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Guided Wave NDT Signal Recognition with Orthogonal Matching Pursuit Based on Modified Evolutionary Programming

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Abstract

This work aims to decompose and construct guided wave NDT signal by orthogonal matching pursuit employ modified evolutionary programming algorithm based on the *t* distribution (M*t*EP), which can reduce the computation complexity. A pipe sample with holes is inspected by guided wave and the test signal is processed by the OMP with M*t*EP. The processed result is compared with the OMP with evolutionary programming algorithm based on the *t* distribution (*t*EP). The result shows that this improved method can reconstruct the signal with better quality, less calculation time, and the echoes signal can be recognized clearly. Therefore, this proposed approach is useful to the guided wave NDT signal recognition.

Keywords: orthogonal matching pursuit; guided wave NDT; defect; signal recognition

1. Introduction

Ultrasonic guided wave can propagate a long distance and detect the whole wall defect under the non-contact condition [1], so it has been used to non-destructive testing (NDT) in pipes. For the reason of the disperse and multi-modes features of guided waves, it is important to develop efficient approaches to recognize the guided wave NDT signals. Matching pursuit (MP) [2] has been used in signal processing such as ultrasonic, radar and guided wave, and fuzzy clustering and classification of signals. It is difficult to numerical

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implementation MP because it need larger number of iterations about inner product of the signal and the match atoms. The evolutionary programming (EP) is a global optimization algorithm developed by L. Fogel L J [3]and Fogel D B [4]. EP searches in parallel from more than one point to optimize the objective functions. It explores simultaneously many paths for searching the global minimum or maximum, this method is better than a GA-based approaches [5]. The EP need many generations iterations to convergence because its step is a fixed value.

In this work, modified evolutionary programming algorithm[6,7] which choose mutations using t probability distributionand chirplet function [8] as the match atoms is used to orthogonal matching pursuit. The guided wave test signals of a pipe sample with holes is processed and reconstructed by OMP. The echoes signal can be recognized and the match parameters can reflect the features of the guided waves.

2. Orthogonal Matching Pursuit based on the Modified Evolutionary Programming

2.1. Orthogonal Matching Pursuit

The steps of the processing signal s using the matching pursuit method are as follows, firstly, determine an over-complete waveforms dictionary ($D = \{h_\theta, \|h_\theta\| = 1\}$), then from the dictionary select an optimal match atom h_0, the atom should make the absolute value of the inner product $|< s, h_\theta >|$ maximum in some extent[2]. We subtract the contribution of atom h_0 from the signal s and get $R^1 s$.

The signal f can be decomposed as

$$s = < s, h_0 > h_0 + R^1 s \quad (1)$$

Repeated the process n times and the signal s will be processed as:

$$s = \sum_{i=1}^{n-1} < R^i s, h_i > h_i + R^n s \quad (2)$$

OMP use the same method as MP to choose match atoms but it need to do orthogonal operation on the chosen atoms based on the Gram-Schmidt rules. Then make projection to the space spanned by the chosen atoms, the weight of the signal and its residual can be got. The same operation is done to the residual until the halt criterion is satisfied. The detailed OMP are as followings,

1. Let $p_1 = h_{\gamma 1}$, $u_1 = p_k / \|p_k\|$.

2. Choose the best atoms, in the step K, atom g_{γ_k} is chosen which can be expressed as

$$< R^{k-1}, h_{\gamma_k} > = \sup_{\gamma \in \Gamma} |< R^{k-1}, h_{\gamma_k} >| \quad (3)$$

3. Do orthogonal operation on the chosen atoms based on the Gram-Schmidt rules.

$$p_k = h_{\gamma_k} - \sum_{n=1}^{k-1} < R^{k-1}, u_n > u_n \quad (4)$$

Normalize the vectors u_k, $u_k = p_k / \|p_k\|$.

4. Renew the residual. Make the residual projection to u_k the residual can be got.

$$R^k = R^{k-1} - < R^{k-1}, u_k > u_k \quad (5)$$

In the above equation (5), R^k and R^{k-1} are the residual of the step k and $k-1$, respectively.

5. Stop check. If the following express is satisfied, then the iteration will halt, otherwise go to step 2.

$$\left\|R^k\right\|^2 = \left|< R^{k-1}, u_k >\right|^2 + \left\|R^{k-1}\right\|^2 \le \varepsilon^2 \left\|s\right\|^2 \tag{6}$$

Then the signal can be decomposed as

$$s = \sum_{k=1}^{m} < R^{k-1}, u_k > u_k \tag{7}$$

2.2. The Modified Evolutionary Programming Algorithm

In the evolutionary programming, each parent creates a single offspring which can be expressed as

$$x_i^{'} = x_i + \sigma_m(n) \cdot F_i(0,1) \tag{8}$$

The main heredity operator $F_i(0,1)$ is the mutation operator and it will do much impact to the calculation efficiency. To improve the calculation capability and efficiency, here we choose a kind of excellent mutation operator based on t distribution for EP.

The t distribution expressed as $T = X / \sqrt{Y/n}$, $X \sim N(0,1)$, $Y \sim \chi^2(n)$, and the probability density are:

$$f(x) = \frac{\Gamma(\frac{n+1}{2})}{\sqrt{n\pi}\Gamma(\frac{n}{2})}\left(1+\frac{x^2}{n}\right)^{-\frac{n+1}{2}}, -\infty < x < +\infty \tag{9}$$

Here n represents the degree, $t(n)$ will close to normal distribution as n increase. Depending on the nature of the Γ function, degree n can be extended from positive real integers into positive real numbers[9]. It is needed to modify the step adaptively to the global optimum with less iterations and less time. Herein, the factor F is given and multiplied to the step. Let $F_0(G) = (\sqrt{G_{\max}^2 - G^2} / 2G_{\max})$,then the factor can be expressed as

$$F = \begin{cases} 0.5 + F_0(G), & 0.35 < F_0(G) <= 0.5 \\ 0.8, & F_0(G) < 0.35 \end{cases} \tag{10}$$

The step $\sigma_m(n)$ is modified as $\sigma_m^{'}(n) = F \cdot \sigma_m(n)$ .The step will change with the evolution generations and accelerate the convergence efficiency.

3. Experiment Signal Process

3.1. Detection Experiment Based on Guided Wave

We set up the detection device based on magnetostrictive effect and put the excitation sensors and receiving sensors at end of the pipe sample. Trough the device we excited several periodic tone bursts which center frequency is 20kHz, thus the wave signal propagate along the axial direction. If there are defect in the pipe, the wave will reflect when reach the defect and the reflect signal will be received by the receiving sensors. The length of pipe sample is 6.72m, the outer diameter is 38mm and the thickness is 3mm. The diameters of the three holes are 10mm,12mm,8mm, location at 2.24m,3.36m,4.48m from the left pipe end.

3.2. Match Atoms Selection

We choose chirplet function as matching atoms in this paper. Because the detection signal is real, the real valued chirplet atom is used , which is

$$h_{\Gamma}(t) = Be^{-(\frac{t-\tau}{u\Delta t})^2} \cos\{2\pi f_c t + 2\pi c t^2 + \theta\} \quad (11)$$

Here f_c represents the center frequency, $\Delta t = 1/f_c$, c represents the chirp-rate which reveal the signal's frequency-varying behaviour.

τ represents the time delay, u represents a non-dimensional parameter of time spread, θ represents the phase shift, and B is an arbitrary constant to achieve $\|h_{\Gamma}(t)\|^2 = 1$.

3.3. Signal Processing

The original inspected signal was shown in Figure 1, which contains defect reflect signal. We separately process the signal by OMP with M*t*EP and *t*EP, and the results are gave in Figure 2.a and Figure 2.b, respectively. From the Figure 2.a, we can see that most of the noises are filtered and it is more easy to recognize the defect echo signal.

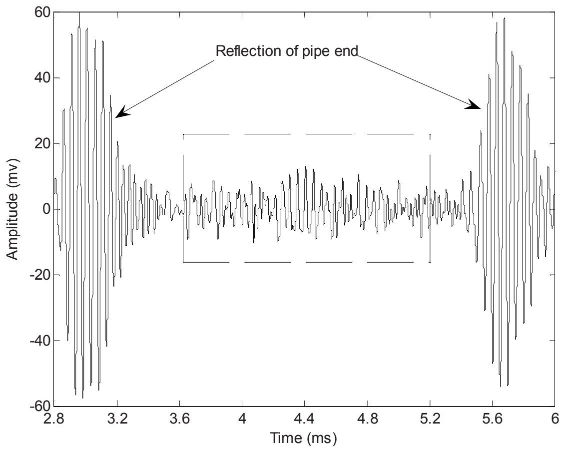
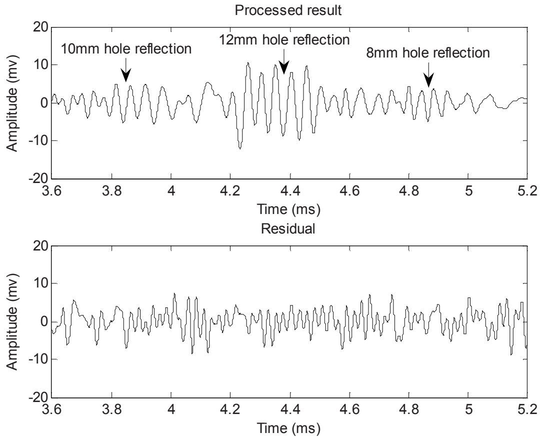
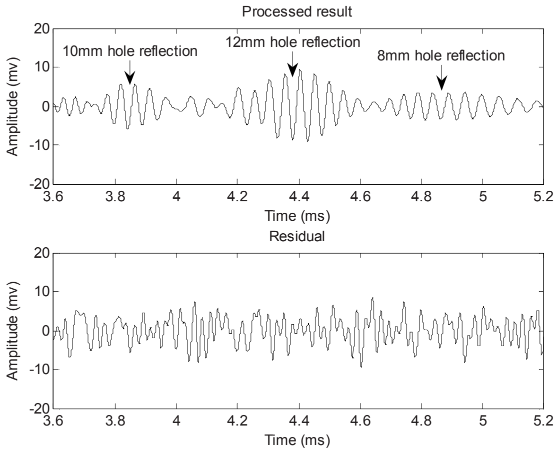


Fig. 1. The original inspected signal





Firure 2. (a)The matched result from OMP with M*t*EP; (b) The matched result from OMP with *t*EP

The parameters get from the processed signal by OMP with M*t*EP and *t*EP are shown in Table I and Table II, respectively. The time delay τ can indicate the center time of the extracted waveforms.

Table 1. The Parameters From OMP Based on M*t*EP

Iteration	f_c (Hz)	τ (ms)	u	c	θ(rad)	B
1	23547.9	3.63	11.2	-96919.0	-0.10	-0.06
2	19302.8	4.43	29.4	24008.6	-0.39	0.13
3	19179.4	4.29	26.3	12501.7	0.49	-0.14
4	17734.5	3.94	29.9	-23622.4	0.43	-0.10
5	17792.1	4.65	29.3	12274.6	1.00	-0.08
6	18192.4	4.47	29.1	26493.7	1.43	0.06
7	20934.6	4.21	25.5	14021.9	-0.37	0.08
8	18922.6	4.93	29.2	-27898.9	-0.13	0.07
9	17259.4	3.83	30.0	9307.7	-1.67	0.05
10	17930.1	4.39	28.3	-15620.1	0.55	-0.13
11	18816.2	3.79	28.0	-11148.0	2.86	0.01
12	19474.4	5.15	28.7	65293.6	-2.89	0.08

Table2. The Parameters From OMP Based on *t*EP

Iteration	f_c (Hz)	τ (ms)	u	c	θ (rad)	B
1	21607.5	3.60	17.5	80814.8	-2.65	0.014
2	20358.7	4.35	26.0	5708.6	2.47	-0.20
3	19440.8	4.88	29.4	-7064.6	-0.93	0.06
4	17701.0	3.92	29.2	-9999.1	2.60	-0.08
5	21022.2	3.92	26.4	-14938.3	1.25	0.08
6	17930.9	4.32	29.6	5895.7	-2.88	-0.07

7	24102.2	4.42	29.3	5626.7	2.024	-0.05
8	24540.6	4.01	22.5	56354.9	-1.81	0.09
9	17740.8	4.04	27.1	14015.2	-0.60	-0.03
10	17328.3	4.88	28.1	-68720.5	-1.23	0.08
11	18579.3	4.87	27.4	26051.8	2.07	-0.02
12	18814.3	4.66	28.7	8226.0	2.51	-0.09

The error ratio for the center frequency of the matched signal from OMP based on M*t*EP and *t*EP are 17.73%, 3.48%, 4.10%, 11.33%, 11.04%, 9.04%, 4.67%, 5.39%, 13.70%, 10.35%, 5.92%, 2.63%, and 8.0375%, 1.79%, 2.80%, 11.50%, 5.11%, 10.35%, 20.51%, 22.70%, 11.30%, 13.35%, 7.10%, 5.93%, respectively. The experiment proved that the error ratio for the center frequency of the matched signal from OMP based on M*t*EP is lower than which based on *t*EP.

4. Conclusion

A kind of modified evolutionary programming algorithm using mutations based on the t distribution is proposed and used to the orthogonal matching pursuit. A pipe sample with holes is inspected and the guided wave signal is processed by the OMP with M*t*EP. The processed result compared with the OMP with *t*EP shows that the improved method can reconstruct the signal with better quality and less calculation time and the defect echoes signal can be recognized clearly. Therefore, this proposed approach is useful to the guided wave NDT signal recognition.

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