Automated Defect Detection of Weldments and Castings using Canny, Sobel and Gaussian filter Edge Detectors: A Comparison Study

Fazel Mirzaei¹, Mohammadjavad Faridafshin¹, Amir Movafeghi², Reza Faghihi¹,³
¹Nuclear Engineering Department, School of Mechanical Engineering, Shiraz University, Shiraz, Iran, fazel.mirzaee@shirazu.ac.ir, Mohammad_farid@outlook.com
²Nuclear Science and Technology Research Institute, Tehran, Iran, amovafeghi@aeoi.org.ir
³Radiation Research center, Shiraz University, Shiraz, Iran, faghihir@shirazu.ac.ir

Abstract

Today non-destructive-testing (NDT) has found growing applications in lots of industrial areas. By progress of technology and improvement of processing systems, a variety of computer algorithms have been proposed for their application in NDT. The purpose of these algorithms is to reduce human intervention in all industrial aspects as much as possible. The radiographical image interpretation is one of the most important applications. An experienced person with highly trained eyes and mind is responsible for radiographic image interpretation; therefore, the output is highly sensitive to the human experience and would suffer from bias and mistakes. Additionally, the cost of training an experienced interpreter is very high. Thus, an automated system with high reliability of interpreting the radiographic images is required. One of the most attractive areas in radiographical image processing is automated defect detection of weldments and castings. Several algorithms on edge detection and pattern recognition have been proposed in the literature. In this paper, we do a comparison study of the performance of three well-known edge detection algorithms in the context of radiographic image processing. Sobel, Canny and Gaussian filter edge detectors were implemented and applied on a welding image database. At the end, the results are shown.

Keywords: Non-Destructive Testing, Edge enhancement, Defect detection, Gaussian filter, Image processing

1- Introduction

In 1988, the work presented in [1] studied for the first time the application of image processing in automatic flaw detection in radiographical images obtained from printed circuit boards (PCB). In 1999, Liao et al. [2] applied a fuzzy clustering method for defect detection in radiographical images of welded joints. [3] Compared two well-known classifiers fuzzy k-nearest neighbors and multi-layer perceptron for detection and classification of weld flaws. Image segmentation is also an area of interest in this field. Segmenting the background from defects in radiographical images is non-trivial because of the low SNR (=1) of defect. Consequently several works have been done on devising approaches specifically for radiographical image segmentation [4], [5], [6],[7]. However, choosing a proper algorithm can be particularly challenging because of the large number of algorithms and needs as well as applications. To meet these needs, three well-known methods in edge-detection were choose. These methods are Canny, Sobel and Gaussian filter edge detectors. To compare their operation, they were implemented and applied on large number of welding images. At the end, the results are shown.

1-1 Canny edge detector

Canny edge detection algorithm was developed by John F. Canny in 1986 [8]. In JFC’s technique, the following five steps are done in the algorithm to satisfy the three most important criteria relative to the edge detection performance: low error rate, good localization of edge points, and having just one response to a single edge. The fourth and fifth steps are for applying a threshold for determining the true edges and suppressing the edges that are not connected to the certain edge.

1-1-1 Smoothing

In this step, a Gaussian filter is convolved with the image to filter out noise and unwanted details for dampening the error rate. By doing this, the signal-to-noise ratio (SNR) at the center of the edge is maximized. The SNR at an edge pixel is given by the equation. If f(x) and g(x) be the impulse response of the filter and edge in 1-D respectively; then the SNR at the edge pixel is computed in the following way[8].
\[ SNR = \frac{\int_{-W}^{W} G(x) f(x) \, dx}{n_0 \sqrt{\int_{-W}^{W} f^2(x) \, dx}} \]  

The numerator and denominator of equation 1 are the filter response to the edge \( G(x) \) at its center and the root-mean-square of its response to the noise alone bounded by \([-W, W]\) respectively. This SNR is optimized with respect to the filter’s impulse response using calculus of variations. Optimization of the SNR is done by applying the Gaussian filter of equation 2 to the image at each location \((x, y)\).

\[ g(x, y) = \frac{1}{2\pi\sigma^2} \exp\left(\frac{-x^2 + y^2}{2\sigma^2}\right) \]  

1-1-2 Localization

Localization of the edges in the image is done in the second step, by finding the gradients of the image in both \(x\) and \(y\) directions. Using this gradients, the pixels not corresponding to the edges will be assigned 0 intensity. According to Canny [8], the 1-dimensional formula given by equation 3 should be maximized.

\[ localization = \frac{\int_{-W}^{W} G^*(x) f'(x) \, dx}{n_0 \sqrt{\int_{-W}^{W} f'^2(x) \, dx}} \]  

Up to now, the edge has been defined as the local maxima in the impulse response of the image with a linear filter. Now, we need to distinguish the non-edge from the real edges detected by the procedure; i.e., just the thin lines of the edges should remain.

1-1-3 Thresholding

At the third step, the probability to which the algorithm finds multiple responses to a single edge is decreased. This is done by applying a threshold on the gradient of the image at each pixel. By doing this, the intensity of the non-edge pixels is reduced. This process is also called “Non-maxima Suppression”.

1-1-4 Double thresholding

After suppressing the non-maxima points in the image, there may be some points that are caused by noise. These points are eliminated by considering an additional threshold on the image. The magnitude of this second threshold should be less than the first one.

1-1-5 Forming continuous edges

In addition of the two thresholds so far, a connectivity factor is also considered to make the edge detection more precise and confident. By considering this factor, only the connected regions that are detected are marked as defect.

1-2 Sobel edge detector

The gradient of the image is defined as the rough changes of the intensity at certain points, then these points are called edges. Because of the discrete nature of the image, the gradient could not be computed unless one assumes a continuous function underlying the image. So, the output is just an assumption of the image gradient; the so called “Sobel edge detector” [9] is an operator that gives such an approximation. This algorithm takes 8 points around each image point forming a 3 by 3 neighborhood of that point denoted by “e” in Fig. 1. The directional derivative is then estimated the central point as the vector summation of the 4 directional derivatives at the 8 neighbors. The magnitude and direction of the gradient is approximated by equations 3, 4 and 6 where \(G_x\) and \(G_y\) are image gradients in the \(x\) and \(y\) direction.
\[ G_x = (c - g - a + i) + 2(f - d) \]  
\[ G_y = (c - g + a - i) + 2(b - h) \]

\[ \theta = \arctan(G_x / G_y) \]

Formulas 4 and 5 are summations over the involved pixels at the mentioned directions. This summation can be implemented as the convolution of a matrix with components representing the coefficients of each point by the image “A”. The output of such convolution is the gradient approximations in the x and y direction (formulas 7 and 8) [10]

\[ G_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \ast A \]

\[ G_y = \begin{bmatrix} 1 & 2 & 3 \\ 0 & 0 & 0 \\ -1 & -2 & -3 \end{bmatrix} \ast A \]

1.3 Gaussian Infinite Impulse Response (IIR) Filter

In this section the application of the known Gaussian infinite impulse response filter (Gaussian IIR for short) through anisotropic diffusion is briefly discussed. Despite the two popular edge detection algorithms discussed so far, edge detection by anisotropic diffusion is of less attention. In this section, Gaussian IIR filter is used in anisotropic diffusion technique for noise reduction and edge enhancement in grayscale radiographical images. Because of the recursive nature of anisotropic diffusion method, the computational time is a decisive factor of whether using this algorithm or not. Alvarez and Mazorra[11] developed a model (formula 9) for noise reduction and edge detection of two-dimensional signals. The stability of their model makes the diffusion to reach the answer in a few iterations.

\[ l_t = CL(l) - I_{n}F(G_{\sigma} \ast I_{yy}, G_{\sigma} \ast I_{y}) \]

In formula 9, \( \eta \) and \( L(l) \) represent two orthogonal directions, where \( \eta = \eta(x) \) is the direction of the gradient and \( L(u) = u_{\xi} \) with \( \xi = \xi(x) \) the direction of the contour – perpendicular to the gradient(Fig 2.)[12]. Moreover, \( G_{\sigma} \) is the Gaussian filter with variance \( \sigma \) and \( C \) is a weighting factor for balancing the effects of anisotropic diffusion and edge enhancement. The function \( F(\ldots) \) is the sign function represented in equation 10.

\[ F(p, q) = s(g(p)s(gn(q)) \]
The first term of the model 9 corresponds to the anisotropic diffusion in the contour direction to smooth the two sides of the edge, i.e. smoothing the non-edge regions. And the second term stands for edge enhancement in the direction of the image gradient; namely, the “Shock filter” term. This filter produces shocks where the edge occurs. Thus, in this model, noise reduction and edge enhancement are done at the same time.

1-3-1 Noise Reduction

To be computationally implementable, the Gaussian filter is approximated by the solution of the two-dimensional heat equation. This filter is convolved with the image gradient and Laplacian in the direction perpendicular to the edge.

\[
m_{\lambda}(\omega) = \frac{(\nu/\lambda)}{(1 - \nu e^{-\lambda k})(1 - \nu e^{-\lambda h})}
\]

This filter is applied to the image k times. In the above formula, the parameters are as follows:

\[
\nu = \frac{1 + 2\lambda - \sqrt{1 + 4\lambda}}{2\lambda}
\]

Where \(\lambda\) is:

\[
\lambda = \frac{\sigma^2}{2k}
\]

1-3-2 Edge Enhancement

After the convolution by a Gaussian filter, the resulting image goes through a shock filter for edge detection. In this stage, 4 cases should be considered:

1. \(\text{sign}(G \ast I_{\eta}) > 0\) and \(\text{sign}(G \ast I_{\xi}) > 0\). This causes the term written in equation 10 become positive and the model would be:

\[
I_t = CI_{\xi\xi} - I_{\eta}
\]

In this case, the pixel is in neighborhood of a regional minimum and the erosion operation would be proceeded[13].

![Figure 2. Directions of \(\eta\) and \(\xi\) in equation 9](image-url)
2. \( \text{sign}(G_o \ast I_{\eta}) > 0 \) and \( \text{sign}(G_o \ast I_{\eta}) < 0 \). In this case the function of equation 10 would be negative and the model would be:

\[
l_t = C I_{\xi \xi} - I_{\eta}
\]

(15)

In this case, the pixel belongs to the neighborhood of a regional maximum and the dilation operation would be proceeded.

3. \( \text{sign}(G_o \ast I_{\eta}) < 0 \) and \( \text{sign}(G_o \ast I_{\eta}) < 0 \). As case 1.

4. \( \text{sign}(G_o \ast I_{\eta}) < 0 \) and \( \text{sign}(G_o \ast I_{\eta}) > 0 \). As case 2.

At time \( t = 0 \), the original image \( I(x, y, 0) \) is convolved with the Gaussian filter defined above. Obtained image is convolved again with a Gaussian to produce a more blurred image. In the subsequent steps the number of regional minima and maxima is not further reduced and the aim is to lower their number so as to obtain a more noise reduced image. This process is done iteratively to meet the number of iterations defined by the user; the more the iterations, the more the efficiency and the more the Computational time. In the end, an image with blurred regions outside the edge is obtained.

2- Result and Discussion

To compare the selected methods, the welding image is obtained from GDxray welding image database. The three methods are then applied on these images and the results are shown below.

![Original image](image1.jpg)

Figure 3. Original image obtained from GDx-ray welding images database

![Canny algorithm Output](image2.jpg)

Fig 4: Canny algorithm Output

![Gaussian IIR filter with 200 iterations and sigma = 10](image3.jpg)

Figure 5. Gaussian IIR filter with 200 iterations and sigma = 10
Obviously, there is no clear difference between the Canny, Sobel and Gaussian IIR algorithm. Thus, we explored the performance of the three algorithms on the GDX-ray welding database and came to the result that the overall performance of the Gaussian IIR filter is higher than Canny and Sobel algorithms based on the number of iteration and amount of sigma. So, for more assessment the number of iterations and sigma are manipulated randomly and the results are shown below.

![Figure 8. Gaussian IIR filter with 200 iterations and sigma = 30](image)

![Figure 7. Gaussian IIR filter with 100 iterations and sigma = 10](image)

![Figure 6. Gaussian IIR filter with 100 iterations and sigma = 30](image)

3- Conclusion
Conclusively, choosing an edge detection algorithm to be applied on radiograph images is highly task specific. The practical solution to the task of selecting the algorithm with highest performance, is considering the demands of the application.

4- Acknowledgement
The authors would like to thank the image processing task group of medical radiation engineering department of the Shiraz University of Iran.

5- References


