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Ultrasonic Signal Analysis with DSP for the Pattern Recognition of Welding Flaws

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ABSTRACT

The researches classifying the artificial flaws in welding parts are performed using the pattern recognition technology. For this purpose the signal pattern recognition package including user defined function is developed and the total procedure is made up the digital signal processing, feature extraction, feature selection, classifier design. Specially it is composed with and discussed using the ststistical classifier such as the linear discriminant function classifier, the empirical Bayesian classfier.

Key Words : Pattern recognition, digital signal processing, feature extraction, feature selection, bayesian classifier, planar and volumetric flaws, artificial flaws

1. Introduction

For the manufacturing of precision apparatus, hidden flaws needs to be detected especially in welds. Ultrasonics means that can be used to detect these flaws.[1] The reflection of Ultrasonic wave from part surface and defects is used to measure parts thickness and flaw. In a conventional pulse-echo method, high voltage pulse cause crystal transducer to vibration, thereby, it can generate ultrasonic pulses. All kinds of engineering materials and structures have flaws, some of which can cause the mortal failures.[8]

Modern times, advanced performance engineering application, the structural integrity are quite often evaluated using fracture mechanics. This evaluation requires information on the flaw geometry (location, type, shape, size and orientation).[1]

The ultrasonic nondestructive evaluation(NDE) method is one of the widely used techniques that can provide information on the flaw geometry. The flaw characterization in the ultrasonic NDE Generally involves three steps; flaw detection (identification of flaw signal in ultrasonic response signal)[7], flaw classification (determination of the flaw type) and flaw sizing (prediction of the flaw shape, orientation and size parameters). In conventional ultrasonic NDE, this flaw characterization is usually done by human operator based on his / her own experiences. So the result is highly operator dependent and offer do not work well in practices for the reliable flaw characterization.[15]

In this paper, presented to detect and quantify the weld defects of Arc welded point is part of development effort to establish an integrated ultrasonic evaluation system. The overall research effort aims to automation the NDE process predict mechanical and structural shape using NDE techniques. The ultrasonic NDE techniques used herein is based on signal processing waveform obtained from pulse-echo scans.

2. Ultrasonic signal processing and pattern recognition

2.1. Pattern recognition

In this section, a course of feature recognition which gain flaw echo from ultrasonic flaw detector, A/D converting and digital signal processing, thus make data type for feature recognition. We can gain some of the feature variable using the digital signal processing, and these mean flaw shape, orientation and size parameter.

In this process, for the purpose of handling each feature variable in same division, we should find between each collection of feature value was classified using decision function, this process is design a classifier. Fig. 1 shows implementation of pattern recognition system.

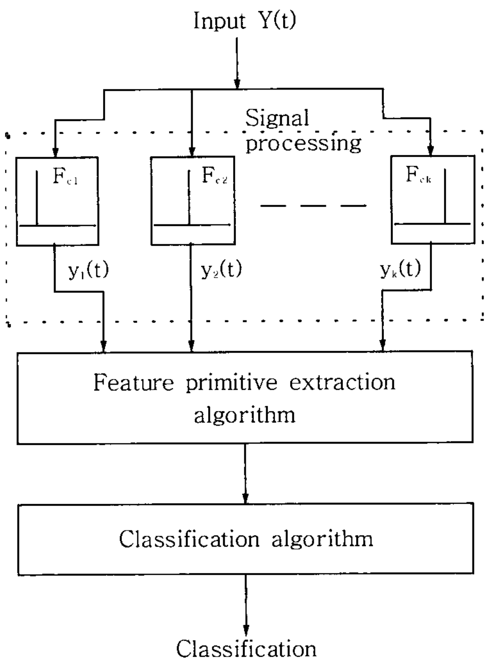
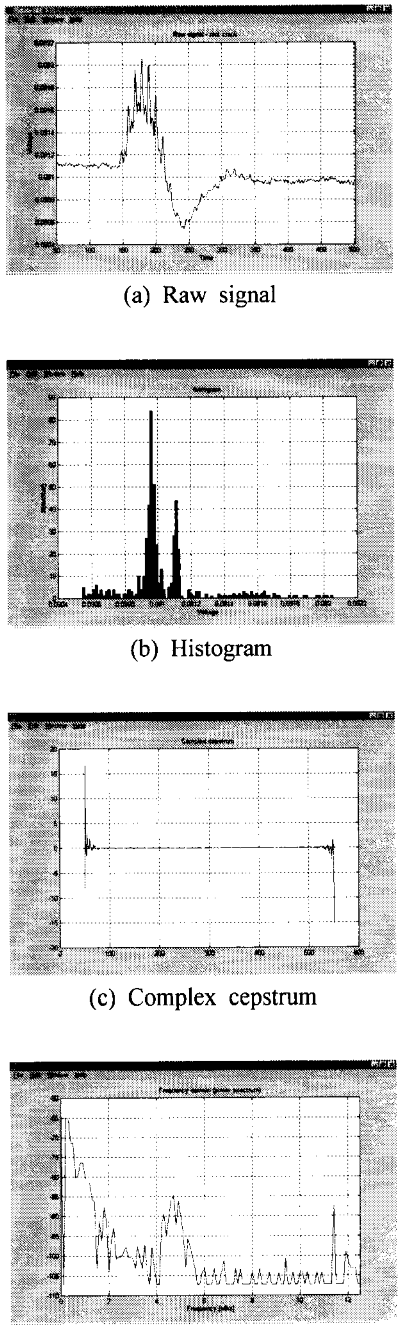


Fig. 1 Implementation of pattern recognition system

Fig. 2 shows the result of signal processing for transformations into not only the extraction from detective wave forms but also the extraction from noise sounds and each variables, which is usually gained or found in the welding detectives by gate.

2.2. Ultrasonic signal processing

Using DSP (Digital Signal Processing), we can handle ultrasonic signal, and extract feature variable for signal in time domain, signal in frequency domain auto-correlation function, probability density etc.



(a) Raw signal

(b) Histogram

(c) Complex cepstrum

(d) Power spectrum

Fig. 2 Signal processing for feature variable

3. Selection of feature variable

In this section, the Euclidean distance measurement is used for ultrasonic flaw signal classification. The classifier measures the distance extracted parameters and their values determined from a group of training signal. For determine classification rate and rank value of feature variable, the principle of class-mean-catter was adoped.

We can represent the distance of each class as :

$$D_{Inter} = \frac{1}{N1\ N2} \sum_{i=1}^{N1} \sum_{j=0}^{N2} D^2(x_k^i,\ x_k^j) \quad (1)$$

and we can represent the distance of n sample (an inner class) as :

$$D_{Intra} = \frac{1}{N} \sum_{k=1}^{N} [\frac{1}{(N-1)^2} \sum_{j=1}^{N} \sum_{i=1}^{N} D^2(x_k^i,\ x_k^j)] \quad (2)$$

Then we can represent rank value and classification rate as :

$$R_C = \frac{D_{Inter} - D_{Intra}}{D_{Inter}} \quad (3)$$

$$V_R = \frac{D_{Intra}}{D_{Inter}} \quad (4)$$

3.1. Minimum-Distance-to-Class-Means classifier

Suppose there are m pattern sample y in decision class $D_i R^n$. Define $\overline{y_i}$ as the sample average of the class D_i sample vectors :

$$\overline{y_i} = \frac{1}{m} \sum_{k=1}^{m} y_k \quad (5)$$

The minimum-distance-to-class-means decision rule assigns any input vector D_i with mean vector y_i closet to x.

Hear we use Euclidean or l^2 distance :

$$\begin{aligned} d(x, \overline{y_i}) &= l^2(x, \overline{y_i}) \\ &= (x - \overline{y_i})(x - \overline{y_i})^T \quad (6) \\ &= xx^T - 2x\ \overline{y_i}^T + \overline{y_i}\ \overline{y_i}^T \end{aligned}$$

The simplest of the discriminant function is $g_i(x) = l^2(x, \overline{y_i})$. Since xx^T dose not depend on the decision-class index i, the discriminant function becomes :

$$\begin{aligned} g_i(x) &= \frac{1}{2}[xx^T - d(x, \overline{y_i})] \\ &= x\overline{y_i}^T - \frac{1}{2}\overline{y_i}\ \overline{y_i}^T \quad (7) \\ &= xw_i^T + w_{i0} \end{aligned}$$

for $w_i = \overline{y_i}$ and $w_{i0} = -\frac{1}{2}\overline{y_i}\ \overline{y_i}^T$, the resulting decision surface define hydroplanes that perpendicuarly direct the n-dimensional lines that connect the class means.

4. Design of the classifier

Suppose we know only the prior probabilities $p(D_1)$ and $p(D_2)$ for two class problem. then it seems reasonable to assign an unknown input vector x to the class with the larger probability of having generated x. So the decision rule becomes $x \in D_1$ if $p(D_1) > p(D_2)$. We know conditional density function $p(x \mid D_1)$ and $p(x \mid D_2)$ as well as the priori probabilities $p(D_1)$ and $p(D_2)$. Then we can calculate the converse or posterior probabilities using Bayes theorem.

$$\begin{aligned} p(D_i \mid x) &= \frac{p(x \mid D_i)(D_i)}{p(x)} \\ &= \frac{p(x \mid D_i)p(D_i)}{\sum_{j=1}^{2} p(x \mid D_j)p(D_j)} \quad (8) \end{aligned}$$

Define the error probability as

$$p(error \mid x) = \begin{bmatrix} p(x \mid D_1), & \text{if } x \in D_2 \\ p(x \mid D_2), & \text{if } x \in D_1 \end{bmatrix} \quad (9)$$

Define the average error probability p_e as

$$p_e = \int_{R^n} p(error \mid x)p(x)dx \quad (10)$$

Define the Bayes decision rule for minimizing the average error probability as

$$\begin{aligned} x \in D_1 \quad & \text{if} \quad p(D_1 \mid x) > p(D_2 \mid x) \\ x \in D_2 \quad & \text{if} \quad p(D_1 \mid x) < p(D_2 \mid x) \end{aligned} \quad (11)$$

Where $p(D_1 \mid x)$ and $p(D_2 \mid x)$ denote the posterior probabilities. In general we cannot directly calculate the probability distribution from measurement. So the decision rule reduces to the form.

$$x \in D_1 \text{ if } p(x \mid D_1)p(D_1) > p(x \mid D_2)p(D_2)$$
$$x \in D_2 \text{ if } p(x \mid D_1)p(D_1) < p(x \mid D_2)p(D_2) \quad (12)$$

In multi-class case.

$$x \in D_i \text{ if } p(x \mid D_i)p(D_i) > p(x \mid D_j)p(D_j) \quad (13)$$

For all $j \neq i$.

Then we can represent the discriminant function as :

$$g_i(x) = p(x \mid D_i)\, p(D_i) \quad (14)$$

Consider to the problem of finding the decision boundary of the Bayes minimum error classfier for ultrasonic flaw signal data.. We know that the form of Gaussian conditional probability density function.

$$p(x \mid D_i) = \frac{1}{(2\pi)^{\frac{n}{2}} |K_i|^{\frac{1}{2}}} \quad (15)$$

$$\exp\left[-\frac{1}{2}(x - m_i)K_i^{-1}(x - M_i)^T \right]$$

Where the covariance matrix K_i is diagonal,

$K_i = \sigma^2 I$ and $\sigma^2 > 0$, $m_i = E[x \mid D_i]$, the mean vector of pattern class D_i. Table 1 shows selected feature variable.

Table 1 Comparison of measured roughness data

Feature Variable	Classification Rate
Rise Time / Rise Slope	0.92
Rise Time / Pulse Duration	0.89
Rise Time / Amplitude	0.93
Rise Time / Mean	0.77
Rise Time / Max.(Ccep)	0.92
Amplitude / Rise slope	0.76
Amplitude / Mean	0.91
Amplitude / Max.(Ccep)	0.93
Amplitude / 2nd PDF	0.85
Rise slope / Mean	0.65
Rise slope / Max.(Ccep)	0.92
Rise slope / 2nd PDF	0.81
Pulse duration / Mean	0.85
Pulse duration / Amplitude	0.74
Pulse duration / Max.(Ccep)	0.65
Pulse duration / 2nd PDF	0.92
2nd PDF / Mean	0.85
2nd PDF / Max(Ccep)	0.78

5. Experiment

In order to manufacture wilding-test material for detecting welding flaws, we use rolled steel for general structure (SB41) as a test material. We applied Arc welding to this plate (SB41) and considered welding flaw of are welding as artificial flaw. In this study, we adapted welding-test materials presented by sonaspection inc. U.K.

Ultrasonic Probe (5Z 10× 10 A70) was generated to 5MHz. Acquisition process of a reflection signal from a flaws using the ultrasonic probe have a pulse in 0.5~1 skip distance by a flaw position and also acquire representation pulse wave of flaw by a flaw shape. For ultrasonic signal acquisition, DSO (Digital Storage Oscilloscope) was set. Fig. 3 shows data acquisition and signal processing system.

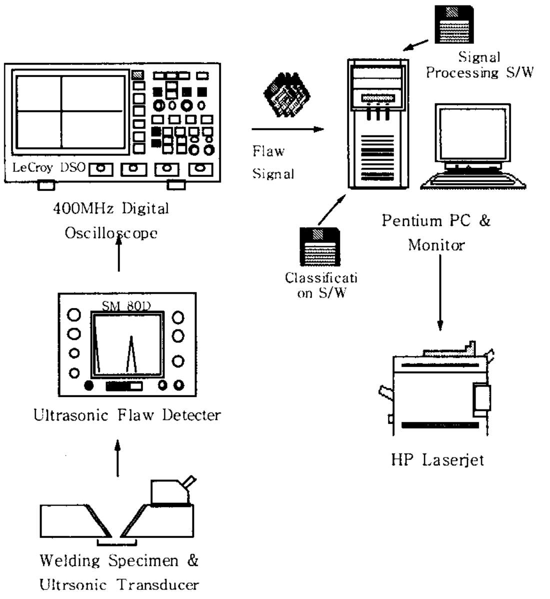
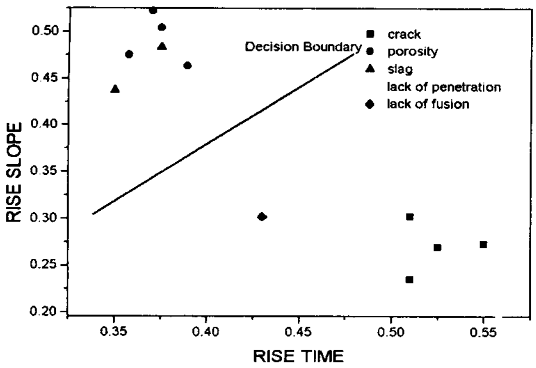
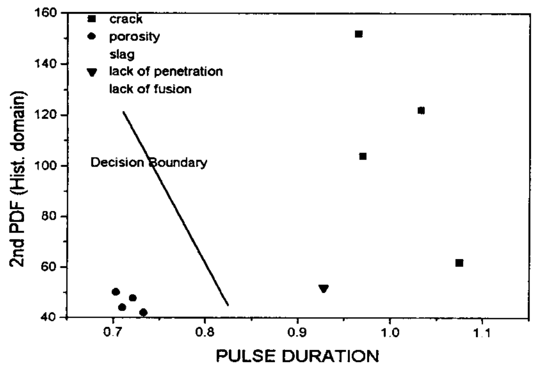


Fig. 3 Data acquisition and signal processing system

We are classification the artificial flaws which happen in welding process to planar flaws (lack of penetration, lack of fusion, side crack, center crack, toe crack, root crack) and volumetric flaws(porosity, slag). We are extracted 78 feature variable from each signal processing domain, Table 1 shows continuous status in feature variable space. In the space of feature variable, we can ratify the certification of feature value Fig. 4 shows a cluster plot of feature variable.



(a) Rise time / Rise slope



(b) Pulse duration / 2nd PDF (Hist. domain)

Fig. 4 Cluster plot of feature variable

6. Conclusion

The pattern recognition technology is applied to classification problem of artificial flaw. (i.e multiple classification problem : crack, lack of penetration, lack of fusion, porosity, and slag, the planar and volumetric flaw classfication problem) According to this results, if appropriately learned the neural network classification problem of natural flaw. And it is possible to acquire the recognition rate above 80% through it is different a little according to domain extracting the feature and classifier.

Acknowledgement

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