A Study for Extracting the Information about Flaws in Ultrasonic Detection Based on NNT Cancellation

Meiming Feng*, Yicheng Zhang, Shusheng Liao and Wenbin Wei
China Nuclear Power Operation Technology Corporation, LTD, Wuhan, 430223, China
*Corresponding author

Abstract—How to extract the information about flaws in ultrasonic detection has been paid attention all the time. Because of strong initial echo, side echo and bottom echo (called “clusters”) existing in the ultrasonic echoes, traditional detection methods are difficult to cancel all clusters at the same time, and the clusters left affect detecting the tiny flaws in the object. In this paper, the neural network technology in machine learning is studied, and applied in signal cancellation. A method for extracting the information about flaws is put forward, in which zero mean, wavelet-denoising and adaptive cancellation based on neural network technology are integrated together. The experimental results show that, compared with traditional detection methods, the method can cancel strong clusters such as initial echo, side echo and bottom echo at the same time, and the CR is bigger, the information about the flaws is reserved better, and it has the real time.

Keywords—ultrasonic detection; signal cancellation; neural network technology; cancellation rate (CR)

I. INTRODUCTION

Ultrasonic detection has been loved in the fields such as metallurgy, machinery, shipbuilding, spaceflight, medical science and nuclear power all the time, because of its character undamaged[1-2]. Ultrasonic signal processing has also been pushed to great mass fervor. In order to stand out flight targets and cancel all kinds of clusters, W. Wei had proposed an adaptive cancellation method based on frequency-domain de-convolution[9]. One can use it to suppress strong initial echoes better than those traditional algorithms such as the adaptive LMS filtering, the changing step length LMS filtering[5,6]. With the extension of fields and the deepness of the details, we find that some algorithms in neural network technology can make some influence in filtering[7,8,9]. Thus, we study neural network technology, signal cancellation principle and method to realize flaw extraction.

Based on the past results, in this paper we present an algorithm for extracting the information about flaws, in which we use an adaptive cancellation by neural network technology. This paper is organized as the following: Section II introduces the fundamental method for extracting the information about the flaws and the flow chart of the system devised; Section III and Section IV explains the principle of wavelet-denoising and NNT approximation respectively in brief; Section V presents an NNT cancellation algorithm for extracting the information about flaws; Section VI analyses the functions of the NNT cancellation algorithm; Section VII gives some conclusions.

II. FUNDAMENTAL METHOD AND FLOW

The signals received by ultrasonic unit usually contain much noise which will affect the clusters’ cancellation. It is necessary to suppress the noise in advance. After that, one can get the information about the flaws by cancellation.

The most fundamental demands for cancellation algorithms are good cancellation effect and less operation time. The cancellation effect can be evaluated by visual observation and evaluation indexes, in which we use MSE and CR to measure it. The operation time is measured by the function etime in MATLAB.

The algorithm for extracting the information about flaws can be described as:

Step 1. Input the reference signal P and the target signal T;
Step 2. Make both P and T zero mean, get P’ and T’ respectively;
Step 3. Suppress noises in P’ and T’ by wavelet-denoising, denote the results as P* and T*;
Step 4. Use cancellation technology to suppress initial echo, side echo and bottom echo existing in the ultrasonic echoes; extract the information about the flaws, which is denoted as E;
Step 5. Display E, the information about the flaws.

Hence, the flow to extract the flaws is shown as Fig.1.

FIGURE I. FLOW CHART TO EXTRACT FLAWS

Here zero mean means that vector P becomes P-mean(P), where mean(P) is the average value of the elements in P.

III. WAVELET-DENOISING

Since the signals obtained from ultrasonic unit are subjected to much noise which affects signal cancellation (SC), that’s to say, CR is not big, it is necessary to suppress this noise. It is well known that wavelet transformation (WT), based on
Fourier transform and Gabor transform, is characteristic of multi-resolution, and there are many kinds of wavelets to choose, and there exist fast wavelet transform algorithms (FWT). Therefore, wavelet transform is widely used in signal processing, image processing. Especially, it is often utilized to eliminate noise.

The bases used in WT are obtained by the shifting and dilating wavelet[10]. The wavelet \( \psi(t) \) is a square integral function whose integral is zero, that is

\[
\int_{-\infty}^{\infty} \psi(t) dt = 0, \quad \psi(t) \in L^2(R)
\]  

(1)

After shifted \( b \) and dilated \( a \), \( \psi(t) \) becomes

\[
\psi_{a,b}(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right)
\]

(2)

For any function \( f(t) \), the wavelet transformation is defined as

\[
Wf(a,b) = \int_{-\infty}^{\infty} f(t) \psi_{a,b}(t) dt
\]

(3)

The inverse wavelet transform is

\[
f(t) = \frac{1}{C_{\psi}} \int_{-\infty}^{\infty} Wf(a,b) \psi_{a,b}(t) \frac{da}{a^2} db
\]

(4)

In the signal processing that computers perform, the discrete formulas are adopted. On the one hand, we discrete the dilating and shifting factors; on the other hand, we use “sum” instead of “integral”. The statement in detail can be seen in the literature [1].

The method adopted in this paper is an auto wavelet-denosing, in which the function chosen is \( \text{wden} \) found in MATLAB, the main works we do is to determine the following parameters: choose a wavelet basic function, determine decomposing levels, select thresholds for the coefficients with high frequency. For example, the statement

\[
\text{wden}(X, 'heursure', 'h', 'one', 3, 'sym8')
\]

means that the wavelet type is Daubechies wavelet whose filter length is eight, the level number of wavelet decomposition is three levels, the basic mode is 'one', the compressing mode adopted is hard threshold, an heuristic variant is chosen in the threshold selection rule.

IV. NNT APPROXIMATION

It is well known that neural networks are composed of elements operating in parallel, and these elements are inspired by biological nervous systems, and in nature the connections between elements largely determine the network functions[89]. By adjusting the values of the connections (weights) among elements, one can train a neural network to perform a particular function. Through the network, a particular input leads to a specific target output. Here, the network is adjusted, based on a comparison of the output and the target, until the network output matches the target. Fig.2 illustrates such a situation.

![Figure II. MODEL 1: RECURSIVE NN FLOW CHART](image)

Of course, one can obtain a neural network function directly based on the LMS error between the output and the target. This situation can be described by Fig.3.

![Figure III. MODEL 2: NON-RECURSIVE NN FLOW CHART](image)

For example, if the input vector and the target vector are known, by some NN function one can devise a net, through which the specific NN weights are obtained and the LMS error between the output vector and the target vector can be least. Suppose that the input vector is \( P = [1 \ 2 \ 3] \), and the target vector is \( T = [2.0 \ 4.1 \ 5.9] \). The net is devised by the following pattern

\[
\text{net} = \text{train}(P,T)
\]

Using

\[
Y = \text{sim}(\text{net},P)
\]

we can get \( Y = [2.0500 \ 4.0000 \ 5.9500] \). From this, we can see that the output vector approximates the target vector closely. These two models are suitable for different cases. The former has bigger error at the starting slice between the output and the target, while the latter is much less than the former.

Nowadays, the NNT has been applied to many fields such as pattern recognition, data classification, control systems, engineering, financial, and other practical applications. They not only have been trained to perform complex functions, but also have been trained to solve problems that are difficult for conventional computers or human beings.

V. NNT CANCELLATION

In adaptive signal processing, adaptive filtering technology can be used to cancel clusters, which is successful in the radar with opportunity transmitters. Wei’s non-recursion deconvolution cancellation can acquire much better effect in cancellation[3,11]. The two models in Section IV are very similar to the above filtering methods. Hence, we try to apply these two models (especially Model 2) in Section IV to signal cancellation. As an example, non-recursive NN cancellation flow chart is given, showing as Fig.4.
Here, we simulate two ultrasonic signals with SNR 26 dB, seeing Fig.5. Suppose that the ultrasonic unit transmit a sine wave, weighted by triangular window. One is an input signal (sometimes called reference signal or history signal) including an initial echo and a bottom echo, the other is a target signal (sometimes called actual signal or present signal), not only including an initial echo and a bottom echo but also including two flaws, of which one is independent, another overlaps the bottom wave.

But, if we use the non-recursive NN cancellation algorithm, we will get a much better effect, in which two flaws can be found clearly, especially the flaw mixed in the bottom wave is separated out, which can be seen in Fig.7.

For convenience to observe and compare these signals, we show Fig.8 that contains the input signal, the target signal, the output signal after approximation and the flaws after cancellation.

From the above algorithm, we can see that, the net can be obtained from the input signal and the target signal, and the output signal can be obtained from the net and the input signal, and the flaws come from the difference between the target signal and the output signal. The simulation experiment shows its effectiveness.

VI. PERFORMANCE ANALYSIS

In order to analyze the performance of the algorithm presented in this paper, we compare this neural network approximation cancellation with other four methods (such as LMS Cancellation, Improved Step-changed LMS Cancellation, Frequency-domain De-convolution Cancellation, Inverse Matrix De-convolution Cancellation) not only subjectively by vision, but also objectively by the evaluation indexes, which include MSE (Mean Squared Error) between flaws’ signal and the signal after cancellation, CR (Cancellation Rate) which is the decibel representation of the ratio of powers (or energies) of cluster before and after cancellation, and the real time (RT). Usually, bigger CR is corresponding to less MSE. For convenience to use, we note LMS Cancellation, Improved Step-changed LMS Cancellation, Frequency-domain De-convolution Cancellation, Inverse Matrix De-convolution Cancellation and Neural Network Approximation Cancellation as LC, ISLC, FDC, IMDC and NNAC respectively.

A. Case without Noise

Considering the case without noise, the simulative input and target signals are as Fig.9, and the ideal flaw signal is as Fig.10.
After cancellation by these five algorithms, comparing Fig 10 and Fig.11 we found that LC and ISLC do work to some extent but reserve some stronger initial echo and a little bottom echo, and FDC and IMDC suppress strong initial echo and bottom echo but the mirroring disturbance appears, only NNAC draws out the information about these two flaws very clearly as the cluster is completely suppressed.

The objective indexes are recorded as Table I. We can see that the MSE, CR in Table I are accordance to the effect in vision, and NNAC is the best of all in effect, and it costs very little time.

| Name  | MSE/No Dim | CR/dB   | RT/s |
|-------|------------|---------|------|
| LC    | 0.0106     | 9.0266  | 5.813|
| ISLC  | 0.0043     | 12.7862 | 0.015|
| FDC   | 0.0153     | 7.5394  | 0.015|
| IMDC  | 0.0155     | 7.4802  | 0.234|
| NNAC  | 1.9204e-005| 36.5633 | 0.016|

Comparing Table I and Table II, we find that more noise means more MSE or less CR, and there is not more change in the real time.

### Case with Denoising

In order to improve the effect in the case with noise, we firstly suppress noise by wavelet denoising, then cancel the cluster, and last extract the information about the flaws. The evaluation indexes are very badly, just as Table II. In this case, NNAC is worse than ISLC in MSE between real flaws’ signal and the signal after cancellation, and it is lower than ISLC twice.
experimental results are as Fig.13. It can be seen that in the background of strong noise, FDC and IMDC don’t work. One can see the information about these two flaws from LC, ISLC and NNAC. Of course, NNAC has not big initial echo left, and is easy to discern the flaws automatically.

The evaluation indexes in this case are as Table III.

| Name  | MSE/No Dim | CR/dB  | RT/s  |
|-------|------------|--------|-------|
| LC    | 0.0392     | 6.3164 | 6.197 |
| ISLC  | 0.0331     | 8.2478 | 0.010 |
| FDC   | 0.0422     | 5.7482 | 0.016 |
| IMDC  | 0.0422     | 5.7482 | 0.250 |
| NNAC  | 0.0293     | 9.3036 | 0.016 |

Comparing Table II and Table III, we find that by wavelet denoising, the MSE reduces, and CR rises, but RT does not change clearly after cancellation.

D. Comparison with CR before and after Denoising

In Subsection B-C, we see that the more noise means less CR, and denoising can enhance CR. Here the rule that the CR of NNAC changes with SNR is concluded as Fig.14. We can see that if the SNR of the input signal or target signal is lower than about 30dB, denoising can boost the CR, if the SNR is bigger than 30dB, it is not necessary to eliminate noise.

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VII. Conclusion

In this paper, we present a method for extracting the information about flaws based on NNT cancellation: zero mean, wavelet-denoising and NNT cancellation. The experimental results show its good performance with less MSE, bigger CR and less time cost in extracting flaws.