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Euclidean Distance Based Color Image Segmentation Algorithm for Dimensional Characterization of Lack of Penetration from Weld Thermographs for On-Line Weld Monitoring in GTAW

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Abstract

Conventional Non Destructive Testing (NDT) techniques for assessing the weld quality are applied after welding is completed. It results in wastage of time, material and manpower. These inherent limitations of the conventional welding processes can be overcome with an automated adaptive welding system to correct the deviation in the welding current and torch speed to provide defect free welds. This system requires an on-line weld-monitoring sensor, efficient image processing algorithm for defect identification and neurofuzzy control software for correlating the defect characteristics with deviations in physical parameters. Infrared Thermography is the best-suited sensor for on-line weld monitoring. It monitors the surface temperature distributions of the plates being welded and produces thermal maps called thermographs. The image processing algorithm for hot spot identification must be a generalized and standardized algorithm that works well for all different frames depicting different percentages of lack of penetration. Moreover time consumed by the algorithm must also be less to suit for on-line weld monitoring. This paper proposes an image processing algorithm that effectively identifies and quantifies the hotspot. The hot spot is then characterized using statistical moments, major axis length, minor axis length and area.

Key words: Lack of Penetration, thermographs, average, Euclidean distance and feature vectors

1. Introduction

Gas Tungsten Arc Welding (GTAW) commonly referred as Tungsten Inert Gas (TIG) welding is best suited for precision welding in atomic energy, aircraft, chemical and instrument industries. It is an arc welding process wherein coalescence is produced by heating the job with an electric arc struck between a Tungsten electrode and the job. A shielding gas is used to avoid atmospheric contamination of the molten weld pool. TIG welding is one of the widely used methods for joining metals. In spite of the numerous advances in the science and technology of welding, failures do occur and weld is still considered to be the weakest portion. This is because the formation of the weld is affected by a number of process parameters, which make it difficult to ensure the quality of the weld. Conventionally, the quality of the weld is ascertained only after the welding has been completed through the use of Non Destructive Testing (NDT) such as ultrasonic or radiography. Since each of these techniques is applied only after the welding is completed, a lot of time, material and manpower are wasted before one comes to know about the soundness of the weld.

Inherent Limitations in conventional welding processes can be overcome if the weld is continuously monitored in real time for the assessment of defects and their automatic elimination by on-line control of the welding parameters. Moreover, the defective weld can be repaired immediately without continuing the process further. This strategy to monitor, control and maintain quality of welds is commonly known as adaptive welding or intelligent welding. Intelligent welding, as the name implies, combines welding equipment with intelligent sensing and control, knowledge of human experts, and Artificial Intelligence (AI) to improve joining efficiency and reduce the weld inhomogenities and defects.

Sensors are the key to success of intelligent welding. Non-Destructive Testing (NDT) sensors, which have been considered, for on-line monitoring include optical, radiography and Infrared (IR). Infrared, has the advantage that it can reveal surface and near surface perturbations. After acquiring thermal images, features corresponding to weld defects are extracted. These feature vectors are related to the corresponding deviations in physical parameters responsible for the defect. With this mapping, the respective physical parameter is then controlled to produce defect free welds. This paper presents an algorithm for automatic identification and quantification of Lack of Penetration, a commonly occurring defect during TIG welding. Thermographs of three depths of penetration are considered.

The paper is organized as follows. Section 2 gives a brief review of Infrared Thermography in Non Destructive Testing. Section 3 provides experimental set up. Section 4 provides the feature extraction algorithm based on Euclidean Distance based Color Image Segmentation algorithm. Section 5 provides the Results and Discussion and Section 6 concludes the work.

2. Related Work

Infrared thermography is not a new technique for on-line weld monitoring. Numerous groups worldwide have used Infrared investigation techniques in the inspection of subsurface defects and features, thermo physical properties, coating thickness and hidden structures. Thermographs are used to the control of welding process problems, such as arc misalignments[1]. Infrared sensors are best suited for weld quality detection as the perturbations that arise due to variations in arc positioning, heat input and the presence of contaminants distinctly manifests itself as differences in the spatial and temporal surface temperature distributions. Hence image analysis techniques can be developed to quantify the changes in the temperature distribution there by enabling adaptive welding techniques for automated weld control[2]. Infrared thermography was used for on-line control of torch path in Robotic Gas Tungsten Arc Welding. These images were transmitted to a central computer where an image processing algorithm was developed to determine the torch from the joint and also transmitted the corrective action to control the torch path. However the developed method was suitable for only single V-groove configurations[3]. Infrared Sensing and Computer image processing techniques can be used as a feasible method to improve the welding process through dynamic control of joint penetration parameters. Welding parameters were varied to obtain different depths of penetration and the corresponding temperature distributions were noted. However relative temperature with respect to a specific chosen temperature was considered instead of the absolute temperature[4]. Infrared Sensing techniques were used to track curved contours of joints with a gap in fusion reactor welding. It was found that a gap in a weld joint produce a significant drop in the measured Infrared intensity or temperature and this temperature reduction can be used to determine the size and position of a joint gap[5]. Infrared thermography is highly suitable for sensing variations in bead width and depth of Penetration due to variations in plate thickness, shielding gas composition and minor element content in GTAW. Macroscopic temperature gradient determined from the peak temperature and the temperature at the solid-liquid metal surface was used to implement weld penetration control[6]. Different passive and active thermographic techniques are used for defect detection. Active techniques include Pulse thermography, Lockin thermography, Pulsed phase thermography and vibrothermography[7-9]. Infrared thermography was used to determine the transient thermal field that accompanies fusion welding procedure in order to study the out-of-plane distortion. Thermographs reveal significant features of the thermal conditions that cannot be modeled theoretically in a practical sense[10]. Lack of Penetration and Tungsten Inclusion are detected and quantified from thermographs. Quantification of thermographs is achieved by image processing algorithm through histogram equalization, image segmentation and morphological image processing. These features extracted from the algorithm are then used for on-line weld monitoring to produce defect free welds[11].

3. Experimental Setup

The experiments were conducted using Precision TIG 375, automatic TIG welding machine. All experiments were conducted using 3mm thick American Iron and Steel Institute (AISI) type 316 steel plates measuring 125 x 50 mm in size, 145 x 50 mm in size and 187 x 50 mm in size. The edges and the surfaces of the plates were prepared using standard preparation techniques to facilitate butt-welding. The Infrared camera mounted at an angle of 45 degrees to the weld plate captures the temperature distribution at the weld pool. The Infrared camera obtains thermal maps called thermographs from the distribution and a custom built interface transfers these images from the camera to the computer for further analysis. The camera detected the infrared radiation used to characterize the thermal distribution of the plates being welded. The infrared camera determines the temperature distribution by sampling a portion of the emitted energy within a wavelength band of 8 to 12 µm. Each scan of the camera was transferred as an image of size. The frame rate of the camera is 40 ms. Lack of Penetration occurs when penetration of the weld metal into the joint is insufficient compared to what is specified for the joint according to the welding symbol. It is caused by too low welding current or too high welding speed or incorrect joint geometry. It is a serious defect as it can contribute to failure as stress raisers and least resistant path.

Torch speed and the current are varied to introduce different types of Lack of Penetration. Four different experiments were conducted to derive the relationship between the Lack of Penetration and the hotspot in the thermographs. The acquired weld thermographs for different levels of Lack of penetration are Result260.avi, Result261.avi, Result262.avi and Result264.avi. Torch speed and current are 10 cm/min, 82 amps; 14 cm/min, 92 amps; 20 cm/min, 102 amps and 12 cm/min, 120 amps respectively. These values correspond to reasonable lack of Penetration, no lack of penetration, Reasonable and Heavy Lack of Penetration.

Thermographs for Result260.avi are acquired in 1.15 minutes. The number of frames is 1881. The frames 1, 2, 25 and 26 are as shown in Figure 1.

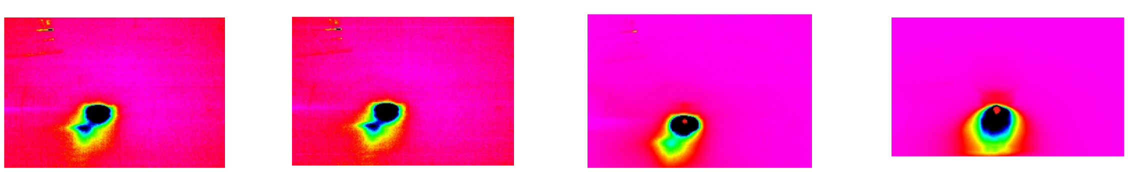

Figure 1a.Frame 1 Figure 1b.Frame 2 Figure 1c.Frame 25 Figure 1d. Frame 26

Thermographs for Result261.avi are acquired in 1.13 minutes. The number of frames is 1841. The frames 1, 2, 25 and 26 are as shown in Figure 2.

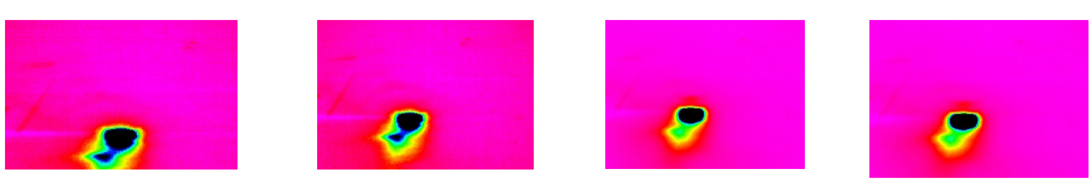

Figure 2a. Frame 1 Figure 2b.Frame 2 Figure 2c. Frame 25 Figure 2d. Frame 26

Thermographs for Result262.avi are acquired in 1.03 minutes. The number of frames is 1578. The frames 1, 2, 25 and 26 are as shown in Figure 3.

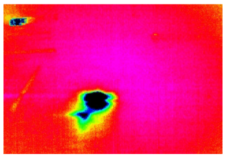

Figure 3a..Frame 1

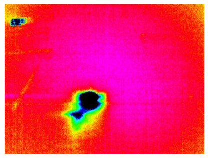

Figure 3b.Frame 2

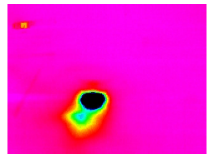

Figure3c. Frame 25

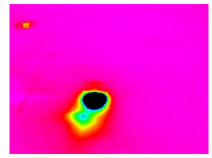

Figure3d. Frame 26

Thermographs for Result264.avi are acquired in 1.09 minutes. The number of frames is 1741. The frames 1, 2, 25, and 26 are as shown in Figure 4.

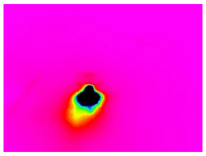

Figure 4a. Frame 1

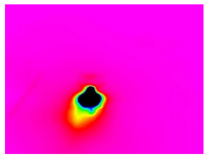

Figure 4b.Frame 2

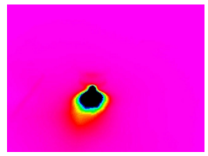

Figure 4c. Frame 25

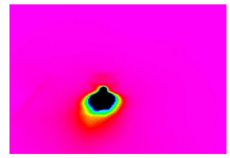

Figure 4d. Frame 26

In the above thermographs, violet color region of these thermographs depict the hot spots. The developed feature extraction algorithm must be capable of automatically identifying and quantifying the hotspot.

4. Euclidean Distance Based Color Image Segmentation Algorithm:

Conventional image processing algorithm involves image enhancement, image segmentation through edge detection and morphological image processing. This algorithm is parameter dependent i.e. performance is based on shape, size and threshold chosen for image enhancement and Image segmentation. Moreover the chosen threshold is also image specific, i.e. it is different for different images even of the same defect. The time taken for executing these programs is also more hence making them unsuitable for on-line weld monitoring.

In Euclidean distance based color image segmentation technique, the RGB color model is considered. Each RGB color pixel is a triplet of values namely Red, Green and Blue. Segmentation provides better results in RGB color model when compared to other color models. Segmentation in color domain is based on similarity detection rather than discontinuity based. Similarity based detection directly groups the similar pixels.

The algorithm involves the following steps. The captured thermographs are acquired as moving pictures. The first step involves converting movie file into frames. On each frame the following operations are performed. Select an estimate of the average color that is to be segmented. Euclidean distance is chosen as the measuring parameter. Let the average pixel chosen be represented as 'a'. The Euclidean distance between the image pixel 'z' and 'a' is

$$D(z,a)=[(z_R-a_R)^2+(z_G-a_G)^2+(z_B-a_B)^2]^{1/2} \qquad (1)$$

Any image pixel 'z' is said to be similar to 'a' if the Euclidean distance between them is less than a specified threshold D_0. Choosing D_0 is dependent on the defect that is to be classified[15]. For all the thermographs of same defect, the value of D_0 is same, hence making this algorithm image independent and parameter independent. Once the difference is less than the threshold value, pixels are considered as hot spot pixels and are retained. Remaining pixel intensity is made as zero i.e. the pixels are darkened. The obtained image thus contains only the hotspot. The hot spot is then quantified using major axis length, minor axis length, area, average and variance.

5. Results & Discussion

In original images the hotspots are coded with violet color which corresponds to an intensity of 0. To enhance the feature extraction process, the original images are complemented so that hotspots are represented with maximum intensity. The intensity of the average pixel is 1,1,1 in RGB domains. The threshold value is 0.07. The original, complemented image and the hotspot isolated image for Result260.avi for the frames 137 and 200 are as shown in Figure 5.

Figure 5: Original, Complemented and Output images of Result260.avi

The original, complemented image and the hotspot isolated image for Result261.avi for the frames 137 and 200 are as shown in Figure 6.

Figure 6: Original, Complemented and Output images of Result261.avi

The original, complemented image and the hotspot isolated image for Result262.avi for the frames 137 and 200 are as shown in Figure 7.

Figure 7: Original, Complemented and Output images of Result 262.avi

The original, complemented image and the hotspot isolated image for Result262.avi for the frames 120 and 150 are as shown in Figure 8.

Figure 8: Original, Complemented and Output images of Result264.avi

The quantitative characterization of the hotspot is as shown in Table 1.

Table 1: Quantitative Characterization of the hotspot

Filename	Frame number	Major axis length (pixels)	Minor Axis length (pixels)	Area (pixels)	Mean	Variance
Result260	137	33.2085	26.8934	600	0.0078	5.1469e-004
	200	34.5470	26.5714	615	0.0080	5.2577e-004
Result261	137	33.0491	27.2627	695	0.0090	6.4568e-004
	200	34.1935	30.7896	789	0.0103	7.7963e-004
Result262	137	32.3543	27.8348	702	0.0091	7.4207e-004
	200	38.7842	24.4038	725	0.0094	8.6117e-004
Result264	120	39.3848	34.0044	784	0.0102	7.9655e-004
	150	43.1988	31.1057	784	0.0102	8.4143e-004

6. Conclusion and Future Work

The developed algorithm works effectively in isolating and quantifying the hotspot in thermographs. This algorithm does not involve edge detection or morphological image processing thereby is parameter independent. Time taken by the algorithm is also less when compared to the conventional algorithm as this algorithm does not involve convolution of edge detection masks over the entire image. Hence this algorithm is the best suited feature extraction algorithm for on-line weld monitoring. Moreover this algorithm is standardized for the defect i.e. the same algorithm works for all the thermographs of different levels of Lack of Penetration. The feature vectors namely major axis length, minor axis length, Area, Mean and variance are to be used as inputs for training the neural networks to determine the deviation in the physical parameter responsible for the defect. These deviations can then be corrected on-line during welding for producing defect free welds.

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