A New Method for Determining Transverse Crack Defects in Welding Radiography Images based on Fuzzy-Genetic Algorithm

Fatemeh Abdi\textsuperscript{a}, Abbas Karimi\textsuperscript{b}, Emad Eddin Hezavehi\textsuperscript{c}

\textsuperscript{a} Department of Computer Engineering, Faculty of Engineering, Islamic Azad University, Arak Branch, Arak, Iran
\textsuperscript{b} Department of Computer Engineering, Faculty of Engineering, Islamic Azad University, Arak Branch, Arak, Iran
\textsuperscript{c} Department of Computer Engineering, Faculty of Engineering, Islamic Azad University, Arak Branch, Arak, Iran

* Corresponding author. Tel.0098-8632146; E-mail address: Yamna1390@gmail.com

Abstract

Keywords: Edge detection, Fuzzy-genetic algorithm, Image processing, Radiographic images.

Transverse cracks are one of the important defects in the welding industry, and if such defects are detected in radiography images, the welded part will be returned to further operations. Among the nondestructive testing methods, industrial radiography is one of the suitable and commonly used techniques for detecting and assessing welding defects. Hence, providing a new method for error-free interpretation of radiography films is necessary. The present research proposes a new method for optimizing the edge detection fuzzy system based on the genetic algorithm that results in the quality improvement of radiography images in terms of better detection of transverse cracks. Based on the results of the proposed algorithm, 15 outputs were randomly applied to radiography images. Visual observations and reliability of the optimized system confirmed the strength of the proposed method for improving the quality of radiography images and the easiness of images’ defects detection.

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1. Introduction

The Welding process is known as the main process for joining similar and dissimilar metals. It is necessary to analyze and test the quality of welding products from different analytic, static, and dynamic dimensions. Welding processes are significant in modern industries such as aerospace, shipbuilding, petroleum, and petrochemical industries. Nondestructive testing (NDT) is an integral and inseparable constituent of quality assurance programs in every industry. In terms of quality control, thus, NDT has an outstanding position in achieving efficient and effective results. Given this, the industrial radiography (RT) is one of the suitable and common techniques for identifying and assessing the quality characteristics of the welding (defects such as cracks, porosity, and slag). Transverse cracks are important in detecting defects, and if they are detected in the radiography image, the welded part should be returned for re-welding. Sometimes, the ups and downs of the handmade welding line mask the defect from radiography image and make its interpretation difficult. Therefore, the present research proposes an algorithm to enhance the quality of industrial radiography images and offers a practical way for a better, more accurate, and easier identification of welding defects. In the proposed method, an optimization method based on the genetic
algorithm was used. After the optimization of edge detection fuzzy system through pre-edge detected samples, the fuzzy system was implemented in four edge detection steps which include: 1) digitalizing and improving the radiography images, 2) prototyping, 3) optimizing the edge detection fuzzy system, and finally 4) images’ edge detection. The algorithm implementation procedure is carried out using MATLAB software.

2. Methodology Background
One of the useful and effective features in object detection relies on the use of information about an object and its edges. Many methods have been developed for edge detection, including methods that are based on wavelet conversion, the algorithm for water division line, morphological operators, ant algorithm, soft computing, and fuzzy edge detection. In addition to the previous edge detection methods, fuzzy edge detection is one of the important methods that have too many applications for edge detection. Abdollah et al. (2009) [1] employed a 3×3 square and evaluated its edge detection ability using eight rules over 9 pixels. Bhagabati and Das (2012) [2] employed a 3×3 square and implemented their proposed edge detection method using ten rules over 4 pixels. Bharti and Kumar (2013) [3] used a 2×2 mask with 16 rules for edge detection over four neighborhood pixels.

3. Proposed algorithm
3.1. Image digitalization
If the radiography imaging system is equipped with a computer interface, radiography image data will be transmitted directly to the computer system. In the traditional methods, however, the radiography films are scanned using a scanner device. In the present research, a set of radiography films owned by Gas Company in Markazi province of Iran was employed as the research sample and an HP 5590 scanner device was used to convert the negatives of radiography films to digital images. The images were stored in a computer system in TIFF format.

3.2. Region of Interest (ROI), Recognition of Interested Parts (Operation Zone)
The first step in the processing of digital images is the separation of the under study zone. For this purpose, different methods were employed. Moallem et al. (2007) [4] used the vertical projection to find the welding zone and its domain. In the optical field, the vertical projection is a machine that converts two-dimensional space to one-dimensional space resulting in a sharp decline in the information volume. The use of Raleigh Probability Density Function (RPDF) for each pixel help in the recognition of welding zone. [5] Mythili Thruanam et al. [6] used a global thresholding method. Wang’s and OTSU methods have been used as the methods of global thresholding techniques. Hassan et al.[7] employed canny edge detector that is based on the gradient of radiography images. In the welding radiography images, it is assumed that images are horizontal, thus selecting the bright zone will help to detect the operating zone. Here, the summation of image pixels’ brightness intensity in a row was used,
and the alpha threshold was selected as the darkness threshold. Having this information, the index of the lowest and highest lines in the bright zone was obtained. Then, the zone between these two lines was selected as the operating zone (equation 1).

\[
I=\{i(x,y)|\maxRowIndex>y>\minRowIndex \mid \maxRowIndex=\max(\text{Index}(\text{rowSum}>\alpha))
\and \minRowIndex=\min(\text{Index}(\text{rowSum}>\alpha)) \mid \text{rowSum}=\text{sum}(i(y))\}
\]

Equation 1. The selection of operating zone’s points from the images (\(i\) is the welding radiography image, \(I\) is the operating zone, \(\alpha\) is the constant showing the intensity of brightness in the dark zone, and \(x\) and \(y\) are the image dimensions).

### 3.1. Pre-processing

After imaging, the images were read as digital images while the RGB images were changed to gray scale. Then the operating zone was selected to eliminate the points that are less than 5 pixels, a mean filter with 5\times5 pixel mask was employed. To correct the gradient of brightness intensity changes, statistic ordering was undertaken. Subsequently, the edge’s gradient was sharpened using a sharp filter. A two-dimensional noise deletion filter with 3\times3 pixel masks, 5\times5 pixel masks, and 10\times10 pixel masks was used in every step to re-correct the brightness intensity distribution histogram.

![Fig. 2: Pre-process algorithm](image-url)
4.1. Fuzzy System

Inspired by Shikha Bharti’s method, here a $2 \times 2$ chi-square is used and edge detection is carried out with four inputs and 1 output over four neighbor pixels (Figure 2). In the system, Mamdani’s Inference Engine and the center of gravity defuzzifier are employed. In addition, the “and” method and “or” method respectively are chosen for minimum and maximum [1] (Figure 3).

![Fig. 3: Shikha Bharti’s 2×2 mask](image3)

![Fig. 4: Shikha Bharti’s Mamdani system](image4)

The system employs 16 rules for edge detection [c], they are all artificial black and white pixels and are determined based on their pre-defined intervals.

<table>
<thead>
<tr>
<th>Fuzzy Inputs</th>
<th>Fuzzy Output</th>
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<tbody>
<tr>
<td>$P_1$</td>
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<td>B</td>
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<td>W</td>
<td>W</td>
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</tbody>
</table>

![Fig. 5: Shikha Bharti’s fuzzy rules system](image5)

If we consider the edge pixel as 1 and non-edge pixel as 0, the resulted array will be as follows:

| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 |

An array of fuzzy function rules [c]
The examination of the image brightness intensity shows an approximate interval for the membership functions base of the fuzzy system input and output.

Based on the selected interval, the input membership function is defined using trapezoidal diagram for the black and white color values and the output membership function is defined as the employing triangular diagram for detecting the edge or non-edge zones.

\[
\begin{align*}
\text{Equation 2) Black color membership function} \\
&= f(0, 70, 100, 170) = \begin{cases} 
0, & x < 0 \\
\frac{x}{70}, & 0 \leq x \leq 70 \\
1, & 70 < x < 100 \\
\frac{170 - x}{70}, & x \leq 170
\end{cases}
\end{align*}
\]

\[
\text{Equation 3) White color membership function} \\
&= f(140, 190, 230, 255) = \begin{cases} 
0, & x < 0 \\
\frac{x - 140}{50}, & 140 \leq x \leq 190 \\
1, & 190 < x < 230 \\
\frac{230 - x}{25}, & x \leq 255
\end{cases}
\]

\[
\text{Equation 4) Edge membership function} \\
&= f(0, 90, 220) = \begin{cases} 
0, & x < 0 \\
\frac{x}{90}, & 0 \leq x \leq 90 \\
\frac{220 - x}{110}, & 90 \leq x \leq 220 \\
0, & 220 \leq x
\end{cases}
\]
5.1. Fuzzy system optimization using genetic algorithm

Since it is possible to define the bases of fuzzy membership functions at the [0 255] interval, obviously different selections are possible but the precision and correctness on the selection rely on a more accurate method. The research tries to select the best interval and domain for the membership function using the genetic algorithm. Furthermore, discovering suitable rules is another aim of the fuzzy system optimization; here the selection is from 65535 possible cases for 16 rules.

5.1.1. Chromosome structure

Shikha Bharti et al. (2013) used a 2x2 mask with 16 rules for edge detection over four neighbor pixels. One of the present research objectives is automatic discovering of suitable rules in each optimization run for the 16 rule system. For this purpose, we need to find 16 answers for the system’s rules using the genetic algorithm.

Each chromosome in the genetic algorithm indicates a point in the searching space and a possible solution to the considered problem. Chromosomes are composed of a fixed number of genes and in the proposed algorithm a 15-component array is used to display the chromosomes. One of the genes was considered for determining the best array from 65535 different cases. The other 14 genes were placed at [0 1] decimal interval and were considered for identifying the input and output membership function.

\[
f(160, 220, 255) = \begin{cases} 
0, & x < 160 \\
\frac{x - 160}{40}, & 160 \leq x \leq 220 \\
\frac{255 - x}{35}, & 220 \leq x \leq 255 \\
0, & 255 \leq x 
\end{cases}
\]

Equation 5) Non-edge membership function

5.1.2. Fitness function

In any problem, a suitable fitness function is created based on the nature of the program. In order to recognize better creatures among a population, it is necessary to define a relevant criterion for identifying better creatures. This process, i.e. the determination of the creature's fitness is called “evaluation of the creature.”
In such an evaluation, a number is assigned to the goodness of a creature; the number for better creatures may be larger (or smaller) which is known as fitness. The fitness is maximized or minimized according to the problem nature.

In the proposed algorithm, the image’s number of edges that are detected by Sobel operator is used as the criterion. The image edges always contain useful information. In general, an edge is the boundary for light intensity changes between two parts of one single image. Here, the evaluation function is from minimum type, so the lowest value is selected as the highest fitness. For example, if we aim at minimizing a function, the inputs with lower function values will be considered as better inputs.

For computing the values from pre-processed images, a sample is considered for edge detection using Sobel edge detector, and its output is compared with the output of every genome generation in the proposed algorithm.

Then, the fitness of each generation is estimated using differences in the detected edges of two images. The result is shown in the diagram form.

A random sample of the population was created through the genetic algorithm toolbar in the MATLAB software. The Roulette wheel method was used for selection operant, mutation operant is set at the rate of one-twentieth on 5 percent of the population, and the combination rate is considered as eight-tenth. The genetic algorithm implementation with the proposed adjustments empirically indicated that the population tended to optimality.
As it can be seen from the Figure 11 and according to the fitness function, the lowest value (smallest difference) is the highest fitness in the diagram. At the final step of the algorithm, one output was randomly selected from the outputs of the proposed algorithm, then it was fed into the fuzzy system. The output image with a higher quality was obtained from the system. The selected rules array as:

\[ 0 \ 0 \ 0 \ 0 \ 1 \ 0 \ 0 \ 1 \ 0 \ 1 \ 1 \ 1 \ 0 \]

- Optimized based for black membership function
  
  \[ 12 \ 63 \ 140 \ 155 \]

- Optimized bases for white membership function
  
  \[ 49 \ 146 \ 204 \ 254 \]

- Optimized based for edge output membership function
  
  \[ 8 \ 24 \ 97 \]

- Optimized based for non-edge output membership function
  
  \[ 140 \ 147 \ 204 \]

The resulted image was compared with the image obtained through the selected domain and with another image from another edge detector such as Canny edge detector. As it is shown in Figures 12 to 16, the previous image noises that could lead to misleading the detection disappear and the welding line edges are quite clear.

Fig. 12: Main welding radiography image

Fig. 13: Pre-processed image

Fig. 14: Edge detected image using fuzzy system

Fig. 15: Edge detected image using Canny algorithm

Fig. 16: Edge detected image using fuzzy system optimized with genetic algorithm
5.1.3 Reliability
In order to demonstrate the proposed algorithm’s efficiency, the method is used for some scanned radiography images with TIFF format employing MATLAB 2013 software with 2.50 GHZ CPU and 4 GB RAM. For the quantitative evaluation of the proposed algorithm, 30 outputs from the outputs of the genetic algorithm were randomly selected and fed into the fuzzy system from which 27 correct answers and three incorrect answers were obtained.

N=30 Number of selected outputs  
Nc=27 Number of correct results  
Nin=3 Number of incorrect results  
The algorithm reliability → R= \frac{Nc}{N}=\frac{27}{30} \times 100=90%  

<table>
<thead>
<tr>
<th>Incorrect detection probability</th>
<th>False negative</th>
<th>False positive</th>
<th>True negative</th>
<th>True positive</th>
<th>Number of tested samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>%10</td>
<td>%90</td>
<td>2</td>
<td>13</td>
<td>13</td>
<td>30</td>
</tr>
</tbody>
</table>

Sensitivity=\frac{True positive}{True positive+False negative}=\frac{13}{15}=0.86

efficiency=\frac{False positive}{True negative+False positive}=\frac{14}{14}=1

6. Conclusion
The genetic algorithm is considered as a very promising optimization method in the image processing field, and it is commonly used to implement various filters and to increase the images’ contrasts. Among the welding defects, transverse crack is a very significant and impossible to ignore defect. Thus, the optimization success in this context is vital and in the fuzzy-genetic system heavily depends on chromosome coding scheme, crossover and mutation strategy, fitness function, domain selection, and the chosen fuzzy rules. For each problem, a detailed analysis should be conducted, and a correct method should be selected.

References