49	37.47
Fuzzy c-means Clustering	8.57	0.00	0.00	0.00	14.34	37.47

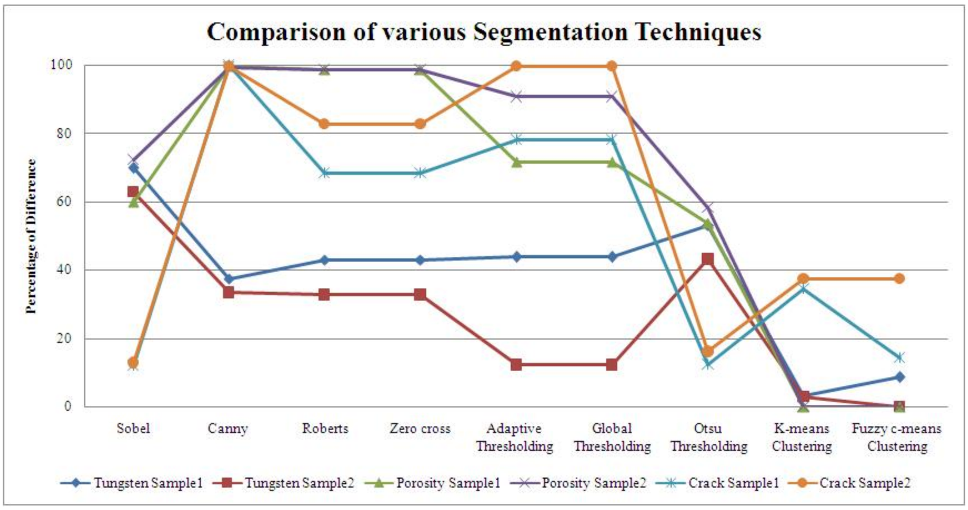

Fig. 1. Performance of various segmentation techniques

Comparing the performance of the segmentation techniques, it is apparent that all these techniques have performed segmentation of the Region of Interest (ROI). In addition, the suitability of the segmentation techniques for extracting ROI is highly debatable due to the varying characteristics of the defect appearance in the image. From the study performed, it is clear that the segmentation of ROI is not in an acceptable format, if the difference between the ground truth image and the segmented image is more than 20%.

5. Conclusion and future enhancement

This study has concentrated on the segmentation of ROI containing defects, such as tungsten inclusion, porosity and crack weld radiographic images. More than 40 samples have been tested for each type of the defect. Two samples of each defect along with its mismatching percentage of the segmentation level with respect to the ground truth image is discussed in this paper. Similar results for the other samples were also found. The analysis of the results lead to the conclusion that the improper selection of the segmentation technique will not help the process of recognition of ROI. Also, a common segmentation mechanism will not be suitable for all kinds of ROI. Based on the observations made in this aspect of the study, it is evident that for extracting circular defects, clustering techniques has performed well with a very negligible percentage of difference (< 10%), while for the elongated defects, the edge based segmentation and thresholding performed well. The percentage of difference in these methods appeared to be less than 20%. To conclude, the segmentation plays a vital role in identifying ROI. Especially, in industrial radiographic images, it plays a significant role depending on which defects are detected. The efforts in this study discovered the fact of developing a unified segmentation technique, which is suitable for extracting both types of ROI.

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