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# Characteristics of butt welding imperfections joint using co-occurrence matrix

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The goal of this paper is to study the characteristics of the butt joint imperfections with different types of joint shapes (curve, straight and tooth saw work piece) according to their class categories (good welds, excess welds, insufficient welds and no welds). The work piece is placed in a center position on the workbench. The distance between camera and workpiece is set as 300 mm during welding imperfections process and the entire work piece image is taken from the same distance to maintain the accuracy. The input feature vector is determined by feature co-occurrence matrix consisting of energy, correlation, homogeneity and contrast both no scaled and scaled by 0.5. Results show that no welds class categories exhibit higher homogeneity compared to the other class categories. This is because the homogeneity value depends on bright and dark parts of a certain size and also include some changes from dark to bright. Meanwhile, insufficient welds class categories produced larger contrast value, but good weld class categories recorded higher contrast value.

[**Keywords:** Co-occurrence Matrix; Butt joint; Imperfections welding]

## Introduction

Previous work in the classification of weld defects noticed that this issue has been investigated widely in different ways. Many researchers have used radiographic image rather than CCD camera only as the input acquisition integrated with external light source or control the welding environment to reduce the noise. Most of the researchers used geometrical parameter in feature extraction which includes size, location, attribute, scale invariant[1,2] and shape of the weld defects. Other parameters can be applied to interpret the data, such as gray value and linguistic description. Linguistic description is done by human expert where it needs the experience and skill to observe the welds defect linguistic description. Perfect knowledge of the geometry of the weld defects is an important step which is essential to appreciate the quality of the weld.

The other aspect of interest here is how to categorize the weld defects. Many of the previous works discuss weld categories in terms of type of welds, defect shape, welds flaw and defect information such as width, location and position. There are several methods to inspect the weld defect, such as statistical tools[3], neural networks[4,5], fuzzy interferences system[6] fitted line profiles, and average gray level characteristic. Statistical approaches are usually implemented using classifiers, such as bayers[7,9], decision tree[8], support vector machine[10,14] and neuro-fuzzy classification (NEFCLASS)[7].

In this paper, we studied the characteristics of butt welding imperfections joint by using co-occurrence matrix. The study was based on work piece sample images taken from welding robot. The imperfection joint classes are divided into four class categories, namely, good welds, excess welds, insufficient welds and no welds. To extract the parameters from the work piece, we used co-occurrence matrix approach in scaled and no scaled images. The features parameters were then evaluated and compared with each imperfections class categories related to the co-occurrence matrix consisting of energy, correlation, homogeneity and contrast.

## Methodology

### Process overview

The characteristics of butt joint imperfections in this paper are determined by four steps as show in Fig. 1. The first step is image acquisition where the imperfections image is captured from a CCD camera at a top of workpiece. Next step is to calculate a co-occurrence matrix consisting of energy, correlation, homogeneity and contrast. This step is done without using filtering techniques and the region of interest

(ROI) is not required. Then the gray value features driven for both no scaled and scaled by 0.5 obtained from co-occurrence matrix. The final step is to group the value of characteristics into the imperfections categories, namely, good welds, excess welds, insufficient welds and no welds.

*Feature extraction*

Feature selection is the most critical step as the success of classifiers depends on the correct feature set[15,16]. The feature value is obtained from the object description in numerical form where there are many ways to select the features. The process to choose the desirable features from the initial set of the features list is called feature selection[17]. Thus, in this paper, features were selected by using co-occurrence matrix. Note that, this features value contains the gray level value either from its pixels or values from neighbors. Fig. 2 shows how to generate features by using co-occurrence matrix for both no scaled and scaled factor by 0.5. The additional features with images factor scaled by 0.5 is applied to determine the highest probability of the butt joint welding imperfection.

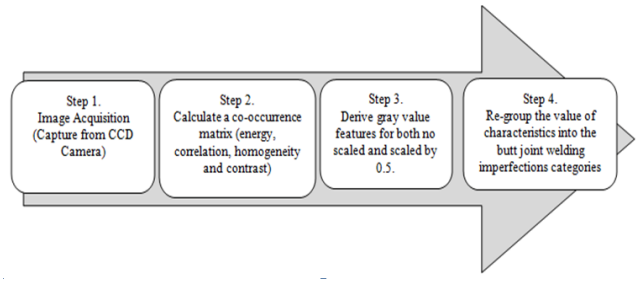



Fig. 1 — Methodology for overall process

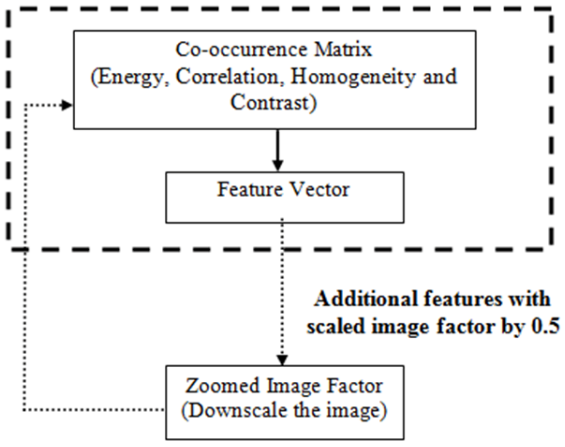



Fig. 2 — Block diagram for generate features

*Co-occurrence matrix*

To determine the co-occurrence matrix from butt welding imperfection joint images relationship between the gray value and its neighboring values need to be defined. The co-occurrence matrix contains two probability values that appear next to each other. The values depend on the direction $\theta$ is used and the distance $d$ at which the matrix is computed. The value of the butt welding imperfection joint image is originally referred to the grayscale value of the specified pixel.

Based on the co-occurrence matrix there are four features that can be derived from co-occurrence matrices. The features are: Energy (calculates the sum of the square elements in the coincidence matrix), correlation (measures the linear dependence of the gray levels on the neighboring pixels), homogeneity (measures the closeness of the distribution of elements in the co-occurrence matrix to its diagonal), and contrast (measures the intensity contrast between neighboring pixels). The formula for the features indicated by the direction (0, 45, 90, 135 degrees) and distance as shown in Equations 1 to 4 where width of co-occurrence matrix is given as width and entry of co-occurrence matrix as $c_{ij}$.

$$Energy = \sum_{i,j=0}^{width} c_{ij}^2 \quad \ldots(1)$$

$$Correlation = \frac{\sum_{i,j=0}^{width}\left(i - \sum_{i,j=0}^{width} i * c_{ij}\right)\left(j - \sum_{i,j=0}^{width} j * c_{ij}\right)c_{ij}}{\left(\sqrt{\sum_{i,j=0}^{width}\left(i - \sum_{i,j=0}^{width} i * c_{ij}\right)^2 * c_{ij}}\right)\left(\sqrt{\sum_{i,j=0}^{width}\left(i - \sum_{i,j=0}^{width} j * c_{ij}\right)^2 * c_{ij}}\right)} \quad \ldots(2)$$

$$Homogeneity = \sum_{i,j=0}^{width} \frac{1}{1+(i-j)^2} c_{ij} \quad \ldots(3)$$

$$Contrast = \sum_{i,j=0}^{width} (i-j)^2 c_{ij} \quad \ldots(4)$$

A calculation of the co-occurrence matrices was performed using 6 (neighboring pixel) distance and the directions $\theta$=0° and $\theta$=90° at which the matrix is computed. The co-occurrence matrices have been scaled to 8-bit (256 gray levels) with image size 533x400 pixel. The explanation of gray level co-occurrence matrix (GLCM) features characteristics is shown in Table 1.

**Results and Discussion**

The system consists of CCD camera, frame grabbers, monitor, computer, and light source. Butt welding imperfection joint images are captured by a

Table 1 — Gray level co-occurrence matrix (GLCM) features characteristics

| Co-occurrence matrix features | Description |
|---|---|
| Energy | Energy is actually the short form for uniformity of energy and indicates that all kinds of gray value combinations are present or if certain gray value combinations are dominant |
| Correlation | Correlation defines the measure of dependency between neighboring values. High correlation values imply a linear relationship between pixel pairs. |
| Homogeneity | Homogeneity is high if large areas in an image have the same gray values. It measures texture homogeneity and receives higher values for smaller differences in gray values of pixel pairs. |
| Contrast | The contrast represented the value between two pixels that is multiplied and squared. A low Contrast value is attributed to low contrast of image texture. |

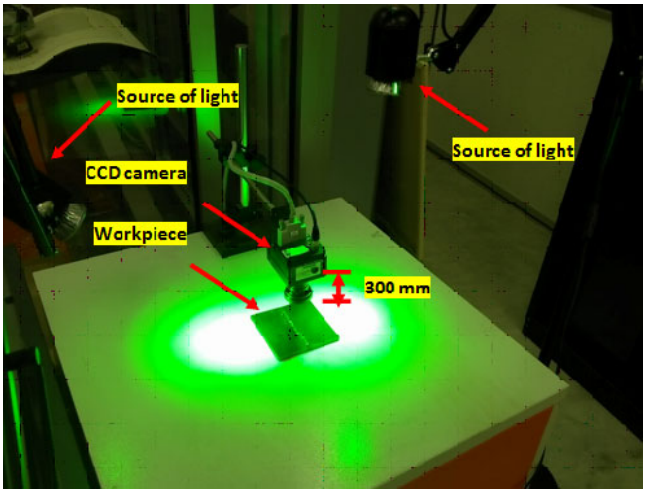



Fig. 3 — Butt welding imperfection joint system set-up

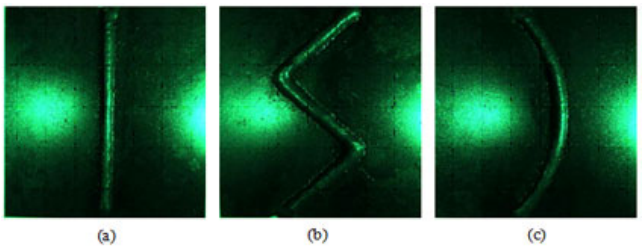



Fig. 4 — imperfections class categories: (a) straight, (b) tooth saw, and (c) curved

Basler camera with 67 frames per second 2 MP resolution. The workpiece are placed in a center position on the workbench. The distance between camera and workpiece is set as 300 mm during welding imperfections process and the entire workpiece image is taken from the same distance to maintain the accuracy by adjusted additional light source in control room environment. The system set-up is shown in Fig. 3.

The butt welding imperfections joint was verified by four imperfections class categories: Good welds, excess welds, insufficient welds and no welds as shown in Fig. 4. The output results were based on three imperfection images data in each class

Table 2 — Sample result of co-occurrence matrix features for straight welding joint shape

| Feature | Good Weld | | Excess Weld | |
|---|---|---|---|---|
| Direction | $\theta = 0$ | $\theta = 90$ | $\theta = 0$ | $\theta = 90$ |
| Energy | 0.0532903 | 0.0525691 | 0.0532903 | 0.0525691 |
| Correlation | 0.94991 | 0.946928 | 0.94991 | 0.946928 |
| Homogeneity | 0.673412 | 0.671247 | 0.673412 | 0.671247 |
| Contrast | 9.21824 | 9.84254 | 9.21824 | 9.84254 |
| | Insufficient Weld | | No Weld | |
| Direction | $\theta = 0$ | $\theta = 90$ | $\theta = 0$ | $\theta = 90$ |
| Energy | 0.05882 | 0.0576135 | 0.05882 | 0.0576135 |
| Correlation | 0.938968 | 0.938205 | 0.938968 | 0.938205 |
| Homogeneity | 0.670267 | 0.66622 | 0.670267 | 0.66622 |
| Contrast | 11.0421 | 11.2672 | 11.0421 | 11.2672 |

Table 3 — Sample result of co-occurrence matrix features for tooth saw welding joint shape

| Feature | Good Weld | | Excess Weld | |
|---|---|---|---|---|
| Direction | $\theta = 0$ | $\theta = 90$ | $\theta = 0$ | $\theta = 90$ |
| Energy | 0.0646059 | 0.0635119 | 0.0658506 | 0.0638784 |
| Correlation | 0.944401 | 0.944736 | 0.921889 | 0.92183 |
| Homogeneity | 0.676406 | 0.673715 | 0.650836 | 0.644023 |
| Contrast | 9.66717 | 9.69389 | 13.946 | 14.0735 |
| | Insufficient Weld | | No Weld | |
| Direction | $\theta = 0$ | $\theta = 90$ | $\theta = 0$ | $\theta = 90$ |
| Energy | 0.0780737 | 0.0759898 | 0.0478025 | 0.0456672 |
| Correlation | 0.928958 | 0.923911 | 0.950107 | 0.945327 |
| Homogeneity | 0.668728 | 0.664688 | 0.66429 | 0.656474 |
| Contrast | 12.2663 | 13.252 | 8.3102 | 9.16955 |

categories for butt joint type shapes. A results sample of a calculation of co-occurrence matrices for four common characteristics of each class categories of butt welding imperfections joint is shown in Table 2 to Table 4

The matrix occurence consists of gray value of corelation, homogeneity, contrast and energy for both no scaled and scaled by 0.5. Fig. 5 to Fig. 7 show

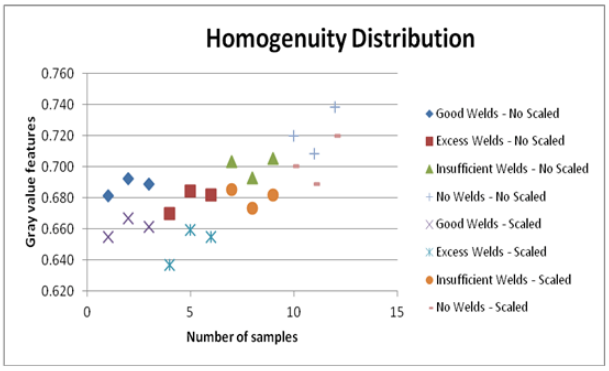
the matrix occurence data of the butt welding imperfections joint image. The data are taken from three sample images of each imperfections categories. Fig. 5(a), 6(a) and 7(a) show the homogeneity results of butt welding imperfections joint. Homogeneity is high if large areas in an image have the same gray values. It measures texture homogeneity and receives higher values for smaller differences in gray values of pixel pairs. No weld class categories exhibit higher homogeneity compared to the other class categories. This is because the homogeneity value depends on bright and dark parts of a certain size but also include some changes from dark to bright. However, a uncolored image has the highest homogeneity value.

Meanwhile, if the matrix shows a thin line from top left to right bottom, this means that the image is blurry which is why the values are so close together. The two correlation values of the same image are very different depending on the rotation of the image where $\theta$=0° causes a low correlation and $\theta$=90° has a high correlation. It is clearly show in Figures 5(b), 6(b) and 7(b).

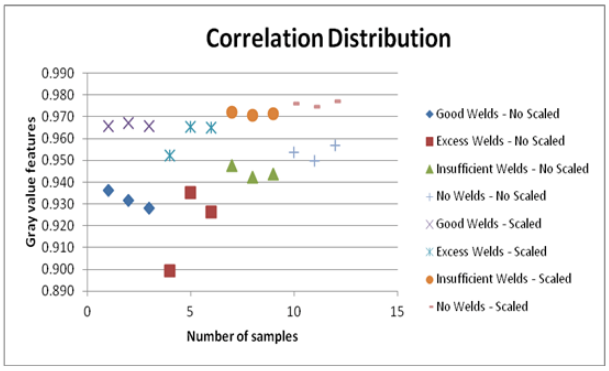
The co-ocurrence matrix energy results are shown in Figures 5(c), 6(c) and 7(c). From the figures, it is clear that the energy is actually the short form for uniformity of energy and indicates that all kinds of gray value combinations are present or if certain gray value combinations are dominant. An image with a constant gray value has the highest energy. It can have values between 0 and 1, with higher values

Table 4 — Sample result of co-occurrence matrix features for curve welding joint shape

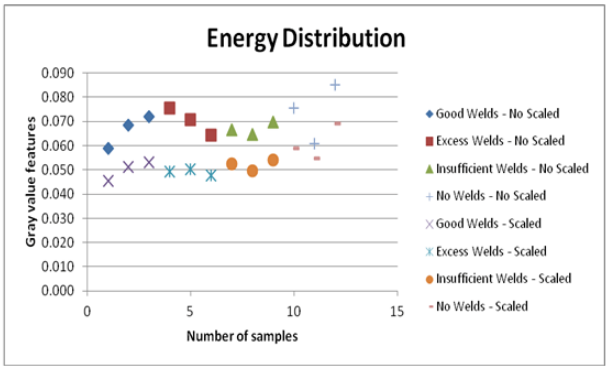
| Feature | Good Weld | | Excess Weld | |
|---|---|---|---|---|
| Direction | $\theta = 0$ | $\theta$ =90 | $\theta = 0$ | $\theta$ =90 |
| Energy | 0.0734787 | 0.0714337 | 0.0835966 | 0.0819113 |
| Correlation | 0.946625 | 0.944468 | 0.913001 | 0.91084 |
| Homogeneity | 0.680538 | 0.677662 | 0.675731 | 0.672015 |
| Contrast | 10.4674 | 10.9823 | 15.4024 | 15.9263 |
| | Insufficient Weld | | No Weld | |
| Direction | $\theta = 0$ | $\theta$ =90 | $\theta = 0$ | $\theta$ =90 |
| Energy | 0.0976121 | 0.0958199 | 0.0560018 | 0.0541501 |
| Correlation | 0.932256 | 0.931668 | 0.965653 | 0.961555 |
| Homogeneity | 0.700197 | 0.696605 | 0.703902 | 0.697859 |
| Contrast | 12.5807 | 12.7951 | 5.97442 | 6.73168 |



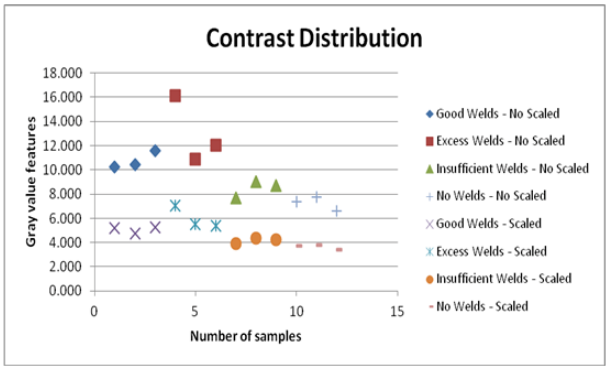

(a)




(b)




(c)




(d)

Fig. 5 — Co-occurence matrix data for butt joint imperfection welding in straight type

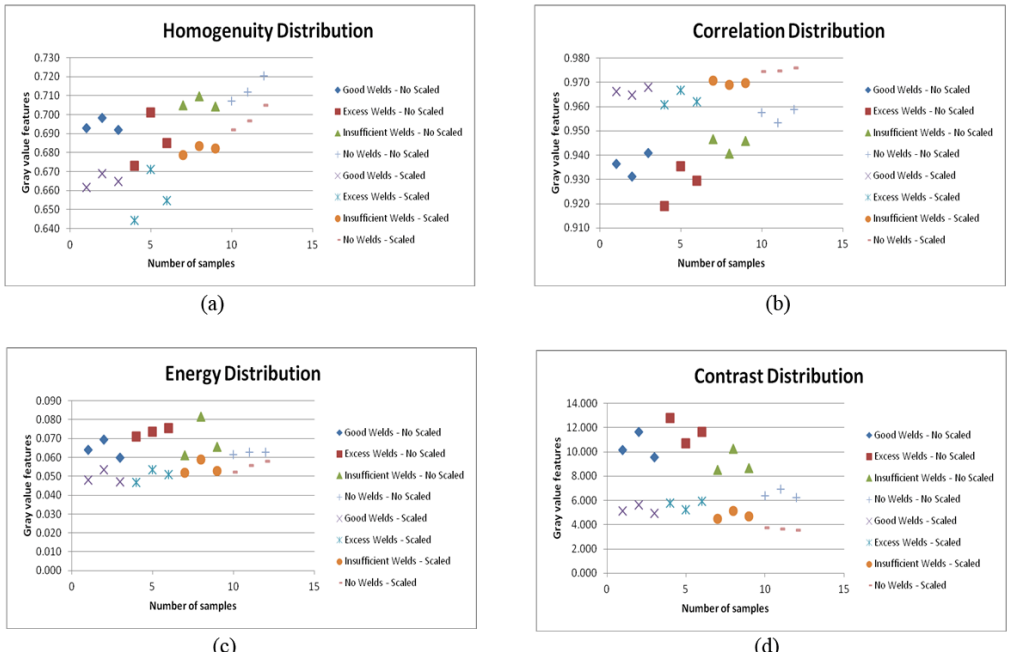



Fig. 6 — Co-occurence matrix data for butt joint imperfection welding in tooth saw type

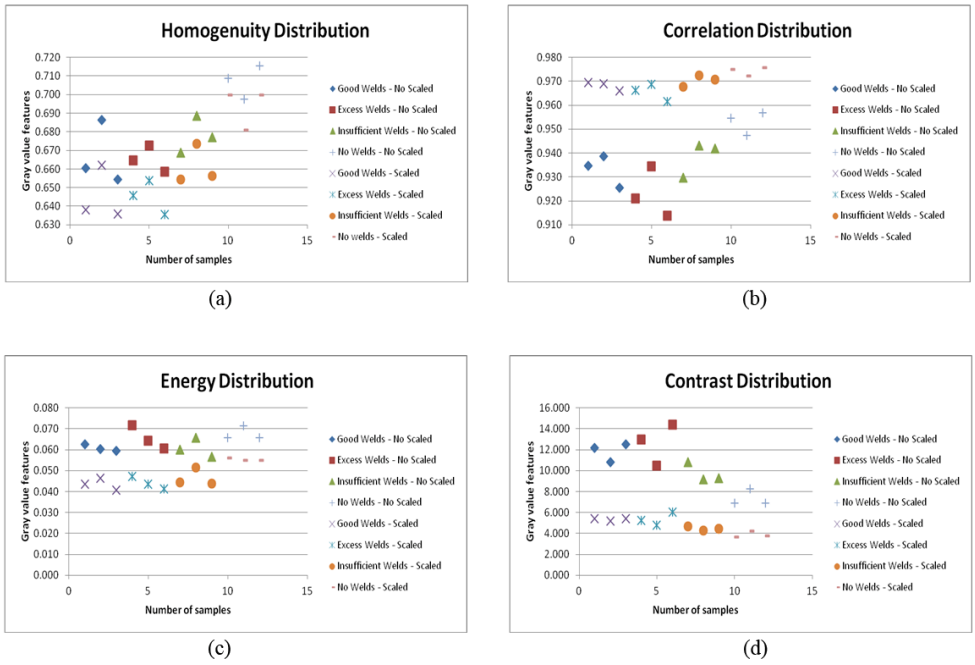



Fig. 7 — Co-occurence matrix data for butt joint imperfection welding in curve type

representing a more uniform texture, when the gray level distribution has either a constant or periodic form. A high energy emerges if there are only few gray value combinations, and the change is always according to the same scheme, while a little energy represent the changes between pixels where there is no uniformity.

The contrast represented the value between two pixels that is multiplied and squared. A low contrast value is attributed to low contrast of image texture. In butt welding imperfections joint, insufficient welds class produced larger contrast value but good weld class recorded higher contrast value. This shows that the contrast value includes the frequency as well as

the intensity. It is clearly shown in Fig. 5(d), 6(d) and 7(d).

## Conclusion

The characteristics of butt welding imperfections joint for straight, curve and tooth saw type of joint shapes were investigated according to the class categories, namely, good welds, excess welds, insufficient welds, and no welds. Input feature vector is determined by co-occurrence matrix consisting of energy, correlation, homogeneity and contrast with no scaled and scaled by 0.5. The results shows no weld class categories exhibit higher homogeneity compared to the other class categories. This is because the homogeneity value depends on bright and dark parts of a certain size and also include some changes from dark to bright. The insufficient welds class produced larger contrast value, but good weld class recorded higher contrast value. This shows that the contrast value includes the frequency as well as the intensity.

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