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Survey on Non-Destructive Evaluation of Weld Quality Inspection Using Digital Image Processing Techniques

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ABSTRACT

Automated inspection of weld quality is essential in any manufacturing industry. Application of digital image processing algorithms for weld quality inspection reduces production time, cost as well as inspection time. Computer aided inspection of weld quality is a non-destructive evaluation (NDE) method which ensures safe and efficient operation of equipment thereby assuring compliance with industry standards and contributing for sustainability. In this paper, a survey on various image processing techniques applied for automated weld quality inspection is performed.

Introduction

Welding plays a vital role in any manufacturing industry including nuclear reactors, petrochemical industries, power generation stations etc,. It is essential to monitor the welding process, detect defects and irregularities before any occurrence of severe damages or non-compliance with industry standards. Manual inspection of weld quality is always subjective in detecting as well as classifying the weld defects in either intermediate/final products, which decreases the reliability of weld quality inspection. Computer aided inspection of weld quality is a non-intrusive, non-destructive evaluation technique which not only saves time but also reduces the production cost in such industries. This ensures safe and reliable operation of equipment throughout their lifespan thereby contributing to the overall development and integrity of the manufacturing industry and hence that of any nation.

The process of detecting weld defects by employing digital image processing techniques, play a vital role in non-destructive testing (NDT). Non-destructive evaluation techniques can be broadly classified into three main categories namely, Ultrasonic testing (UT), Eddy current testing (EC) and X-ray Fluorescence (XRF). In such techniques, deploying machine vision / digital image processing techniques for detecting defects and irregularities makes the quality inspection process to be safe and reliable.

This paper presents an overview of a computer vision system dedicated for non-destructive evaluation, the functionalities of different stages in such a system and also explains various techniques behind weld defects detection and classification. This paper also deliberates some recent advancements in automated weld quality inspection using digital image processing techniques.

The rest of the paper is organized as follows. Section II summarizes some important non-destructive evaluation techniques.

Section III presents a survey on research focused on automated weld quality inspection. Section IV deliberates the functionalities of various stages in a machine vision system for weld quality inspection. Section V illustrates the general methodology adopted for weld defects detection and classification.

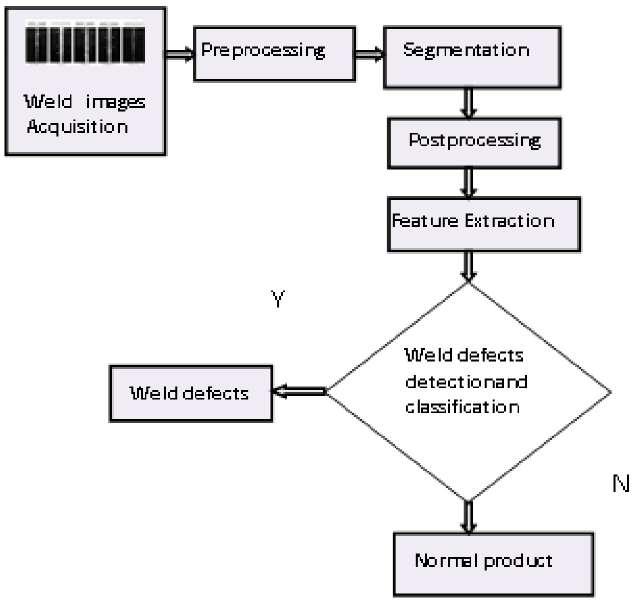

Figure 1. Block diagram of a machine vision based weld quality inspection system.

The above block diagram shows a general machine vision system for detecting weld defects and classifying these defects. The purpose of digital image processing technique is not only to detect and classify the weld defects automatically but also to present a better visualization of information from weld images and to formalize the methods of radiographic expertise for making the inspection process robust and reliable [1].

The possible welding defects such as incomplete fusion or lack of fusion, lack of penetration, porosity are shown in Fig.2.

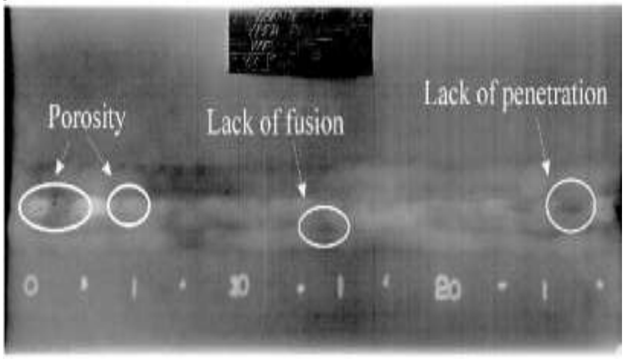

Figure 2. Types of weld defects

Prominent non-destructive evaluation (NDE) techniques

Some prominent non-destructive techniques are Ultrasonic testing (UT), Eddy current (EC) testing and X-ray Fluorescence (XFR). Ultrasonic testing is the oldest non-destructive technique, being practiced over several decades. It utilizes high frequency ultrasound waves which when passed through materials with defects, cracks etc,.get reflected off from those deformations. By capturing and monitoring the reflected (echoed) ultrasound waves, the internal condition of such deformations can be analyzed by a well-trained human operator in a non-intrusive manner without affecting the environment leading to sustainability.

Eddy current testing technique is based on the principle of electromagnetic induction. It is widely used in aerospace industries wherein inspection of thin metals for corrosion, defects, cracks etc,. is done non-intrusively. Eddy current is established when a current carrying probe and its magnetic field are kept in contact with a defective conducting material. The flowing eddy current generates its own magnetic field, which interacts with the eddy current probe coil and its field. Due to this phenomenon of electromagnetic induction, the previously established eddy current gets altered. This in turn changes the amplitude and phase angle of probe impedance. The resulting changes in probe impedance can be analyzed by a trained operator for detecting defects, cracks in welds.

X-ray Fluorescence (XFR) technique is based on the atomic level interaction of matter with short-wavelength, high energy electromagnetic radiations called X-rays. These X-rays penetrate through weld surfaces resulting in secondary emissions of X-rays. By studying these secondary X-rays, both qualitative and quantitative characterization of weld materials can be performed in a non-intrusive fashion. In all these non-destructive evaluation techniques, human operator can be replaced by an automated system deploying machine vision algorithms for weld quality destruction without any hazards to surroundings thereby ensuring environmental sustainability.

Survey on automated weld quality inspection

This section highlights certain recent research advancements undergone in automated weld quality inspection deploying digital image processing techniques.

Chu, H. and Wang, Z. [2] present a novel image processing method that can automatically extract the weld joint profile and feature points, measure the weld bead size, and detect defects.

Three-dimensional (3D) profile of the weld surface can be reconstructed with the aim of monitoring the weld quality online.

Otto Haffner etal [3], discusses the possibility of implementing algorithms of recognition and evaluation of welds using visual system in single-board computers. Result of this paper is computing time comparison of chosen embedded single-board computers and weld segmentation results based on entropy.

H.D.Chen etal [4], explains various artificial intelligence techniques employed for machine vision based automated weld quality inspection. Wavelet based denoising is performed on Ultarsonic testing weld images and thresholding based segmentation is done to segment out the desired portion from UT weld images. After extracting suitable features, support vector machines (SVM) are employed to classify various weld defects.

Components of automated weld quality inspection system

An automated weld quality inspection system deploys digital image processing techniques for detecting as well as classifying the weld defects. If the weld images are not acquired in digital format, they have to be converted from analog format into digital format.

I. Weld images acquistion sub-system

The weld images can be acquired by means of irradiating the product using a normal or an infra-red camera. Thus the weld image acquisition sub-system plays an important role in automating the process of weld quality inspection. The weld quality inspection can be performed by various non-destructive methods including Ultrasonic Time of Flight Diffraction (TOFD), X Ray (RT) techniques etc,. These techniques incorporate processing of digitized weld images, segmenting, feature extraction and finally weld defects detection & classification. The TOFD based weld quality inspection uses an experiment model Microplux of M9S AEA technology, U.K. with manual scanner. The capture of B scans was done using a manual weld scanner [2]. The X Ray based inspection employs a scanner AGFA Arcus II (800 dpi, 256 gray levels) [3].

II. Preprocessing

Visual quality of the acquired digitized weld images acquired by the corresponding scanners is improved by several pre-processing methods.

For TOFD based inspection, pre-processing is done by Contrast-Limited Adaptive Histogram Equalization (CLAHE) [2]. This enhances the contrast of the entire image by processing individual, small portions of the image called ‘tiles’. These artificially introduced boundaries are then removed using bilinear interpolation technique. The advantage of CLAHE is that the over-amplification of noise signal is not performed.

For X Ray (RT) based inspection, the initial pre-processing is done by using a 3 x 3 median low pass filter. This accounts for noise removal with a minimum amount of blurring [5]. The improved by two techniques namely global and local contrast enhancement. The global contrast enhancement is done by dynamic stretching (Look Up Table - LUT) and the local enhancement is based on the statistical properties of pixels on a neighborhood around each pixel in the image.

I. Segmentation

The defects such as cracks, porosities, gas inclusions are to be separated from the background of pre-processed weld images called segmentation.

For TOFD based inspection, the defect region was manually identified and selected as Region-of-Interest (ROI) [2]. In X Ray based inspection, this is done by a suitable segmentation technique such as Otsu's multi-level thresholding [6] [7] [8] or Niblack - Sauvola thresholding [9]. Karthikeyan etal discusses various segmentation techniques applied for radiographic X Ray weld images [10].

II. Postprocessing

The segmented weld image needs to be post processed in TOFD based weld quality inspection. The segmented image is processed with dilated gradient mask for reducing the false boundaries formed during pre-processing.

III. Feature Extraction

Feature extraction plays a very important role in any machine vision based recognition and classification systems. For detecting and classifying welding defects, essential features are extracted from the processed digital weld images. Geometrical features such as area, perimeter, brightness, difference can be extracted from these images [6]. The sizes of defects are calculated as maximum length oriented in the direction of weld seam (X) and maximum length in the vertical direction of weld seam (Y) as shown in Fig.3. Shapes of defects are obtained as the ratio of maximum length oriented in the direction of weld seam by maximum length in the vertical direction of the weld seam i.e X/Y [11].

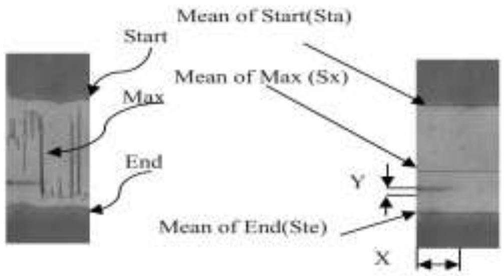

Figure 3. Feature extraction from weld defects.

IV. Detection and classification of weld defects

After extracting geometric or other features by suitable feature extraction techniques, various possible welding defects have to be identified. The most common welding defects are lack of penetration (LOP), incomplete fusion (IF), porosity, external undercut (EUC) [11]. Lack of penetration (LOP) takes place when the metal fails to penetrate the weld joint (Fig.4).

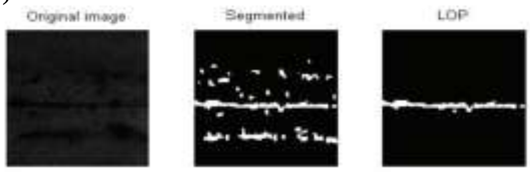

Figure 4. Sample image of Lack pf penetration (LOP).

EUC is the erosion of the base metal next to the crown of the weld. This appears as a dark irregular line along the outer edge of the weld area and is shown is Fig.5.

Figure 5. Sample image of External undercut (EUC).

Incomplete fusion (IF) is a phenomenon in which the filler metal does not fuse properly with the base metal. Such a condition appears as a dark lines oriented in the direction of the weld seam along the weld joining area. This is illustrated in Fig.6.

Figure 6. Sample image of incomplete fusion (IF).

After detecting weld defects, they can be classified into above categories by deploying classifiers such as KNN, Support Vector Machine (SVM) etc,.

Conclusion

Thus, this paper has dealt with non-destructive evaluation of weld quality using various digital image processing techniques. Such automated techniques not only aid in reducing production time, inspection time and production cost but also lead to environmental sustainability. Moreover, these machine vision techniques are safe and more reliable than experienced radiographers where in latter case the inspection is subjective to physical stimuli, physical and mental states of the operator, and environmental conditions during inspection. Further, such a weld quality control can also be performed based on 3D measurements of weld indentation using modern machine vision techniques and soft computing approaches.

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