Development and Research of Active Vibration Control Simulation Software Based on Filter X-Lms Algorithm

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Abstract

Vibration is one of the most common phenomena during the operation of mechanical equipment. However, strong vibration not only does not benefit mechanical equipment, but also reduces the service life of mechanical equipment, and even causes equipment damage. Therefore, measures must be taken to control the vibration phenomenon, so as to eliminate or reduce the adverse effects of vibration on the mechanical equipment. For this purpose, this paper analyzed the LMS adaptive filtering algorithm to improve the standard LMS adaptive filtering algorithm, then used the improved filter x-LMS algorithm for system identification, and designed the active vibration control simulation software based on filter x-LMS algorithm through on-line identification and offline identification methods for error paths. On this basis, the interface of the simulation software was developed and the simulation experiment was carried out to verify the active vibration control of the software. The simulation experiment result shows that the MATLAB software platform can be used in the software application from the control algorithm development to the software design. The software can realize the visualization of human-computer interface simulation and the execution effect is satisfactory. In addition, good active vibration control effect can be achieved.

Keywords: X-LMS Algorithm, Active Vibration Control, Simulation Software, Software Development.

1. INTRODUCTION

1.1 Research overview

At present, people are trying hard to find the approach and method that can effectively solve the problem of mechanical vibration. With the rapid development of technology, vibration control theory is gradually becoming mature, which has been applied in practical engineering. For the definition of vibration control, some scholars think that vibration control covers broader areas, which is a prevalent engineering problem. Vibration control refers to the use of corresponding means or measures to make the action of structure or mechanical equipment under dynamic load within a specific limit to meet engineering requirements (Zhao et al., 2017). Vibration control is characterized by its ability to adapt to different configurations of mechanical equipment, and its different control mechanisms. In general, the classification of vibration control is mainly based on active control of vibration and passive control of vibration. The passive control of vibration refers to a kind of control method without external source of energy. It has the characteristics of simple technique, stable performance, and good economy. However, this control method has weak control effect on low-frequency vibration, which is difficult to achieve the desired control effect. This makes it more and more difficult to meet people's structural and mechanical vibration requirements (Ni and Yang, 2017). The active control of vibration can meet the control requirements of low-frequency vibration, making it become a complementary method for passive control of vibration due to its strong adaptability. The classification of active control of vibration is mainly based on closed-loop vibration and open-loop vibration. Open-loop control of vibration means the controller is driven by control algorithm to control vibration of actual object, without consideration of vibration state of the object, therefore it also is called as program control. The so-called closed-loop control of vibration means the control was conducted when vibration state of control object is regarded as a controller feedback information, which makes it effectively meet the engineering requirements in the vibration response, thus having wide applications (Zhou, 2017).

1.2 Research purpose

This paper aims to design an active vibration control simulation software based on filter x-LMS algorithm to eliminate the adverse effects of vibration on the mechanical equipment and structure and to meet the actual
engineering requirements. To this end, this paper completed the following tasks, first of all, LMS adaptive filtering algorithm was analyzed to clarify the classification and convergence characteristics of LMS algorithm, and standard LMS adaptive filtering algorithm was improved accordingly for system identification; Second, the improved x-LMS algorithm was analyzed and error path on-line identification and offline identification methods were applied to achieve the software's active control of vibration. Third, using the MATLAB / GUIDE tool, GUI layout and programming of the algorithm were conducted through on-line identification and off-line identification methods for error paths. On this basis, the interface was developed. Finally, the single-layer vibration isolation test bench was taken as the actual control object of the algorithm to conduct the simulation test of the control effect of the active vibration control simulation software based on the filter x-LMS algorithm.

2. LMS ADAPTIVE FILTERING ALGORITHM

2.1 LMS adaptive filtering algorithm

In recent years, a great deal of researches on the LMS algorithm have been carried out, which would become an important research topic for a long time to come. The weight vector of the LMS algorithm was updated by the order of the sampling points, and its expression formula was \( V(m + 1) = V(m) - \mu V(m) \) among it, \( V(m) \) was weight value generated when sampling point m was added; \( V(m) \) was the gradient vector when sampling point m was added; \( \mu \) represented the convergence speed and stability of the algorithm, which was also called the convergence factor (Zhang et al., 2017). Through the formula of Widros-Hoff's LMS algorithm of \( V(m + 1) = V(m) + 2\mu(\mu(m))\delta(m) \) when the weight vector was updated, it was found that weight vector of LMS algorithm was only the estimated value as known signal statistics were replaced by instantaneous estimation in the formula. However, the subsequent adjustment of weight vector would make the estimated value increased slowly, thus making the filter more and more adaptable to the signal characteristics. Therefore, the weight-value convergence was realized. The expression formula of its convergence condition was \( 0 < \mu < \frac{1}{\lambda_{\text{max}}} \), among it, \( \lambda_{\text{max}} \) was the maximum eigenvalue for input data variance matrix, which made the algorithm difficult to reach Wiener solution in theory. However, it would fluctuate around the Wiener solution.

2.2 Improved LMS adaptive filtering algorithm

Many improvements have been made to the algorithm by analyzing the standard LMS adaptive filtering algorithm. Common LMS adaptive filtering algorithms included normalized LMS algorithm, leaky LMS algorithm, symbolic LMS algorithm, block LMS algorithm and variable step-size LMS algorithm, etc. The update formula of weight vector for normalized LMS algorithm was \( V(m + 1) = V(m) + \frac{\mu}{\gamma + ||X(m)||} X(m)e(m) \). This algorithm was improved based on the principle of minimum interference of filter, which could effectively overcome the shortcoming of larger gradient noise of standard LMS algorithm. The expression formula of leaky LMS algorithm was \( V(m + 1) = u V(m) + \mu e(m) X(m) \), among it, \( u \) represented the leakage factor, which could effectively avoid the non-convergence problem of the standard LMS algorithm. The disadvantage of this algorithm was that the performance of the adaptive filter would be slightly reduced (Wu and Liu, 2017). The definition formula of symbolic LMS algorithm was \( \varepsilon = ||e(m)|| \) the simplified version of standard LMS algorithm, which could effectively reduce the number of multiplication of the algorithm, so that the wideband processing of the algorithm could be extended correspondingly, but its disadvantage was that the convergence speed was relatively slow. The expression formula of variable step-size LMS algorithm was \( V(m + 1) = V(m) + \mu(m) e(m) X(m) \) when weight vector was iterated. The algorithm had rapid convergence speed and small steady-state error, which made it suitable for the transverse filter. In addition, it had wide applications. In order to eliminate the effect of error path on the standard LMS algorithm that caused the deviation of negative gradient of performance function in the application, mathematical modeling was placed in front of the filter weight coefficient, thus creating filter x-LMS algorithm. The date formula of filter x-LMS algorithm was \( V(m + 1) = W(n) + 2\mu X(m)e(m) \).

3. DEVELOPMENT AND RESEARCH OF ACTIVE VIBRATION CONTROL SIMULATION SOFTWARE BASED ON FILTER X-LMS ALGORITHM

3.1 Simulation software interface development based on x-LMS adaptive filtering algorithm

The simulation software interface development based on x-LMS adaptive filtering algorithm was conducted mainly through MATLAB GUI development tool. The simulation interface was divided into six parts, namely...
The introduction interface of simulation platform was a brief description of the software. The unknown system interface and input signal settings interface provided the corresponding unknown system and input signal data for the simulation function of the software. The other three interfaces were part of algorithm analysis and identification simulation analysis interface. Among the six interfaces, the system identification simulation interface could obtain the error signal, expected signal and output signal of the algorithm after data processing. The six interfaces adopted tab-style, with tabs corresponding to simulation interfaces. Its parameter settings were arranged from left to right. The functions of the simulation software mainly included input signal identification, algorithm simulation identification, unknown system model settings, algorithm characteristic comparison, graphs saving and recognition result analysis (Zhang et al., 2016).

### 3.2 Simulation platform for off-line identification of error paths

In the simulation platform development for off-line identification of error paths, seven sub-interfaces were mainly developed. The seven sub-interfaces were introduction interface of simulation platform, input signal setting interface, primary channel setting interface, error path setting interface, identification signal setting interface, offline identification simulation interface and active control simulation interface respectively. The seven sub-interfaces had their corresponding tabs. Through the development of these interfaces, relevant input reference signal of active vibration control could be set through the software, and corresponding primary response channel was generated according to the input signal. The error path was then built according to the instrument and the actual wiring, and then offline identification estimation for the error path was conducted. The main parameters were set to achieve the control simulation of vibration (Lu, 2016). Figure 2 was schematic diagram of simulation platform structure for off-line identification of error paths.

As can be seen in Figure 2, except for the active control simulation interface, the other interfaces development was basically the same as those proposed above. In the input signal setting interface, relevant input reference signal for the active vibration control was set. The signal was also regarded as sinusoidal signal, which had periodic characteristics. The error path setting interface, primary channel setting interface and the above unknown system settings interface were used to build the system model (Zhao et al., 2016). The offline identification simulation interface and identification signal setting interface simplified the function of system identification simulation software based on the above filter x-LMS algorithm. By using these two interfaces, the software realized the offline identification function of the error path and obtained error path model.
3.3 Simulation platform for online identification of error paths

In the simulation platform development for on-line identification of error paths, six sub-interfaces were mainly developed, of which error path setting interface, input signal setting interface, identification signal setting interface, simulation platform simplified interface and primary channel setting interface were all universal interfaces. The development of superimposed noise technology interface was mainly presented. In the error paths, superimposed noise was generated at the filter controller output. On-line identification of error paths were conducted either by reduction of the power of superimposed noise or consideration of controller output as an input reference signal in the identification process. The latter identification method would not make superimposed noise uninhibited in the on-line identification process, but it would have a great impact on the software's vibration control effect and algorithm's convergence. At this stage, the feasibility of these two methods remained to be further verified. In this paper, an active vibration control when the system is online was implemented by building a way for on-line identification of error paths for superimposed noise at the system output. First of all, four basic parameters of the system were set, and superimposed noise interface was used to simulate the active vibration control. It might also be noted that when the signal was set, data length of the identification signal and the input signal were ensured to be identical, namely, the simulation time was kept consistent with the sampling frequency so that the software can be successfully simulated (Zhang et al., 2015).

4. THE EXPERIMENTAL TEST OF VIBRATION ACTIVE CONTROL SIMULATION SOFTWARE BASED ON FILTERED X-LMS ALGORITHM

In order to verify the effect of developed vibration active control based on filtered x-LMS algorithm, this paper takes vibration isolation test bed with single layer as the actual control object to test the effectiveness and correctness of x-LMS algorithm.

4.1 Brief introduction to test bed

Test bed is established in software Pro/E, which is a kind of three-dimensional entity model. There are four vibration isolators installed in test bed. Two rectangular platforms are arranged above the test bed. One of them is equipped with vibration source in which eccentric mass block is set. This vibration source is three phase asynchronous motor, with the rotational speed of 1370 revolutions per minute and the frequency between 30Hz to 70Hz. The test bed is provided with photo sensor as well. It can detect reflective sheeting in motor shaft. Also, four actuators are arranged within the test bed and each actuator has a built-in acceleration transducer. In addition, the power amplifier is also installed in the test bed (Gao and Liu, 2015). This test system is composed of two parts vibration signal analysis and vibration signal measurement. The vibration signal is analyzed with the help of PULSE data acquisition system, while the vibration signal is measured with the help of acceleration transducer. Two aspects will be measured with regard to vibration signal measurement. One is the measurement for response signal of test bed. The other is the measurement for rotational speed signal of three phase asynchronous motor.
This test system mainly includes controller, signal amplifier, acceleration transducer, PULSE data acquisition system, photo sensor and high/low passes filter, etc. and the collected signals are taken as the input parameters of controller and PULSE system (Guo et al., 2014).

4.2 The experiment of error channel identification effect

In the experiment of error channel identification effect, four error channels to be identified will be constructed. The output in two ways will be executed by signal generator for white noise signal and the power amplifier will be taken as actuator, then the signal is input to trigger the test bed. The response signal of test bed will be collected by acceleration sensor of actuator and then, as the expected signal of software x-LMS algorithm, input into controller by applying charge amplifier. The input signal of the other way is treated as reference signal of such algorithm. The expected signal and reference signal will be converted by controller and processed by x-LMS algorithm. Then, the identification for mathematical model of this error channel will be carried out (Deng, 2014). This test process performs the visual observation towards error signal and change of weight through software Lion Debugger 6.1. When the observed weight waveform is stable and the error signal can fluctuate within the specified range, the test is over. And the record of fluctuations concerned with weight and error signal will be given.

4.3 The vibration active control effect of off-line error channel identification

The experimental result shows that, based on filtered x-LMS algorithm, vibration active control simulation software is with high accuracy when carrying out off-line error channel identification. The system stability is strong. These further prove the validity and rationality of control algorithm of software design. As to the effect of vibration active control, the effect of vibration active control in signal channel single frequency excitation is the best. And a certain effect is also achieved in vibration active control of four channels single frequency excitation. This is because that, when the active controls for four channels vibration are performed at the same time, it will be affected by the active control force generated among four channels so that the phenomenon of vibration coupling comes into being in the process of vibration active control, while there is no vibration coupling occurred in single frequency excitation. Thus, the effect of vibration active control is better (Meng et al., 2014). Therefore, when in vibration active control, double frequency sinusoidal signal or multiple signal frequency as excitation should be selected as far as possible to achieve the optimal vibration active control effect.

5. CONCLUSION

To sum up, this paper carries out analysis and simulation research for LMS algorithm and vibration active control algorithm, designs a kind of simulation software for vibration active control based on filtered x-LMS algorithm and executes the experimental test with regard to error channel identification effect and vibration active control effect of this software. The experimental result shows that this software can achieve good identification and vibration active control effect for vibration phenomena in mechanical equipment, effectively eliminate or lessen the adverse effect of mechanical equipment brought by vibration and reach the desired control effect.

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