Design and Development of Ultrasonic Testing Virtual Instrument

Zhihong FENG, Changyun MIAO, Hua BAI, Yanli YANG

Tianjin Polytechnic University, Tianjin 300387, China. Email: fengzh@163.com

Abstract

The optimization problem of ultrasonic testing instrument is studied in this paper. Using ultrasonic nondestructive testing technology to detect quality of products or parts, because the function of conventional ultrasonic testing instruments is custom-built and defined by manufacturers, it is very difficult to meet ever-changing testing requirements such as testing accuracy, testing efficiency and testing automation. In order to meet different testing needs in practical ultrasonic testing, an ultrasonic testing virtual instrument system is designed and developed by combining ultrasonic testing technology with virtual instrument technology, the system hardware is designed by combining FPGA with ARM, data is transmitted via Ethernet, echo signal noise is processed by using wavelet analysis, the system software is mainly developed by LabVIEW. The experimental results show that ultrasonic echo data can be collected, processed, analyzed and displayed by this system and be transmitted via Ethernet, this system is characterized by simple operation, flexible expansion, versatility and high performance.

Keywords: Virtual Instrument, Ultrasonic Wave, Testing System, Data Collection, Modular

1. Introduction

The quality of products and parts needs to be tested in industry, military, aviation and other fields to ensure product quality, reduce economic loss and casualties, such as detection of bridge structure components, steel plates and forgings of military weapons or nuclear power station. Currently, nondestructive testing methods mostly used are ultrasonic testing, radiation testing, magnetic particle testing, penetration testing, etc. Radiation testing has strong radiation to humans and environment, and testing accuracy is low; Magnetic particle testing is mainly used for testing surface defect and near-surface defect, can not effectively detect internal defects, and need to de gauss after tested working parts is tested; Penetration testing can only detect surface defects, efficiency is low; however ultrasonic testing is one of the most commonly used nondestructive testing techniques because of its strong energy, good direction, no harm to human and some other advantages [1].

Traditional instrument provides only limited functions to users by the front panel because its software and measurement circuits are packed together. However, virtual instrument provides all software and hardware equipments that measure and control needs to users, its function can be defined completely by users, so it has traditional instrument incomparable advantages, such as flexible use, rich function, cheap price, repeatable development and so on [2], virtual instrument is widely used in aerospace, fault diagnosis, power engineering, test and measurement and some other fields [3] [4].

In order to improve the quality of construction and products, inspection requirement is higher and higher. At home, present nondestructive testing mostly uses traditional instrument, it is hard for traditional instrument to meet the testing requirements when testing task changes, and to buy new instrument is expensive, so it is necessary to develop a set of ultrasonic testing virtual instrument system. In this paper the ultrasonic testing system hardware is designed by combining ultrasonic testing technology with virtual instrument technology, the system software based on virtual instrument is mainly designed and developed by LabVIEW8.5 [5]. This system communicates via Ethernet, the ultrasonic detector can transmit ultrasonic echo data to PC in time for processing and displaying, PC can also control detector in time, the volume of whole circuit is reduced in this design, and it is easy to realize the automation of testing process, this system can be developed repeatedly to meet different testing requirements, it is of great significance for improving the efficiency and precision of defects testing [6].

879
2. System principle

System uses ultrasonic pulse reflection method to test defect, its basic principle is shown in figure 1, ultrasonic probe produces high frequency pulse ultrasonic under the excitation of negative high voltage pulse, and then ultrasonic wave gets into the internal of tested working parts through coupling medium. Ultrasonic wave will reflect when meeting the interface consisted of different acoustic impedance medium. Therefore, if the internal of tested working parts has no defects ultrasonic will reflect when arriving at the bottom, waveform display window exists only initial wave and bottom wave, as shown in figure 1(a); if the internal has defects there will appear defects wave between initial wave and bottom wave, as shown in figure 1(b). Therefore, when testing working parts whether there is a defect or not in the internal can be determined and the defect can be located and recognized by analyzing collected ultrasonic echo data.

![Detection principle diagram of defective working parts](image1)

(a) Detection principle diagram of defective working parts

![Detection principle diagram of faultless working parts](image2)

(b) Detection principle diagram of faultless working parts

Figure 1. Detection principle diagram of ultrasonic pulse reflective method

System working principle is shown in figure 2. The system is started, the first is to set relevant parameters according to testing requirements, then principal computer transmits controlling signal via Ethernet, the detector starts to work, ultrasonic probes launch ultrasonic signal to tested working parts at the same time receive ultrasonic echo signal, then echo signal is transmitted to principal computer for processing and displaying after being preprocessed by detector.

![Block diagram of system working principle](image3)

Figure 2. Block diagram of system working principle

Ultrasonic virtual instrument testing system is consisted of hardware system and software system. Hardware is the material foundation of acquiring ultrasonic echo data, software is the soul and the concrete manifestation of superior points.

3. Structure of ultrasonic virtual instrument testing system

3.1. Structure and function of hardware system

In this paper, using Ethernet to communicate which can realize the interconnection of detector and principal computer, the detector can transmit data in real time to principal computer to process and display, the principal computer can also control and switch detector in real time, the ultrasonic detector’s Ethernet ability can reduce volume of the whole equipment circuit to the greatest extent and can reduce power consumption, so detector can be conveniently installed on motion control equipment and testing process can be automated easily, at the same time, Ethernet communication is characterized...
by high speed, reliability and low cost which can structure well ultrasonic testing system and complete online processing and display in real time.

Ultrasonic testing system hardware is mainly consisted of probes, analog circuit, digital circuit, power supply circuit and principal computer [7], system composition block diagram is shown in figure 3. In the design, FPGA system is mounted to ARM bus as peripheral unit, the ARM processor reads directly ultrasonic echo data in FPGA and packs them, and then transmits them to principal computer via Ethernet in order to realize communicating with principal computer.

![Hardware block diagram of ultrasonic testing system](image)

Ultrasonic probe can produce ultrasonic signal into tested working parts under the stimulus of drive signal, and at the same time, ultrasonic probe can convert ultrasonic echo signal into electrical signal for being received by receiving circuit.

Analog circuit mainly includes ultrasonic transmitting circuit, isolation limiter circuit, pre-amplification circuit, controllable gain amplification circuit and band-pass filter circuit. Analog circuit mainly produces ultrasonic signal, receives echo signal, and then regulates it by isolation circuit, amplification circuit and filter circuit into electrical signal suitable for A/D collection circuit to receive, wherein, ultrasonic transmitting circuit mainly drives ultrasonic probe, ultrasonic probe will produce ultrasonic signal when it is inspired by electrical signal; isolation limiter circuit mainly isolates and limits amplitude of high voltage and low voltage; pre-amplification circuit mainly amplifies preliminary ultrasonic echo; controllable gain amplification circuit mainly amplifies once again magnified ultrasonic echo according to actual demand; band-pass filter circuit mainly filters noise wave which gets into equipment in the testing process by hardware circuit.

Digital circuit mainly includes FPGA+ARM master control circuit, A/D collection circuit, D/A conversion circuit and Ethernet interface circuit, it makes full use of advantages of ARM in control and advantages of FPGA in high-speed sampling logic control; A/D collection circuit collects analog signal under the timing control of FPGA; D/A conversion circuit controls controllable gain amplification circuit in order to choose different magnification. Analog circuit mainly collects, processes, and transmits ultrasonic signal.

Power supply circuit is mainly composed of a DC-DC high voltage module and switch power supply circuit and supplies power to the whole circuit. DC-DC high voltage module supplies high voltage DC to emission circuit, linear power supply circuit provides ±5V, ±3.3V, ±2.5V, ±1.2V voltage to the whole instrument.

3.2. System software layer classification

Specifically, ultrasonic testing system software can be divided into two parts: data collection and data procession. Data collection is to set up data collection and some relevant hardware in
corresponding drive program and to make them to work according to setting parameters. Data processing, that is to transmit collected data to computer for operating and processing, includes filtering, storing data, reading data, displaying waveform, analyzing and processing data(such as Fourier transform, spectral density calculation, etc.), in LabVIEW these functions have integrated function modules, namely VI, as long as to set correctly output parameters and input parameters of each VI.

The ultrasonic testing system software based on LabVIEW is mainly divided into three layers as shown in figure 4. The top layer is main VI, namely the program interface VI (called interface layer or interactive layer), it is responsible for implementing program interface, interacting with users, and calling next layer of VI. The next layer is the function layer, namely sub-VI, it is mainly responsible for collecting data, analyzing and processing data, displaying data, storing data, printing data and other functions, and it can be called by main VI. The bottom is drive layer, each program function can complete more meticulous and general functions by calling different drive, such as data collection device driver, file read/write driver and graphic display driver, etc.

![Software layer classification of ultrasonic testing system based on LabVIEW](image)

**Figure 4.** Software layer classification of ultrasonic testing system based on LabVIEW

4. System simulation

4.1. Driver layer

Collecting data has various hardware equipments, including various board-type equipment, traditional instrument and embedded intelligent equipment, etc. These device drivers are not the same, but function and use method is generally similar, that is to open or initialize equipments through the interface VI provided by calling driver, and then to set up equipments and to read data from them, finally, to close equipments [8].

The NI Company’s hardware equipments are generally equipped with LabVIEW driver, other company’s many hardware equipments are also equipped with LabVIEW driver, however some hardware equipments are not provided with LabVIEW driver, but these hardware equipments are generally equipped with DLL form of C language driver.

If driver is not provided to hardware equipments, it has to be wrote by oneself, when writing a driver the first is to design its structure (contain what VI, each VI function and its realization). In LabVIEW there are three methods to drive DAQ device [9]: reading and writing port directly (I/O mode); calling C language source code (CIN mode); calling dynamic link library (CLF mode). On the one hand the CIN mode can greatly improve the accuracy of data collection, on the other hand, some signal processing algorithms that are not provided in LabVIEW or are difficult to realize can be added easily into drivers, but programming is relatively complicated, and programs can be not directly modified in LabVIEW, and this method can not display data in time when collecting data, data can be displayed together only after all data are collected, therefore, this method is not suitable for real-time occasion. Data can be collected and displayed at the same time in I/O mode or CLF mode, but their weakness is that collected waveform is easily anamorphic when the input signal frequency is higher.

4.2. Function layer and main module

This system uses modular method to design software, namely dividing module by function, according to the system structure and function the program is divided into several layers in longitude and is designed from overall to detail, each module is independent, so it is easy to maintain system and expand function. System function layer is divided into the following several modules: data collection
module, data management module, data processing module, result judge module, main control module may call each module. The specific structure is shown in figure 5.

![Diagram](image)

**Figure 5.** Software structure of ultrasonic testing system

### 4.2.1. Data collection module

After being started, according to detection requirement this system drives each device and then sets parameters including channel selection, gain, alarm mode, sampling frequency and sampling depth and other parameters, and then this system starts to work. Parameters settings interface is shown in figure 6.

![Parameter settings interface](image)

**Figure 6.** Parameter settings interface

### 4.2.2. Data management module

Ultrasonic echo data are stored in temporary open array after being collected, due to the limitation of array space and the passage of sampling time, new data will overwrite old data. The system opens up a file to save collected historical data and processed data. Data can be stored to a text file or an Excel file in user’s chosen path. Data playback is the reverse process of data storage process. Data storage can broadcast data and analyze data again off-line, and data playback provides important basis to user for analyzing off-line. Printing report, which is convenient for finding later, can transform some testing information such as shape and size of tested working parts, testing date, testing result into report form.

### 4.2.3. Data processing module

Ultrasonic echo signal often has different levels of noise signal, especially when testing some small defects, echo signal energy is very small, it is often easy to be flooded in noise signal so that it can easily cause mistaken judge or leakage judge, in order to improve the accuracy and reliability of ultrasonic testing, this design uses the wavelet multi-resolution decomposition method to reduce ultrasonic echo signal noise [10], this method can reduce effectively noise, and at the same time retain defects feature information maximum [11] [12].

The process of noise reduction based on wavelet transform is generally divided into four steps:

1. Choosing appropriate basic wavelet function.
2. Determining the wavelet decomposition layers and decomposing signal by wavelet.
Choosing appropriate threshold value and processing threshold value of every layer of detail information.

Reconstructing low frequency information and detail information after being decomposed by wavelet in order to get processed signal.

Using Matlab to transform wavelet for reducing noise in ultrasonic echo signal, the processing result is shown in figure 7.

![Echo signal with noise](image1)

![Using db3 wavelet, three layers decomposition](image2)

![Using db2 wavelet, three layers decomposition](image3)

![Using db4 wavelet, three layers decomposition](image4)

**Figure 7.** Processing result of using dbN wavelet and three layers decomposition

In addition, signal display can be converted from time domain to frequency domain by discrete Fourier transform (DFT) in order to understand the signal frequency component and the intensity size of each component, at the same time some signal characteristics, which provides basis for testing result, can be extracted respectively from time domain and frequency domain. In order to calculate quickly the design uses FFT VI in LabVIEW [13].

### 4.2.4. Result judge module

Processed signal need being analyzed and recognized, such as whether a defect is existing or not, its position, size and type. The result decision basis can be extracted only from time domain signal or frequency domain signal, also can be extracted from time domain and frequency domain at the same time [14], after extracted characteristics are selected, in LabVIEW to design neural network pattern recognition program [15]. At present, BP algorithm is used most of the artificial neural network in nondestructive testing, the BP neural network is a typical multiple feedback neural network, the network structure is simple, easy to learn, and has been applied in many fields, the BP network structure in this paper is composed of three layers: (1) the input layer, corresponding characteristics of defect information; (2) the hidden layer, which is used to deal with data; (3) the output layer, corresponding to various types of defects. Each layer is composed of many neurons with the ability of nonlinear mapping, each neuron among layers is connected by weight coefficient, and there is no connection between neurons in each layer. Relevant information on behalf of transform relationship between input and output is mainly distributed in the connection weight coefficient between neurons. The network connection weights can be continuously adjusted through training and learning, until the error between actual network output and expected network output reaches required accuracy grade, the connection weight between neurons will no longer changes, at this moment, the network learned and trained has the ability of automatically recognizing signal characteristics. In practical application, as long as we input the feature vector, which reflects defect information, to the trained network, the type of defect can be judged form the network output.
4.3. Experimental results and analysis

Main VI interface of system is shown in figure 8. Users may call different sub-VI through interface VI (main VI) according to their own requirements. After system is started, the first is to initialize system and to set relevant parameters, then to click the start button, and the system starts to collect ultrasonic echo data of every channel and display them in corresponding window, figure 8 is waveform of scanning different parts of one steel plate through four channels. Main channel, which displays waveform in big window, can observe waveform details and data (current channel, gain, gate position, gate width, and so on), other channels, which display waveform thumbnails, can observe waveform profile and alarm, main channel can be switched at any time by clicking the waveform thumbnails. In this experiment, defect echo data within gate width in channel 1 and channel 3 surpass given gate height, light in channel 1 and channel 3 turns light and defect alarms that explains there are defects at tested current position in channel 1 and channel 3. The experiment results indicate that this system is able to collect, process, and analyze data from multi-channel, and experiment results are satisfactory. In addition, when detection requirement changes it is also very convenient to modify or expand system.

Figure 8. Main interface of ultrasonic testing system

5. Conclusion

Ultrasonic nondestructive testing technology has a wide range of applications in aerospace, fault diagnosis, test and measurement, and some other fields, but traditional ultrasonic testing instrument has finite function, it is very difficult to meet practical detection requirements in performance, in this paper, an ultrasonic testing virtual instrument is constructed by combining ultrasonic testing technology with virtual instrument technology. First of all, system hardware platform is constructed by using FPGA and ARM as main control circuit, this system hardware can collect ultrasonic echo data and transmit them through Ethernet, and the system software is developed with LabVIEW as main development platform. This system software can process, analyze and display collected data. Simulation results show that this system can display ultrasonic testing data in time, store data and playback data, analyze waveform data and decide testing results, and alarm when there is a defect in tested working parts, this system can meet different needs in actual testing, it is of great significance for improving defect recognition technology and reliability, precision, efficiency, performance of ultrasonic testing instrument and the automation of detection process.
6. References


