Ultrasonics 73 (2017) 1–8

Contents lists available at ScienceDirect

Ultrasonics

journal homepage: www.elsevier.com/locate/ultras

Efficient feature selection for neural network based detection of flaws in steel welded joints using ultrasound testing

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ARTICLE INFO

Article history:
Received 20 January 2016
Received in revised form 7 August 2016
Accepted 23 August 2016
Available online 24 August 2016

Keywords:
Ultrasonic evaluation
Welded joints
Feature extraction
Neural networks
PCA

ABSTRACT

This work studies methods for efficient extraction and selection of features in the context of a decision support system based on neural networks. The data comes from ultrasonic testing of steel welded joints, in which are found three types of flaws. The discrete Fourier, wavelet and cosine transforms are applied for feature extraction. Statistical techniques such as principal component analysis and the Wilcoxon-Mann-Whitney test are used for optimal feature selection. Two different artificial neural network architectures are used for automatic classification. Through the proposed approach, it is achieved a high discrimination efficiency by using only 20 features to feed the classifier, instead of the original 2500 A-scan sample points.

1. Introduction

Welding may be defined as a process of joining of materials (usually metals or thermoplastics) by bringing their surfaces close enough together for atomic bonding to occur [1]. In modern industries such as aerospace, oil and gas, manufacturing and construction, welding processes are critically important. Non-destructive evaluation (NDE) techniques have been applied to verify the integrity of welded components. Among them there are ultrasound testing, X-ray imaging, and also some optical, electrical and magnetic measurements [2]. The ultrasound testing is widely used for weld evaluation as it combines high-efficiency with simple and safe execution procedure.

The accuracy of an ultrasound testing procedure usually relies on the operator experience. In this context, digital signal processing techniques (such as signal transformations [3] and neural networks [4]) have been proposed for ultrasound testing problems in order to provide decision support information. For example, both Fisher linear discriminant and three-layered neural network are applied in [5] for the detection of welding defects in steel plates. The input parameters for the neural network based classifier are pre-selected from the Fisher linear discriminant analysis. The combination of wavelet decomposition and an artificial neural network classifier is used in [6] for the detection of flaws in thin welded steel plates. Different defects such as porosity, tungsten inclusion and lack of fusion are considered and high classification efficiency (approximately 94%) is achieved. Other applications of neural networks for automatic ultrasound evaluation of welded joints can be found in [7,8]. Ultrasonic guided waves are used in [9] for the detection of small notch cuts in ASTM-A53-F steel pipes. Wavelet, Hilbert and Fourier transforms are applied for feature extraction and an artificial neural network is used for automatic classification.

Classifiers based on artificial neural networks have been also widely applied for different purposes such as condition assessment of electrical equipment [10], on-line event selection in particle detectors [11], command of a wheelchair using a brain-computer interface [12], detection of oil spill in the sea using synthetic aperture radar information [13] and decision support for bio-medical diagnostics [14].

An important aspect to be considered in automatic classification systems is the proper choice of the input features set [4,15]. Statistical signal processing techniques are usually employed for this purpose [16], as the presence of non-relevant or redundant information may contribute to decrease the classification efficiency. The neural network based classifiers usually benefit from compact and relevant set of input features.

This paper proposes the application of an artificial neural network based classifier [4] for decision support in ultrasound testing of steel welded joints. Three welding defects are considered: lack

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http://dx.doi.org/10.1016/j.ultras.2016.08.017
0041-624X/

of fusion, porosity and slag inclusion. One of the main contributions of this work is the use of different signal processing techniques such as Fourier, wavelet and cosine transforms to extract discriminant information from the A-scan (time-domain) signals. The discrimination efficiency obtained by feeding the classifier from these features is compared. Another important contribution is the application of statistical feature selection methods, such as principal component analysis [17] and significance tests [15], to select a compact set of relevant and discriminating features. Additionally, two different classifier architectures are proposed for the flaw detection problem.

This work is organized as follows: the used experimental setup is presented in Section 2; the proposed signal processing chain is defined in Section 3; the experimental results are described in Section 4; and finally, the conclusions are presented in Section 5.

2. Problem definition

The test piece used in this work is a carbon steel 1020 plate ($400\ \text{mm} \times 310\ \text{mm} \times 19\ \text{mm}$) welded through both tungsten inert gas (TIG) and shielded metal arc welding (SMAW) processes. Welding defects (lack of penetration, porosity and slag inclusion) were generated during the manufacturing process and their precise locations were confirmed through X-ray testing. The classification problem consists thus on assigning, for each signal, one of the four classes of interest: normal condition (ND - no defect), lack of penetration (LP), slag inclusion (SI) and porosity (PO). Although the used test piece did not present cracks, which are serious welding defects, the considered flaws may generate a crack when the weld is tensioned. Moreover, weld cracks are efficiently detected using different NDE methods (i.e. magnetic-particle or liquid penetrant, in the case of superficial cracks, and ultrasound or X-ray, for internal cracks), and the proposed system can also be easily adjusted to allow crack identification.

In this work, an experimental setup composed of Krautkramer USM-25 ultrasonic signal generator and 5 MHz transducers is used for signal acquisition (see Fig. 1). For system design, approximately 100 A-scan signals (pulse-echo configuration) for each class of interest were recorded. For this, the transducers were placed at several positions along two lines parallel to the weld bead (the adopted perpendicular distances from the weld bead center line were 43.3 mm and 37.5 mm).

The analog to digital conversion is performed using an oscilloscope with maximum sampling rate of 500 MHz and 8 bits for data quantization. The digital signal processing routines are executed in a personal computer, which is connected to the oscilloscope through an USB interface. The signal generator provided the triggering information for the oscilloscope in order to initialize the data acquisition. For each acquired signal 2048 time-samples are generated.

3. Proposed method

The digital signal processing chain proposed in this work comprises three steps (see Fig. 2). Initially, feature extraction is performed over the measured signals. In the following, the most relevant features are selected as inputs to the classifier system, which is the third processing step. The proposed signal processing chain is described in the following sub-sections.

3.1. Feature extraction

In this work, feature extraction is performed using different algorithms such as the discrete Fourier transform (DFT), the discrete cosine transform (DCT) and the discrete wavelet transform (DWT), which are described briefly in this section.

The DFT is a traditional method to obtain the frequency-domain information of a given discrete-time signal. It is widely applied for feature extraction in ultrasound testing problems (see for example [18,19]). The DFT for a finite-length discrete-time signal $x[n]$ can be obtained from Eq. (1) [3]:

$$X\left(e^{\frac{j2\pi k}{N}}\right) = \sum_{n=0}^{N-1} x[n] e^{\frac{-j2\pi kn}{N}}, \quad 0 \leqslant k \leqslant N-1. \tag{1}$$

The DCT is a linear transformation that expresses a finite-length discrete-time sequence $x[n]$ as a linear combination of cosine functions. It is widely applied in image processing for information compaction (see for example [20,21]), as it concentrates the signal energy into a small number of coefficients. The DCT can be defined as in Eq. (2) [3]:

$$C(k) = \alpha(k) \sum_{n=0}^{N-1} x[n] \cos\left[\frac{\pi(n+0.5)k}{N}\right], \quad 0 \leqslant k \leqslant N-1, \tag{2}$$

where $\begin{cases} \alpha(k) = \sqrt{1/N}, & k = 0; \\ \alpha(k) = \sqrt{2/N}, & 1 \leqslant k \leqslant N-1. \end{cases}$

Different from the two previous transformations, the wavelet analysis makes use of finite-length functions $\psi(t)$ (called

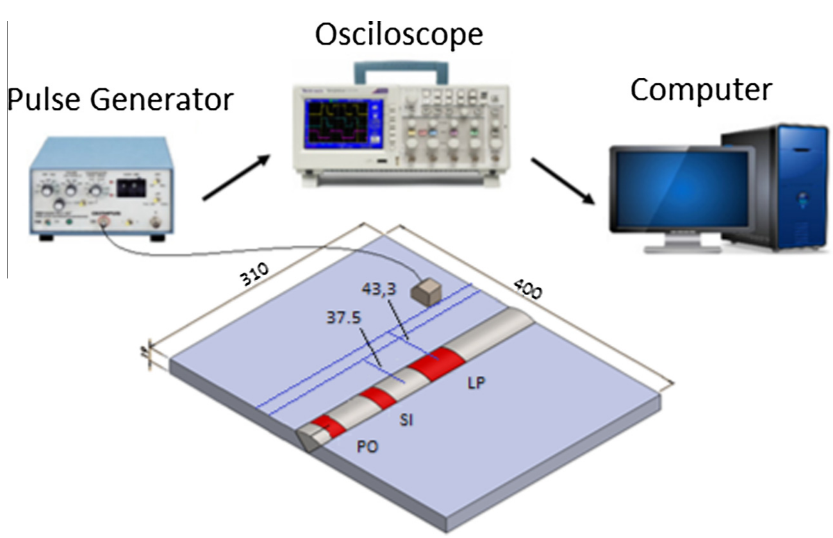

Fig. 1. Diagram of the used experimental setup, the defects locations are indicated in the test-piece.