Research Journal of Applied Sciences, Engineering and Technology 4(21): 4469-4473, 2012
ISSN: 2040-7467

Submitted: May 01, 2012 Accepted: June 08, 2012 Published: November 01, 2012

Application of Novel Subspace Pursuit on Guided Wave NDT Signal Decomposition and Recognition Based on Improved Evolutionary Algorithm

[1]Chuanjun Shen, [1]Yuemin Wang, [2]Yan Liu, [1]Fangjun Zhou and [1]Fengrui Sun
[1]College of Architecture and Power, Naval University of Engineering, Wuhan 430033 China
[2]College of Science, Naval University of Engineering, Wuhan 430033 China

Abstract: In this study, we propose and apply a kind of novel subspace pursuit method to guided wave Non-Destructive Testing (NDT) signal decomposition and recognition to reduce the complexity of subspace pursuit. Modified Differential Evolution Algorithm (MDEA) is applied to the Modified Subspace Pursuit (MSP) by choosing chirplet function as match atoms. A steel pipe with hole and notch is detected by guided wave and the measured signal is decomposed and reconstructed by MSP. The matching result is compared to the matching result from MP with DEA. The defect echo can be identified easily from the processed signal. The matched parameters get by MSP and MP are compared and analyzed. The defect locations are more exactly get from MSP than from MP.

Keywords: Guided wave, modified differential evolution, modified subspace pursuit, signal decomposition and recognition

INTRODUCTION

As a promising and efficient long-range pipe Non-Destructive Testing (NDT) approach, guided wave has been used in pipe NDT because it can propagate a long distance in pipes at high speed and detect the whole pipe wall under the non-contact condition (Rose *et al*., 1994; Kwun *et al*., 2000; Yoon *et al*., 2005; Wang *et al*., 2004). It is hard to recognize guided wave testing signal because the multi-modes and disperse feature of guided waves. It is important to develop efficient signal processing approach to recognize the inspection signal. Traditional signal analysis method such as wavelet analysis (He *et al*., 2006; Lyutak, 2005), correlation analysis (Zhang *et al*., 2009), time-frequency analysis (Xu *et al*., 2010) have been used to process guided waves signal.

Another new approach is Matching Pursuit (MP) proposed by Mallat, it have been used in signal processing such as ultrasonic, radar, guided wave, fuzzy clustering and classification of signals. J.C. Hong proposed a kind of chirp dictionary-based matching pursuit approach to approximate the guided wave signals and estimate the damage extent and location and it is proved very useful.

It is difficult to numerical implementation MP because it need large number of iterations about inner product of the signal and the match atoms. There are some modified MP such as orthogonal matching pursuit, optimized-orthogonal matching pursuit, regularized orthogonal matching pursuit, two dictionaries matching pursuit and subspace pursuit. Only under the condition that the sparsity K is small, the above algorithms can recover the signal with high probability. Generally, the subspace pursuit can recover the signal better than other algorithms. Subspace pursuit reconstruct signal by choosing N atoms and approximation the signal by the linear combinations of the atoms. It still needs large computations because the coefficients need to be calculated by LMS method.

In this study, we propose and implement a modified subspace pursuit by mdea to reduce the complexity of subspace pursuit. The proposed method is applied to decompose defect steel pipe guided wave inspection signal. The processed result is compared to the processed result from MP with DEA. The defect locations of the processed signal from MSP are more exactly than from MP with DEA through comparing the parameters of the matched signals. The computation time by MSP is a little shorter than by MP. Therefore, MSP is a kind of useful signal recognition and defect location approach for pipes guided wave NDT.

METHODOLOGY

Modified subspace pursuit employ modified differential evolution algorithm: Subspace pursuit reconstruct signal through choosing atoms $g_1, g_2, \ldots g_N$ and approximation the signal by the linear combination of the atoms which makes:

Corresponding Author: Chuanjun Shen, College of Architecture and Power, Naval University of Engineering, Wuhan 430033 China

$$\left\| f - \sum_{i=1}^{N} x_i g_i \right\|_2^2$$

minimum. After the first iteration decomposition the signal can be expressed as:

$$f_1 = \sum_{i=1}^{N} x_i g_i$$

The modified subspace pursuit is proposed and the signal decomposition and reconstruction is similar to the matching pursuit but there is no inner product. At first, it choose a single atom g_{1j} and coefficient a_{1j} which make the norm $\|f-a_j\, g_{1j}\|^2_2$ minimum. Then the first decomposition signal can be expressed as $f_1 = a_j g_{1j}$. Repeating the above calculations on residual signals, the reconstruction signal meet the demand precision can be got. The detailed procedure of the MSP algorithm are as follows:

- Choose a single atom g_{1j} from $g_{11}, g_{12}, ..., g_{1N}$ and coefficient a_{1j} from $a_{11}, a_{12},..., a_N$ which makes $\|f-a_j\, g_{1j}\|^2_2$ minimum.
- Calculate the residual.
- Repeating the above calculations on the residual signals, $Rf_1 = f–f_1 = f–a_{1j}g_{1j}$, $f_2 = a_{2j}g_{2j}$, $Rf_2 = Rf_1–f_2,…, Rf_{n-1} = f_{n-1}–a_{n-1}\,jg_{n-1j}$, $f_n = a_{2n}g_{2n}$.
- Stop check.
- If express (1) is satisfied then the iteration halt. If not, then k = k +1 and go to step 2:

$$\left\| Rf^{\,k} \right\|^2 = \left\| Rf^{\,k-1} - a_{kj} g_{kj} \right\|^2 \le \varepsilon^2 \| f \|^2 \tag{1}$$

At last, the signal can be written as:

$$f = a_{1j} g_{1j} + a_{2j} g_{2j} + ... + a_{mj} g_{mj} \tag{2}$$

This method can improve computation efficiency because it avoids the inner product about signal and matching atoms.

In this study, chirplet functions are chosen as matching atoms and chirplet atom expressed as:

$$g_{s,u,\xi,c}(t) = \frac{1}{\sqrt{s}} g\left(\frac{t-u}{s}\right) e^{i(\xi t + ct^2)} \tag{3}$$

Because the detection signal is real, the real valued chirplet atom is used, which is:

$$g_\Gamma(t) = e^{-\left(\frac{t-\tau}{s\Delta t}\right)^2} \cos\{2\pi f_c t + 2\pi c t^2 + \varphi\} \tag{4}$$

In which, $\Delta t = 1/f_c$, τ is the time delay, f_c is the center frequency, s is a non-dimensional parameter of time spread, *c* is the chirp-rate which reveal the signal's frequency-varying behavior, φ is the phase shift.

The Differential Evolution Algorithm (DEA) is a kind of intelligent algorithm based on differential and mutation Stum and Price (1995). This algorithm is noticeable in solution search efficiency and stability. The convergence ability of DEA is lower than other algorithms such as EP Fogel *et al*. (1966) and GA Holland (1975). There are some literatures on the improvement of DE algorithm (Mingguang Liu, 2005; Xia Huiming and Zhou, 2009). Based on DEA, the Modified Differential Evolution Algorithm (MDEA) is proposed and the improvements including the following aspects:

The mutation process is modified. In the mutation process of choosing 3 elements, one is chosen from the current population with the fitness bigger than the average fitness, the other two elements are chosen randomly from the current population. Then the three elements are ranged by fitness, the element with the biggest fitness is chosen as the basic vector and the other two make difference and multiply the factor F to add to the basic vector, then the new element is expressed as:

$$x_j^{i'}(t) = x_j^{r_1'}(t) + F(x_j^{r_2'}(t) - x_j^{r_3'}(t)) \tag{5}$$

The intercross factor F is modified. Let:

$F_0(G) = (\sqrt{G^2{}_{\max} - G^2} / 2G_{\max})$, modify F as:

$$F = \begin{cases} 0.5 + F_0(G), 0.35 < F_0(G) < 0.5 \\ 0.8, F_0(G) < 0.35 \end{cases} \tag{6}$$

The intercross probability P is modified. Let $P_0(G) = 0.45\sqrt{G/G_{max}}$, modify P as following:

$$P = \begin{cases} 0.4 + P_0(G), 0.35 < P_0(G) <= 0.45 \\ 0.75, P_0(G) <= 0.35 \end{cases} \tag{7}$$

The mutation process will improves local search capability because its evolution is similar to perform local search around many excellent elements. Both the intercross factor and intercross probability will change with the evolution generations other than a fixed value. It improves local search capability because there is more difference added to the basic vector which can improve the convergence efficiency when the generation is small.

The procedure of numerical implementation of MSP based on MDEA is as follows:

- **Initialize MDEA parameters:** Initialize the population numbers N, intercross factor F, intercross probability P and evolution generations G_0, G_{max}s, the range of parameters τ, s, f_c, c, φ, *a*. produce a random population $\Gamma(t = 0) = (\Gamma_1(0),..., \Gamma_N(0))$.
- In the above population, $\Gamma(t = 0) = (x^i_1(0),..., (x^i_6(0))\ \Gamma_N(0)$, x_1, x_2, ..., x_6 are the corresponding parameters of τ, s, f_c, c, φ, *a*.
- **Elements evaluation:** Calculate the objective value $f(\Gamma_i)$.
- **Mutation and reproduce:** Produce three different integers r_1, r_2, $r_3 \in \{1, 2,..., N\}$ and a random integer j_{rand} $j_{rand} \in \{1, 2,..., 6\}$, for each $\Gamma_i(G)$, the element after mutation can be expressed as:

$$x_j^{i'}(G) = \begin{cases} x_j^{r_1}(G) + F(x_j^{r_2}(G) - x_j^{r_3}(G)), rand(0,1) < P, or\ j = j_{rand} \\ x_j^i(G), else \end{cases} \tag{8}$$

- **Selection:**

$$\Gamma_i(G+1) = \begin{cases} \Gamma_{i'}(G+1), & f(\Gamma_i(G)) < f(\Gamma_{i'}(G)) \\ \Gamma_i(G), & else \end{cases} \tag{9}$$

- **Stop checkout:** The evolution will stop and output the optimized elements if the stop condition is satisfied, otherwise, go to step (2).

RESULTS ANALYSIS

Guided wave testing experiment: The guided wave inspection system based on magnetostrictive effect is setup. The dimension of the steel pipe are length of 6.50 m and diameter 48 mm with thickness 5 mm. There are a hole depth 3 mm with diameter 8 mm and a notch length of 20 mm with depth 3 mm in the pipe. The location of the hole and notch are 3.5 and 5.0 m from the left pipe end, respectively (Fig.1). The sensors are placed at the left pipe end. The detailed experimental setup can reference to literature

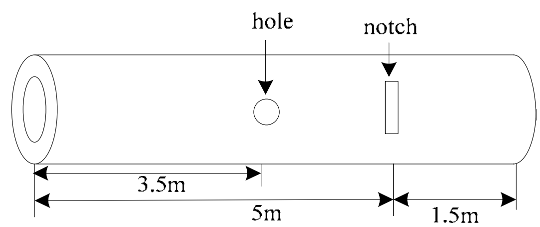

Fig. 1: The sketch map of the defect steel pipe

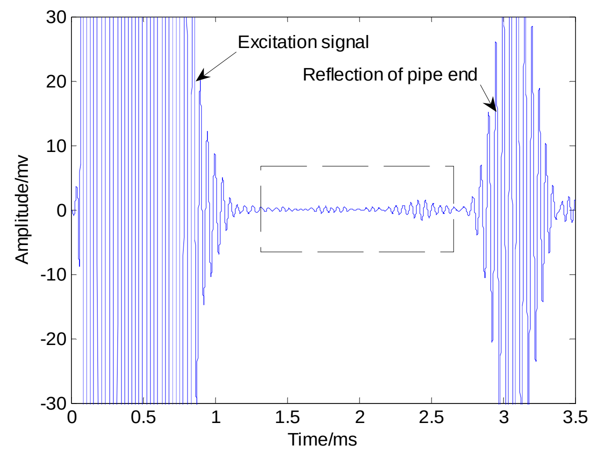

Fig. 2: The detection signal

(Yuemin *et al*., 2004). At first, several periodic tone bursts with center frequency of 20 kHz are excitated by guided wave instrument. Guided wave will be generated and propagate along the axial direction of steel pipes. When the wave reaches to defect or pipe end, it will reflect and received by receiving sensors. The tested signal from the steel pipe include the pipe end and defect echo is shown in Fig. 2.

Guided wave signal processing Based on msp: The signal include the defect echo (within the dashed frame in Fig. 2) is processed by MSP based on MDEA and the processed result is plotted as Fig. 3. The same signal is processed by MP with DEA to validate the performance of MSP. The processed result is shown in Fig. 4. As shown in Fig. 3 and 4, most of the noises are eliminated and the defect signal can be recognized easily. The parameters from the matched signals by MSP and MP are shown in Table 1.

The error of the center frequency of the processed signal from MSP and MP are 1.56, 13.17 and 1.70, 10.89%, respectively. The location of the defects can be computed by the time delay from Table 1. The center time of the excitation is ι_0 = 0.45ms. The propagation time of the defect echo from the left pipe end is

Table 1: The parameters from MSP and MP

Iteration method	1 MSP	1 MP	2 MSP	2 MP
f_c (Hz)	19688.000	19661.000	22635.000	22178.000
τ (ms)	2.428	2.428	1.800	1.794
S	16.500	18.500	15.500	14.100
c	941.100	1240.600	9642.100	7747.700
φ (rad)	-1.179	1.970	1.249	-2.671
a ($\times 10^{-3}$)	-1.470	33.150	4.800	10.650

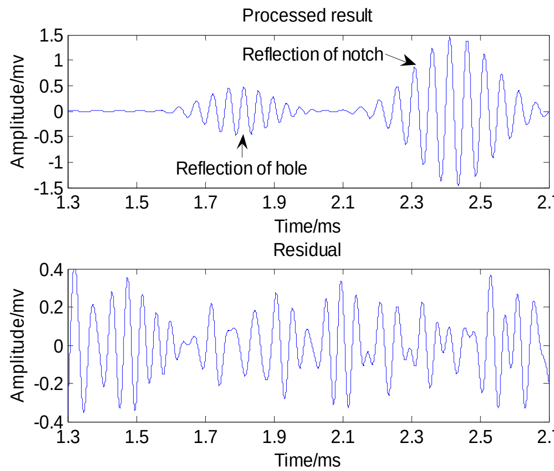

Fig. 3: The match result from MSP based on MDEA

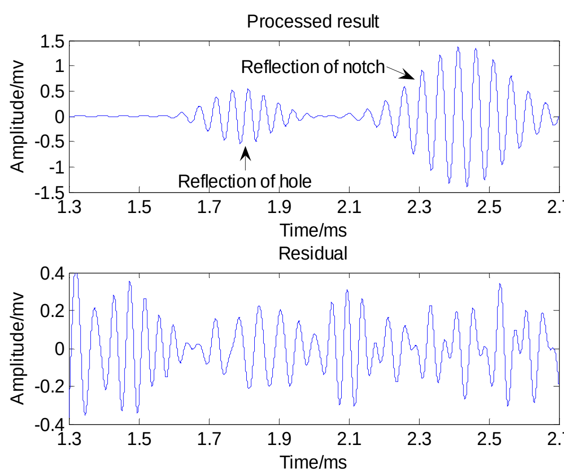

Fig. 4: The match result from MP based on DEA

$\iota_i - t_0$. The velocity of the guided wave is υ = 5100m/s. The distance of the defects from the left pipe end are computed as S_i ($\iota_i = t_0$) x υ/2 and their value are 3.4425 m and 5.0439 m, respectively. They are the defect reflection of hole and notch location of 3.5 and 5.0 m from the left pipe end, respectively. The error ratio of the defect locations are 1.64 and 0.88%, respectively. The same calculations are done on the result from MP and the distance of the defects and the pipe end are 3.4272 and 5.0439 m, respectively. The error of the defects location are 2.08 and 0.88%, respectively.

MSP and MP need two iterations to decompose and reconstruct the signal. The computation time for MSP is 11.172254s and MP is 11.491388s. The computation time by MSP is a little shorter than by MP and its defect location is more exactly than by MP.

CONCLUSION

The proposed modified subspace pursuit is numerical implementated by MDEA to reduce the complexity of subspace pursuit. The proposed method is applied to decompose defect steel pipe guided wave inspection signal. The processed result is compared to the processed result from MP with DEA. The defect locations of the processed signal from MSP are more exactly than from MP with DEA through comparing the parameters of the matched signals. The computation time by MSP is a little shorter than by MP. Therefore, MSP is a kind of useful signal recognition and defect location approach for pipes guided wave NDT.

ACKNOWLEDGMENT

The author thanks for the project supported by the China Postdoctoral Science Fundation (No. 20110491881).

REFERENCES

Fogel, L.J., A.J. Owens and M.J. Walsh, 1966. Artificial Intelligence through Simulated Evolution. Wiley, McGraw-Hill, pp: 170.

He, F., Y. Gao, Z. Zhou and J. Bai, 2006. An overview of testing application of wavelet in guided waves. 12th A-PCNDT 2006-Asia-Pacific Conference on NDT, 5th-10th Nov 2006, Auckland, New Zealand, pp: 1-6.

Holland, J.H., 1975. Adaptation in Natural and Artificial System. University of Michigan Press, Ann Arbor, MI.

Kwun, H., J.J. Hanley and A.E. Holt, 2000. Detection of corrosion in steel pipe using the magnetostrictive sensor technique. SPIE, 2459: 140-148.

Lyutak, I., 2005. Wavelet analysis of ultrasonic guided waves in pipeline inspection. IEEE Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, IDAACS 2005, 5-7 Sept., Dept. of Software of Comput.-based Syst., Ivano-Frankivsk Nat. Tech. Univ. of Oil and Gas, Ivano-Frankivsk, pp: 517-522.

Mingguang Liu., 2005. Differential evolution algorithm and improve-ment. Syst. Eng., 23(2): 108-110.
Rose, J.L., J.J. Ditri, A. Pilarski, K. Rajana and F. Carr, 1994. A guided wave inspection techniques for nuclear stream generator tubing. NDT E Int., 27(6): 307-310.
Stum, R. and Price K., 1995. Differential evolution-A simple and efficient adaptive scheme for global optimization over continuous spaces. Technical Report TR-95-012, ICSI.
Wang, Y., Y. Kang and X. Wu, 2004. A technique of nondestructive inspection of steel pipes based on magnetostrictive effect. J. Vib. Meas. Diagnosis, 24(3): 210-213.
Xia Huiming and Zhou Yongquan, 2009. Improved differential evolution strategy optimization algorithm for multiple hump functions. Comput. Eng. Appl., 45(32): 41-44.
Xu, K., D. Ta and W. Wang, 2010. Time frequency analysis of the ultrasonic guided waves in the long bone. Chin. J. Biomed. Eng., 29(1): 66-70.
Yoon, Y.K., I.P. Chan, H.C. Seung and S.W. Han, 2005. Torsional wave experiments with a new magnetostrictive transducer configuration. Acoustical Soc. Am., 117(6): 3459-3468.
Yuemin Wang, Yihua Kang and Xinjun Wu., 2004. A technique of nondestructive inspection of steel pipes based on magnetostrictive effect. J. Vib. Meas. Diagnosis, 24(3): 210-213.
Zhang, W., Z. Wang and H. Ma, 2009. Correlation analysis of ultrasonic guided wave in damaged pipe. J. Jinan U., 30(3): 269-272.