Research Article

Design of MultiChannel Parallel Dynamic Testing Virtual Instrument Based on Dynamic Measurement

Dawei Shen , Dongxing Pei, and Tiehua Ma

State Key Laboratory of Dynamic Measurement Technology North University of China, Taiyuan, Shanxi 030051, China

Correspondence should be addressed to Dawei Shen; shendawei@nuc.edu.cn

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With the rapid advancement of virtual instrument technology, converting the data measurement and control platform to a virtual one has become fashionable. This study focuses on dynamic measurement in order to create a multichannel parallel dynamic testing virtual instrument and then test the instrument's performance. System login, user management, database storage, query and compression, data processing and real-time display, multifunctional analysis, remote access, and report generation modules have all been designed and implemented. A dynamic measurement uncertainty evaluation method based on quasi-Monte Carlo (MC) method is proposed in light of the common phenomenon that static is used instead of dynamic in the current evaluation process of dynamic measurement uncertainty. For this example, the actual results show that the algorithm produces very reliable and stable calculation results.

1. Introduction

With the rapid development of science and technology, the dynamic performance test of large-scale complex structures in operation shows a far-reaching application prospect and will have a significant impact on the development of national economy [1, 2]. In China's national defense, communication, aviation, meteorology, and other fields, the amount of information required for measurement, control, and processing is increasing and the speed is getting faster and faster. At the same time, the tasks of measurement and control are becoming more and more complex, huge, and scattered, so the requirements of field, remote and network measurement, and control are put forward [3]. The traditional stand-alone instrument cannot meet the requirements of large quantity and high-quality information collection, so a computer-controlled measurement and control system are produced to transmit information.

Traditional data acquisition equipment has limited functions, high upgrade and maintenance costs, complicated connection lines, and other drawbacks that make it impossible to meet today's data acquisition and processing needs. More and more users are eager to build a data

acquisition and processing system on the virtual instrument platform in order to solve this set of problems [4, 5]. The dynamic measurement method is used to monitor the machine's parameter change during operation, and signal analysis and processing technology is used to extract the characteristic information of the system parameter change from the vibration and noise in order to judge the nature of dynamic data, monitor, predict, and diagnose the working process and the state of the system in order to achieve the goal of preventing failure [6]. Due to the inevitable existence of random errors or thousands of noises in the test process, the dynamic measurement data are also random like the constant static test data. It can be seen that another basic feature of the dynamic measurement data is that it contains both deterministic change parts and random change parts, that is, it is always a random function of the test time, that is, a random process that can be simply called randomness [7]. Virtual instrument is a hot spot in the field of measurement and control at present, and it represents the development direction of instrument technology in the future, therefore, through the use of virtual instrument technology and the purchase of necessary data acquisition hardware to build their own virtual instrument system. This can not only meet

the actual test function, but also save a lot of manpower and financial resources, and also ensure the accuracy and reliability [8].

Modern dynamic measurement technology [9, 10] is a technical discipline that studies dynamic signal acquisition, transformation, transmission, and real-time processing using modern science and technology. It is used to test systems and processes and combines modern sensor technology, microelectronics technology, computer technology, signal analysis and processing technology, and other technical disciplines. Dynamic measuring instruments have been in development for a long time. The development of dynamic measuring instruments has been revolutionized by the introduction of virtual instruments. Virtual dynamic measuring instruments are rapidly developing due to their high-cost performance, high reliability, and flexibility of dynamic addition of functions. This study's main goal is to design a multichannel parallel dynamic test virtual instrument based on dynamic measurements.

2. Related Work

Literature [11] puts forward the concept of personal instrument, which is the inevitable result of the increasing requirements of the test system for intelligent instrument and the increasing proportion of microcomputer software and data storage capacity in the instrument. In literature [12], a second-line comprehensive tester for an aviation radio station is developed, which integrates eight instruments into a virtual instrument system and is convenient to use. In literature [13], the automobile engine detection system based on virtual instrument technology is used for the factory detection of automobile engines. In literature [14], according to the idea of modular programming, the software architecture of the acquisition system is divided into main program layer, logic layer, and driver layer from top to bottom. Literature [15] realizes multichannel data collection, analysis, and storage, so the optimization of programs and the running efficiency are very important. Literature [16] divides the data acquisition system into system login and user management module, real-time display module, data storage module, etc. When a certain function needs to be realized, it is only necessary to call the corresponding sub-VI in the main function main-VI. Literature [17] puts data or messages into a queue, and the following cycle refers to the consumer, who is responsible for taking out the data or messages in the queue one by one, making corresponding response processing, and the producer and the consumer use the queue to communicate [18]. The measurement of the measured signal is completed. The output forms of the test results are also varied, either indicated by an indicator or recorded by a recorder, or transmitted to a data processor for further processing operation or spectrum analysis, so as to turn them into input signals needed by subsequent equipment, and finally be displayed or printed or plotted.

Despite the lack of a unified definition for dynamic measurement, the measurement system must be in motion throughout the measurement process to be consistent. There

are various external disturbances in the process of dynamic measurement, so it is a Gaussian or nonGaussian process, which is always a random function of time. Furthermore, the measured object could be a random function. The measurement system obtains several random sequences or random processes when sampling the measured object. As a result, dynamic measurement is unpredictable. The fitting analysis method of a dynamic measurement system is thoroughly examined in literature [19]. To estimate and evaluate dynamic measurement results, literature [20] uses "static instead of dynamic" or random process characteristic parameters, which is contrary to the scientific uncertainty principle. A new method based on nonstatistical theory was introduced in literature [21]. When there is no definite functional relationship or distribution law between the target and each factor, for example, using fuzzy mathematics theory to find the best measurement scheme can produce better results. In literature [22], the training model of a neural network is used to estimate the indirect measurement quantity and evaluate the uncertainty in the complex indirect measurement model, and so on. Literature [23] examines and studies the system's reliability, identifies flaws in the current measurement system's reliability analysis, and proposes a scheme and measures for improvement. The limitations of classical error theory were highlighted. This study examines the flaws and flaws in the current measurement system's reliability analysis.

3. Research Method

3.1. Design of Parallel Dynamic Testing Virtual Instrument. Compared with traditional instruments, virtual instruments are characterized by breaking the concept of "all-purpose" function of traditional instruments, and centralizing the analysis, display, storage, printing, and other management of signals to the computer for processing. The virtual instrument can achieve the multipurpose effect of one machine, because it is extremely convenient to set up the measurement function, short in technical update cycle and short in system establishment time. At the same time, because the measurement is completely digitized, the influence of environmental interference and system error is reduced, thus saving hardware links and reducing the development cost and maintenance cost of the test system, and so it is economical and practical.

Oscilloscopes, logic analyzers, spectrometers, signal generators, and other common instruments have powerful functions that can be realized using a virtual instrument. It can also detect parameters of specific systems, such as automobile engine parameters, furnace temperature, blood pulse wave, ECG parameters [24], and other data, using special probes and software. It can be used for military equipment testing and fault diagnosis, as well as aerospace engineering education [25]. Virtual instruments are also widely used in the fields of automatic control and industrial control. The majority of closed-loop control systems necessitate precise sampling, timely data processing, and quick data transmission. The virtual instrument system satisfies all of the above criteria and is ideal for measurement and

control integration design. The Internet has ushered in a new era of data sharing, hastening the development of new network technology and virtual instrument remote computing, both of which are impossible for traditional independent instruments. You can use virtual instrument technology to use the Internet's powerful functions to control instruments and equipment remotely, or collaborate with colleagues in other offices or even other countries to complete a project.

As shown in Figure 1, the hardware system of the data acquisition system in this study mainly consists of the following five parts: device manager, data acquisition part, communication interface part, human-computer interaction, and operation auxiliary module part [10].

The device manager uses the MSP430F5438 MCU of TI, which is mainly responsible for analyzing the commands of the upper computer, triggering four acquisition modules to collect data, and finally packaging and transmitting the collected data to the upper computer.

The key circuit module and LED indicator module are the main components of the man-machine interaction section. The key circuit module is used to start each device of the lower computer, while the LED indicator lamp is used to display the lower computer's power supply and working state. The power supply module and JTAG circuit module make up the majority of the operation auxiliary module. The power supply module provides power to the entire hardware system, while the JTAG circuit module is used to download the program to each MCU and debug the system remotely.

Software design is the key to virtual instrument. In order to realize the scalability and maintainability of the test system software, it is necessary to carefully design the structure of the software in the design stage of the system software. The system software is designed by modular method, which can be roughly divided into the following modules: data acquisition module, data analysis module, data access module, data output module, etc., as shown in Figure 2.

In the system, the definitions of each code module and the interfaces between them are standardized, so that the extensibility change in one module will not affect other modules in the program, thus increasing the flexibility of the system. During the test process, users can change the signal parameters and test methods at any time as needed.

Parallel dynamic test virtual instrument software has the following functions:

- (1) By controlling the hardware system through parameter setting, multichannel parallel data acquisition can be realized, which can not only acquire data without trigger, but also acquire data with trigger (single channel).
- (2) Multichannel real-time acquisition, analysis, and display.
- (3) Data analysis function (time waveform diagram, frequency response function, coherence function, self-power spectrum, cross power spectrum, FFT (fast Fourier transform) analysis, etc.).

FIGURE 1: Hardware block diagram.

FIGURE 2: System structure diagram.

- (4) Window selection function: Hanning window, Hamming window, flat window, etc.
- (5) Function: linear average, exponential average, etc.

The soft panel window's composition or layout has a significant impact on its usability as well as its aesthetic appearance. The placement of controls and the design's simplicity are all factors in composition [17]. The instrument's main panel design has the ability to conduct multichannel testing and display graphics synchronously, which is one of its main features. In trigger acquisition mode, the system has the ability to set data acquisition parameters and trigger parameters. At the same time, four-channel tests can be run and graphic analysis can be used to display the results. You can choose between single-channel, double-channel, four-channel, and eight-channel test graphic display modes by selecting the display mode on the panel. The system program flow chart is shown in Figure 3.

TCP/IP is used to communicate between the acquisition and preprocessing module, transmission control module (and multiscreen display), and echo analysis module in remote mode. The application layer has the following two channels: a data channel for sending high-speed real-time acquisition data and a command channel for sending control

FIGURE 3: System program operation flow chart.

commands. Data transmission and command processing are provided by the acquisition system that also listens for and processes two types of requests. The system uses a multithread software processing mode, which creates a background thread in the program to handle sampling while the foreground thread takes care of other tasks like display and storage. The collection thread function is prioritized, the background collection thread is in interrupt mode, and the shared buffer is enabled. The shared buffer synchronization problem between the sampling thread and other threads is solved by the event synchronization thread.

3.2. Error Traceability of the Actual Dynamic Measurement System. Dynamic of measurement system (refers to the relationship between time-varying input and output during dynamic measurement of measurement system) is the ability of measurement system to accurately measure rapidly changing physical quantities. When the input changes, the output of the measurement system is jointly influenced by the research object and the dynamics of the measurement system, which can be expressed by parametric models such as differential equations, transfer functions, and nonparametric functions such as impulse response, step response, and frequency characteristics.

Whether it is static or dynamic measurement, the measurement data may contain some incorrect measurements, which are referred to as outliers, due to the measuring

equipment, data transmission, or manual operation. As a result, outliers in the measured data must be carefully examined and eliminated. The correct diagnosis of faults and statistical analysis of the real dynamic characteristics of the system will be greatly influenced if the outliers cannot be correctly eliminated and replaced. One of the most pressing problems in engineering applications is determining how to effectively identify and eliminate outliers in dynamic measured data.

The signal generating link of this system consists of the main shaft and the eccentric wheel. Driven by the spindle motor, it rotates at a uniform speed, and the spindle drives the eccentric wheel connected with it to rotate the wheel together. Let the angular velocity of spindle rotation be, then the rotation rule of eccentric wheel is as follows:

$$x_0(t) = e \cos \omega t. \quad (1)$$

When the eccentric wheel rotates, it pushes the probe of the inductive displacement sensor in contact with it, so that the measuring rod moves in the magnetic cylinder of the coil. This signal sensing link can be regarded as a cam mechanism of an eccentric wheel with a pointed follower. When the eccentric wheel rotates with the main shaft, the displacement $x(t)$ of the measuring rod in contact with it is as follows:

$$x(t) = R(\cos \alpha - 1) - e(\cos \phi - 1), \quad (2)$$

where R is the radius of eccentric wheel, $x(t)$ is the displacement of the measuring rod, e is eccentricity, ϕ is the angle of eccentric wheel, ω is the angular velocity of eccentric wheel, and α is the pressure angle of the follower.

The reliability and value characteristics of a measurement system should be equally important, but current measurement system analysis frequently reveals the phenomenon that the weight value characteristics overshadow the reliability. This method is unscientific and unreasonable, as it ignores the impact of reliability on system quality assessment. The international general index to evaluate the value accuracy and reliability of a measurement system whose main function is to transmit value is measurement uncertainty, according to the analysis of measurement system value characteristics.

Usually, when evaluating the uncertainty of measurement results, it is necessary to give the specific functional relationship between the measured value and each input value, especially (in the general form)

$$Y = f(X_1, X_2, \dots, X_n). \quad (3)$$

Among them, the measured Y is also called output, and the input X_i is called influence. Establishing a mathematical model is actually a process of correctly seeking the functional relationship between each input quantity and its output quantity.

If a series of observation values $x_1, x_2, \dots, x_n$ are obtained by independent measurement with equal precision for n times, the arithmetic average $\bar{x}$ of the observation data is usually taken as the best estimate of the measured value as follows:

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i. \quad (4)$$

If the estimated value to be measured is taken from relevant data, and the given measurement uncertainty $U(x)$ is k times of the standard deviation, the standard uncertainty is as follows:

$$u(x) = \frac{U(x)}{k}. \quad (5)$$

Uncertainty is a metric that expresses the precision of a measurement. When the characteristics of a measurement system change over time, the measurement system's uncertainty changes and drifts with the passage of time. The theory and method of data processing are gradually developing to a high level, and the theory of dynamic measurement uncertainty has become the focus of current discussion and research, thanks to the continuous emergence of modernization, automation, and high-precision measurement technology. In general, there are some very complicated phenomena that do not conform to statistical laws in the process of dynamic measurement and testing, and dealing with them using current statistical methods is very difficult. This chapter's proposed method for evaluating uncertainty in dynamic measurement focuses on improving the random number generation method. The probability distribution of random variables is obtained using the quasi-MC method according to the characteristics of dynamic measurement data, based on the theory of random processes and the application of the MC (Monte Carlo) method to evaluate measurement uncertainty.

Quasi-MC method is to replace random sample points in MC sampling with selected deterministic sample points, in which deterministic sample points are obtained by some transformation from a low-deviation sequence that fills the sampling space more uniformly than pseudo-random numbers. As shown below, the calculation error of quasi-MC method in this study can be expressed by Koksma-Hlawka inequality as follows:

$$\left| \frac{1}{N} \sum_{i=1}^N f(x_i) - \int_{I^d} f(u) du \right| \leq V(f) D_N^*(x_1, x_2, \dots, x_N), \quad (6)$$

where the random sequence $x_1, x_2, \dots, x_N \in I^d$, I^d represents the d -dimensional space $[0, 1]^d$, d is the dimension of the sequence elements, N is the number of the sequence elements, $V(f)$ is the bounded variation function of function f in Hardy-Krause sense and in space I^d , and $D_N^*(x_1, x_2, \dots, x_N)$ is the star deviation.

With the continuous passage and continuation of the system measurement time, the dynamic measurement system will continuously obtain new measurement data. Let the measurement sequence at m moment m be as follows:

$$\begin{aligned} x_{1m} &= \{x_{1m}(1), x_{1m}(2), \dots, x_{1m}(n)\} \\ &= \{x_1(m+1), x_1(m+2), \dots, x_1(m+n)\}. \end{aligned} \quad (7)$$

Similarly, the probability density function $f_{1m}(x)$ of the output sequence x_{1m} at this moment is determined by calculation.

This evaluation method of uncertainty can continuously introduce new data and remove old data, and keep track of the change rule of uncertainty in dynamic measurement, so as to realize the evaluation of uncertainty in dynamic measurement system.

4. Results Analysis and Discussion

Generally, the life cycle of measurement system can be divided into the following three stages: running-in period, stable period, and failure period. The reliability of the measurement system and the uncertainty of measurement always show the opposite changing trend in the whole life cycle, and the relationship between them also strongly shows that it is scientific and reasonable to evaluate the reliability of the measurement system with the uncertainty of measurement.

Dynamic measurement has dynamic characteristics such as correlation and randomness, and will be influenced by random factors in the process of analyzing and evaluating the reliability of the measurement system. Therefore, the reliability of the dynamic measurement system is also dynamic, and it is a random variable with certain uncertainty.

In order to study the traceability of system measurement error, the spindle is driven by the motor at a speed of 200 rpm, and the signal of one period is intercepted. The numerical results are shown in Figure 4.

In the whole measurement process, there are many factors that affect the measurement results and cause measurement uncertainty. Measurement elements, such as measurement object, measurement equipment, measurement environment, and measurement method or principle, will have different influences on the measurement results in the measurement process.

All the factors that have a significant impact on the measurement results are the sources of measurement uncertainty. Before evaluating the measurement uncertainty, the sources of measurement uncertainty should be analyzed. Figure 5 shows the comparison result of the synthetic curve of error and traceability result.

The object to be measured, measurement conditions, measurement personnel, measurement standards or standard parts, measurement equipment, measurement methods, and so on are all examples of sources of measurement uncertainty. Furthermore, for those systematic errors that have been identified, they must be corrected, and the corrected values are uncertain. If the uncertainty of the correction value has little impact on the composite standard's uncertainty, the uncertainty of the correction value can be ignored. The correction value may not be added to the measurement result if the correction value is extremely small.

Repeated experiments on the pressure sensing system were carried out in order to trace the system's error and diagnose the subsequent accuracy loss.

The handwheel of the piston pressure gauge was continuously shaken (including the progress and return strokes) to simulate the working state of the pressure gauge under test by providing it with a constantly changing pressure across

FIGURE 4: Output signal and standard signal when the speed is 200 rpm.

FIGURE 5: Comparison with the synthetic curve of error tracing results.

the entire range. The data of five groups of process measurement errors and four groups of return measurement errors are shown in Figures 6 and 7 respectively.

As can be seen from Figure 7, with the increase of measurement times, the measurement error of pressure gauge increases correspondingly, and it follows a certain rule.

The actual measurement system will not only be influenced by external factors throughout the measurement process, but the internal structure of the measurement system will also change. The system's stability, repeatability, and reproducibility will evolve over time. In particular, compared to the initial measurement period, the estimated value of the measurement result drifts away from the measured true value, resulting in the gap between the estimated value of the measurement result and the true value gradually increasing. As a result, as measurement time goes on, the accuracy and reliability of the entire measurement system will deteriorate, eventually leading to the difference between the measured result and the measured true value exceeding the system's allowable range, and the measured data losing its research value.

FIGURE 6: Five groups of measurement process error curves.

FIGURE 7: Four groups of measurement return error curves.

The dynamic uncertainty of the measurement data is calculated under the same measurement conditions, using the sampled original output pulse number of 30 times inertial gyro as an example, and the MC method is compared to the quasi-MC method.

In this experiment, the influence of environment, noise, and internal factors of the system on the generation of measurement results will not be considered for the time being, so as to highlight the different effects of the pseudo-MC method and the MC method for the evaluation of uncertainty in dynamic measurement after the change of random number generation method. Figure 8 shows the simulation results of different sample sizes.

Note: M in Figure 8 represents the sample size, sMC represents the standard uncertainty calculated by the MC method, $sQMC$ represents the standard uncertainty calculated by the quasi-MC method, mMC represents the

FIGURE 8: Simulation results of different sample sizes.

measurement result calculated by the MC method, and mQMC represents the quasi-MC method calculated measurement result.

Although the uncertainty of dynamic measurement is different from that of static measurement, the theory and method of static measurement uncertainty can be reasonably used for reference and extended to the study of dynamic measurement uncertainty. This will not only greatly improve the comparability and transferability of dynamic measurement results, but also accelerate the research process of dynamic measurement uncertainty, so that it can quickly rise to a higher and newer research level and be applied to practice as soon as possible.

Depending on the situation, different mathematical models are established by different measurement systems. When we have a thorough understanding of the measurement principle, we should first derive a preliminary mathematical model theoretically based on the measurement principle, and then thoroughly analyze the measurement system, adding one by one the missing inputs that have a significant impact on measurement uncertainty, and perfecting the mathematical model that was initially established. The mathematical model created in this manner is referred to as a “black box” model because it excludes the influence of the input quantity on the measurement result and the relationship between the input quantity and the measured quantity is unclear, resulting in low measurement result uncertainty evaluation reliability.

Figure 9 shows the measurement results and corresponding uncertainty calculated by traditional MC method and this method. Figure 10 shows the measurement results and corresponding uncertainty calculated by the traditional MC method and this method for the next repeated measurement at the same sample capacity.

It can be seen from the data in Figure 10 that the accuracy of dynamic measurement uncertainty evaluated by this method is better than that of MC method. By analyzing the data in Figure 10 and comparing the standard deviation of the evaluation results of traditional MC method and this method, it is obvious that the stability of this method is better than that of traditional MC method.

FIGURE 9: Dynamic measurement results and standard uncertainty obtained by different methods.

FIGURE 10: Measurement results and standard uncertainty obtained by eight simulations with the same sample size.

Under the influence of self or external factors, there will always be measurement errors in the whole measurement process, and some measurement errors obviously deviate from the measurement results. Therefore, it is necessary to preprocess the measurement data before calculating the measurement uncertainty. According to the theoretical method of measurement error analysis and processing, the data are processed to eliminate gross errors and reduce systematic errors, so as to improve the reliability of measurement results.

For this kind of data, the reason must be analyzed and checked for its appearance as much as possible, so as to have a more sufficient basis for choosing data. But sometimes the reason is not found. At this time, it cannot be easily kept or discarded at will, but outliers should be identified. If the measured value, which is not an abnormal value, is

subjectively discarded, the measurement accuracy will be improved on the surface, but in fact it is a false result. Therefore, exploring practical solutions is of great practical value to the measurement and testing of physical quantities.

If the number of sampling points is long enough, according to the law of large numbers, it can be approximately considered that it obeys the normal distribution, and good outlier elimination effect can be obtained by directly using Leiter criterion. However, for the position measurement data, its change is slow and has obvious trend characteristics. At this time, it is difficult to get ideal results by using Leyte criterion to eliminate outliers. Leiter criterion is aimed at static measurement data values, and its validity needs to be judged by physical prior knowledge, which obviously cannot meet the requirement of automatic elimination of abnormal values in dynamic measurement system.

5. Conclusion

This topic is presented in the context of virtual instrument technology's rapid development and the rapid development of new data analysis and processing technologies. The main goal of this project is to create a multichannel parallel dynamic test virtual instrument based on dynamic measurement, to create a complete dynamic test system by combining dynamic measurement theory, and to collect and analyze signals using this system. The software framework is built according to the requirements, and several functional modules, such as system login and user management, report generation, remote access, and database compression, are realized. Each module's calling interface is designed, and the entire collection system's interface is designed as well. It is decided to use a dynamic measurement uncertainty evaluation method based on the quasi-MC method, which not only reduces the number of sampling points but also has a low uncertainty error, high accuracy, and good stability of evaluation results.

The user switches between the three communication modes in this system manually via the configuration dialog box, and further automatic identification can be accomplished through programming to avoid user error and improve the system's fault tolerance.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

All the authors do not have any possible conflicts of interest.

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