

# Remote collaborative pseudo-dynamic testing system based on acquisition board control<sup>\*</sup>

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Accepted on September 26, 2007

**Abstract** In this paper, NetSLab network platform for remote collaborative pseudo-dynamic testing, which was developed recently by a research group led by the Hunan University, is presented. Aiming at MTS system which is widely used in structural testing, the control method with acquisition board was investigated in this study to realize the communication interface between NetSLab and MTS system, and open up the remote collaborative pseudo-dynamic testing system. Using the developed testing system, a collaborative pseudo-dynamic testing on LAN was carried out successfully. The result manifests that the data transmission and collaborative control can be implemented accurately between NetSLab and MTS system, so that the usability of the testing system is validated.

**Keywords:** remote sharing of testing equipment, network platform, communication interface, acquisition board control, collaborative pseudo-dynamic testing

With the development of Internet technology, various systems for remote communication based on Internet have been developed and applied in research and practices. Telecommunication technology enables structural laboratories distributed geographically in different areas to link together and realize data transmission and remote control, so that more complex models or actual structures can be investigated.

Several attempts have been made to carry out collaborative testing with remotely distributed laboratories. The Network for Earthquake Engineering Simulation (NEES) project<sup>[1]</sup> invests substantial fund and efforts to build an integrated system via high-performance network, called NEESgrid that links earthquake engineering researchers and communities across the whole U.S. with advanced experimental equipments and computing resources. The aim of NEESgrid is to build a collaboratory for earthquake engineering research. Some members of NEESgrid, including the University of Illinois at Urbana-Champaign, the University of Colorado at Boulder and other research communities, collaborated to carry out the Multi-Site Online Simulation Test with large-scale model on July 30, 2003<sup>[2]</sup>. By the collaboration of the University at Buffalo, the University of California at Berkeley, and the University of Colorado at Boulder, etc, fast hybrid simulation with geographically

distributed substructures was carried out in July 2004, which solves the problem of testing velocity in MOST and improves the reliability of the testing results<sup>[3]</sup>. In Taiwan of China, National Center for Research on Earthquake Engineering (NCREE) has established a networked collaboration platform, called ISEE (Internet-based Simulation for Earthquake Engineering), for collaborative networked structural experiments among geographically distributed structural laboratories<sup>[4]</sup>. Using the ISEE environment, a networked pseudo-dynamic testing about a three-story and three-bay reinforced concrete columns and composite steel beams moment frame was performed by the NCREE and the Stanford University in US in October 2004<sup>[5]</sup>. A collaborative hybrid testing of a multi-span bridge was carried out between NCREE, the National Taiwan University and the Carleton University in Canada in February 2006<sup>[6]</sup>.

In mainland China, supported by the National Natural Science Foundation of China, a key project, "collaborative testing method and system for pseudo-dynamic earthquake simulation of modern structure" was established in 2004. The project members include Hunan University, Harbin Institute of Technology and Tsinghua University. One of the major technologies of setting up remote testing system is to develop a network platform that provides a data model

<sup>\*</sup> Supported by National Natural Science Foundation of China (Grant No. 50338020)

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and the communication protocols in order to realize the data transmission and control on the Internet. A network platform for remote pseudo-dynamic testing, called NetSLab (Networked Structural Laboratories)<sup>[7,8]</sup>, has been developed by Hunan University. Another major technology is to realize the communication interface between NetSLab and the testing control system that enables NetSLab to control the testing equipment to carry out physical testing. The communication interface should be accomplished according to the characteristic of different control system respectively. This paper presents in detail the method and the course of operating test system and developing software programming based on acquisition board control. The feasibility of the developed testing system is validated by the results of a collaborative testing on LAN on a cantilever steel beam.

## 1 Network platform

### 1.1 Networked structural laboratories (NetSLab)

NetSLab platform was developed on the concept of the networked structural laboratories that links several remotely located laboratories and computers by Internet<sup>[7,8]</sup>. Such distributed structural testing integrates several single laboratories into one powerful networked testing system, enhancing experimental capability and sharing resources. For some large-scale structural testing with complexity, substructure testing or simulation analysis can be performed respectively in remote laboratories, the whole testing results of which can be integrated by the network platform. Tests that could not be completed in single laboratory will be possible.

The operation of the networked structural laboratories needs a network platform that provides the data model and application protocol of remote testing to realize the data communication and control among remote laboratories. NetSLab is such a platform based on the concept of client/server.

### 2.2 NetSLab application

NetSLab provides a standard ActiveX control (named UPCTrlATX) with powerful function for user to develop application. The control supports any high-level program language with ActiveX control function, such as VB, VC++, etc. In addition, the development of NetSLab is targeted to the flexibility and suitability in various network environments<sup>[8]</sup>.

At present, based on MTS testing system, the project group of Hunan University has developed the NetSLab testing platform for single-degree-of-freedom (SDOF) system under the Visual Basic programming environment. Although NetSLab of current edition aims at SDOF, all programs are targeted to form a standard module in order to expand the platform for multi-degree-of-freedom system conveniently. The whole platform includes four modules as following:

1) Controller: who organizes the whole testing procedure, inputs the structural information and the earthquake acceleration, and combines the feedback information of each tester to perform the time history analysis of structural system, then sends the target displacement to each tester. There should be only one controller in one testing.

2) Actual Tester: who receives the command from controller, carries out physical structural testing, and obtains restoring force and other testing results, then sends the results back to controller.

3) Virtual Tester: who does not connect testing equipment to carry out physical testing, but simulates the characteristic of structural restoring force using computer.

4) Observer: who shares testing results and provides the people to observe the course of testing without any interference of the processing.

## 2 Remote collaborative pseudo-dynamic testing system

This paper aims at developing an actual tester for remote collaborative pseudo-dynamic testing. During the pseudo-dynamic testing using NetSLab, the controller takes charge of the whole process of the testing. The controller program performs the time history analysis of structural system, figures out the displacement of current step, and then sends the target displacement to every tester via NetSLab platform. Every tester operates its own tester program, receives the target displacement, and then sends the displacement command to the control program of the specific testing equipment. The control program of testing equipment mobilizes the actuator to the target displacement, and sends the measured restoring force back to the controller via NetSLab. The controller program then continues to calculate the target displacement of subsequent next step. Such cycle is repeated till the

end of a complete testing.

As mentioned above, the tester program of NetSLab platform that can carry out physical testing is needed to perform two main functions:

- 1) To communicate with the controller program, and to receive displacement command;
- 2) To communicate with the control system of testing equipment, to realize collaborative control to testing equipment and send command to move actuator and receive feedback.

The tester program should be developed on the characteristic of control system of each tester. At present, MTS system is widely used in structural testing of civil engineering. Therefore, the tester program developed on MTS system will have versatility and significance.

## 2.1 MTS system and its interface with NetSLab

MTS system mainly consists of FlexTest GT control system and electro-hydraulic servo actuator. FlexTest GT control system is the product of MTS Corporation in America, which consists of the computer and GT controller box. The series of software named MTS 793.10 should be installed in the computer to control actuator and carry out testing. MTS 793.10 software is the composition of several software packages with powerful function, including the Function Generator Software, the Basic TestWare Software, the Multi-Purpose Testware (MPT) Software and the Station Manager Software<sup>[9, 10]</sup>. As the main control module, the Station Manager Software will send the target command to the actuator and receive the feedback from the actuator via the input/output (I/O) channel of GT controller box during the testing. MTS Corporation provides commercial DLL (Dynamic Link Libraries) that enables users to program conveniently by VC++, VB or other program languages to perform I/O function and control the actuator. But this method has its flaws. Once the testing control system was changed, the program code would lose its function and should be rewritten. Moreover, this DLL only provides the I/O function, but does not prevent the possible damage of excessively large signal to the actuator. The users need program additional code to perform the protection function, which may increase the risk of the testing system to some extent.

GT controller box provides the hardware interface of I/O channel that can connect other hardware devices. Therefore, the control to the I/O channel of GT controller and the control to the actuator can be realized by controlling these hardware devices. Although this method needs an additional computer to program to control these hardware devices, the method makes it flexible and convenient for users to develop testing system or function by using familiar program language. This method can also protect the actuator more efficiently by the "interlock" function in MTS software. The program avoids complex low-layer technology of MTS software and only has relation with hardware, so the method is suitable for any other testing system.

## 2.2 Acquisition board control system

The acquisition board control uses the Analog/Digital (A/D) and Digital/Analog (D/A) acquisition board to joint with the I/O channel of GT controller. The control to the actuator is realized by programming to control the acquisition board. For the hardware, the acquisition board provides easily operational connection method. For the software, the acquisition board can be driven and controlled by the ActiveDAQ method based on the ActiveX technology<sup>[11]</sup>. A good many ActiveX controls can be loaded in high-level program language for application. Because NetSLab program supports the ActiveX, the interface between the ActiveDAQ method and NetSLab program can be implemented easily.

### 2.2.1 Hardware connection between acquisition board and GT controller box

The hardware connection between acquisition board and GT controller box is schematically shown in Fig. 1. In this paper, the PCL-818L and PCL-728 serial acquisition board of the Advantech Corporation are selected respectively as the A/D and D/A acquisition board. The PCL-8115 terminal board is used to connect with A/D acquisition board, which not only makes the connection convenient, but also increases the number of input channels. During the pseudo-dynamic testing, the feedback displacement is received from the LVDT sensor connected with the specimen, the voltage signal of which is collected into A/D acquisition board via the filter. The feedback force is received from the load cell of the actuator, the voltage signal of which is collected into the Analog Input (AI) channel of the GT controller box, and then output via the Analog Output (AO) channel and collected into A/D acquisition

tion board via the filter. The voltage signal of the calculated target displacement is sent out into the AI

channel of the GT controller box, and then output into the drive valve of the actuator via the AO channel.

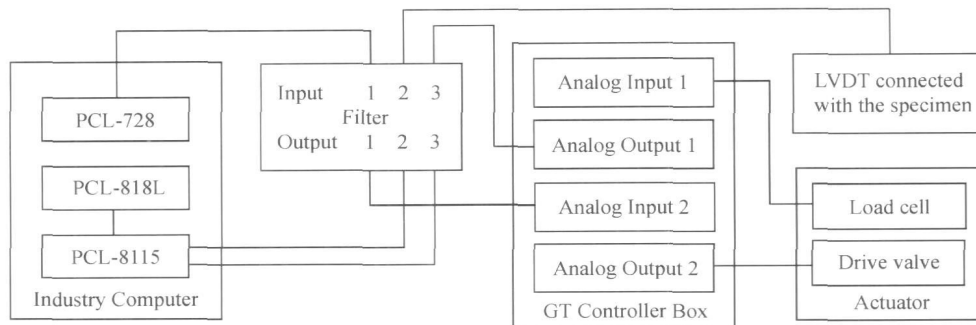


Fig. 1. Connection between acquisition board and GT controller.

**2.2.2 ActiveDAQ control method** The serial acquisition board of the Advantech Corporation provides many ActiveDAQ components driven under the environment of Visual Basic program. These components are the collection of ActiveX controls for performing I/O operations within any compatible ActiveX control container<sup>[1]</sup>, including the DAQAI control, the DAQAO control, the DAQDI control, the DAQDO control, the DAQCounter control and the DAQPulse control used respectively to perform the function of analog input, analog output, digital input, digital output, counter and pulse. The control to the I/O channel of the acquisition board can be realized by the Visual Basic program using the DAQAI control and the DAQAO control. Of course, the device manager software DevMgr.exe, the DLL driver ActiveDAQ.exe and the driver of the acquisition board should be installed in the industry computer. After the components of the Advantech DAQ AI Control and the Advantech DAQ AO Control are added from the toolbar of Visual Basic6.0, the DAQAI control and the DAQAO control can be used to program in application.

### 2.3 Tester program

The interface between the ActiveDAQ program and NetSLab program is implemented under the environment of high-level program language, Visual Basic6.0. Accordingly, the tester program of NetSLab platform and the system for remote pseudo-dynamic testing is implemented.

**2.3.1 Flow chart for remote collaborative pseudo-dynamic testing** The main flow chart for remote collaborative pseudo-dynamic testing is schematically

shown in Fig.2. In tester program, the displacement control method for pseudo-dynamic testing is used to program. The target displacement command is got from the controller program and sent out via the DAQAO control of the acquisition board. At one time, the feedback displacement from LVDT is read in via the DAQAI control. During this course, if the error between the feedback displacement and the target displacement cannot meet the error limitation, the compensation of the error will be sent out continuously via the DAQAO control until the error meets the request. Then the restoring force is read in via the DAQAI control and sent back to the controller program.

**2.3.2 Tester program of NetSLab** The interface between the acquisition board program and NetSLab program can be implemented by inserting both the ActiveDAQ control and the UPCtrlATX control into the tester interface. The tester program mainly includes several parts as follows:

1) The startup process of NetSLab, which activates the communication function of NetSLab and returns the communication condition and information with the controller program.

2) The window of configuring the network parameters, which configures the IP address of the controller, the port number, and the tester name, etc.

3) The window of setting the parameters of the actuator and acquisition board, which sets the error limitation of the actuator, the limitation of the feedback force and displacement, and the calibration coefficient of the acquisition board, etc.

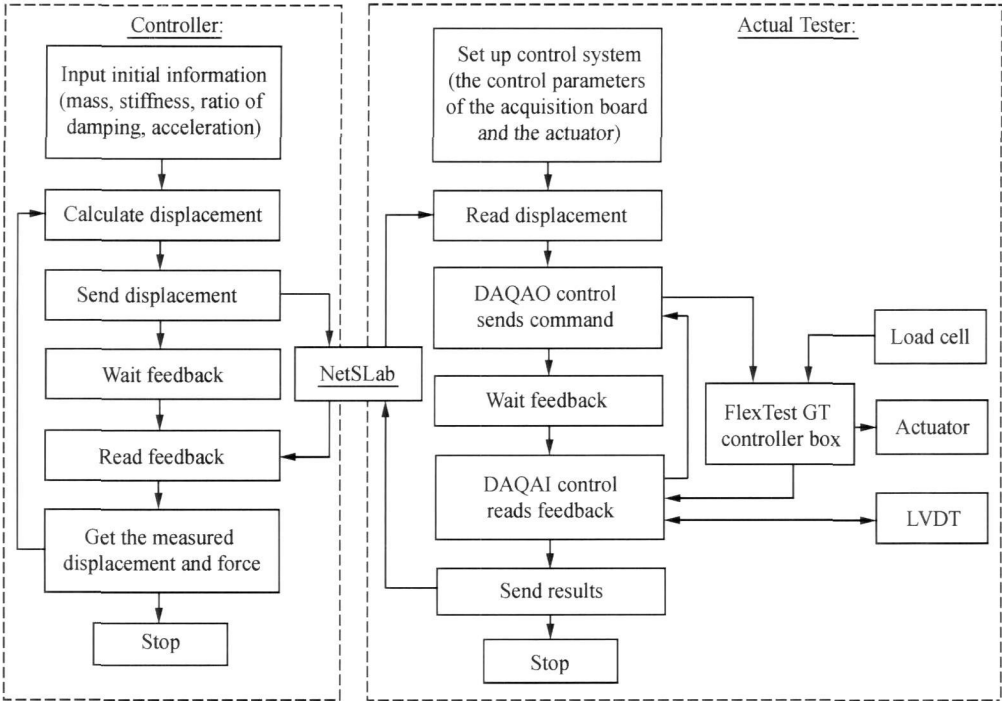


Fig. 2. Flow chart for remote collaborative pseudo-dynamic testing with acquisition board control.

4) The triggering of the function sub-process under UPCtrlATX control and the triggering progress of acquisition board program, which starts the testing process, and performs the main function of the tester program mentioned above.

5) The window of displaying the testing process, which shows the real-time testing information per step, including the time history curve of displacement and the curve of restoring force, etc.

3 Collaborative pseudo-dynamic testing on LAN

Using the integrated testing system, a collaborative pseudo-dynamic testing on LAN was carried out at the Mechanics and Structural Testing Center of the Harbin Institute of Technology in order to prove the performance of the testing system, the communication and the accuracy of the data transmission between the tester program and the controller program, and the condition of the tester program controlling the testing equipment.

3.1 Testing model and testing equipment

The testing model was a cantilever steel beam that can be simplified as a SDOF specimen. As shown in Fig. 3, the testing model was fixed on the foundation. The electro-hydraulic servo actuator was hori-

zontally placed to load force between the top of the steel beam and the strong reaction wall. The top horizontal displacement of the specimen was measured by an LVDT with the range of  $-50$  to  $+50$  mm. The restoring force was measured by the load cell built in the  $-250$  to  $+250$  kN capacity actuator.

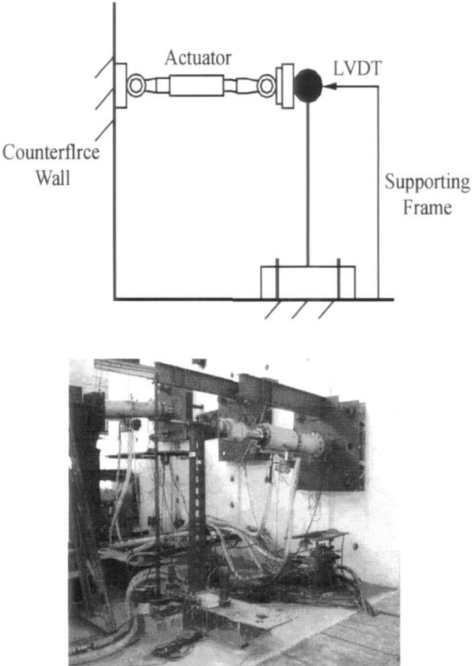


Fig. 3. Testing equipment. (a) Sketch map of testing equipment; (b) equipment picture.

### 3.2 Parameters of testing program

Some testing resource, including the actuator and the I/O channel, should be configured in MTS 793.10 Software. The “External Command” control mode should also be set up using MPT Software. The tester program of NetSLab was running on the industry control computer with acquisition board, and the controller program was running on the other computer on LAN. Some parameters of both programs should be configured before the testing.

#### 3.2.1 Parameters of controller program

1) Model parameters: the stiffness was 350 kN/m, the mass was  $2.21 \times 10^3$  kg, and the damping ratio was 1%. 2) Network parameters: the tester port was “3050”, and the tester name was “TestOne”. 3) As shown in Fig. 4, the earthquake wave was the El-Centro earthquake ground acceleration (NS, 1940) with the peak acceleration of  $3417 \text{ mm} \cdot \text{s}^{-2}$  and the interval of 0.02 s. During the testing, the first 400 steps of the earthquake wave were conducted with the peak acceleration reduced to  $350 \text{ mm} \cdot \text{s}^{-2}$ .

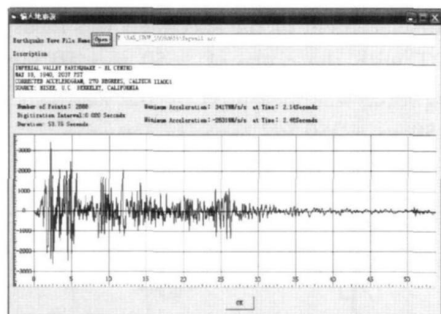


Fig. 4. El-Centro earthquake ground acceleration of the earthquake wave.

#### 3.2.2 Parameters of tester program

1) Actuator parameters: The error limitation should be selected according to the loading capability of the testing equipment and the need of the precision. The 0.5 mm was selected as the minimal error limitation to improve the velocity of the testing and not to consider the precision of the testing excessively. In order to protect the testing model and device, the range of the displacement and the force of the actuator are limited as  $-15$  to  $+15$  mm and  $-20$  to  $+20$  kN respectively. 2) Network parameters: the tester name was “TestOne”, the IP address of the controller on LAN was “210.46.68.189”, the port of the controller was “3051”, and the tester port was “3050”. 3) The calibration coefficient of the sensor: Every 1 V voltage signal input or output by the acquisition board was corresponding with the feedback displacement of 9.6

mm, the feedback force of 25 kN and the target displacement of 25 mm. 4) Delay time: The command will be sent out by the actuator with “Ramp Command”. The interval of the adjacent two commands was 100 ms.

### 3.3 Operation of program

After running the MPT Software, the whole testing process was started by the controller program. During the course of the testing, the whole testing system operated under the stably collaborative condition. The interfaces of the controller program and the tester program showed the real-time testing information per step. As shown in Figs. 5 and 6, the time history curve of displacement and the curve of restoring force in both interfaces are completely the same, which demonstrates that the tester program can realize the control to the MTS system efficiently, connect with the controller program accurately, and achieve its function successfully. In addition, each step cost about 3.5 s. Most of time was spent on the loading of the actuator, because the loading capability of the actuator was limited; on the other hand, the actuator had to compensate the error between the target displacement and the feedback displacement iteratively. The testing successfully validated the usability of the developed testing system.

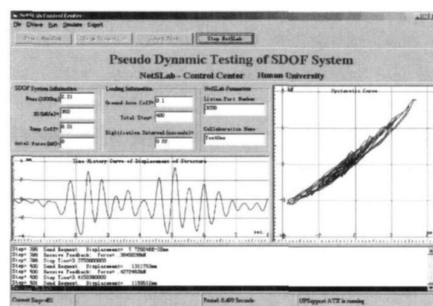


Fig. 5. Interface of controller program.

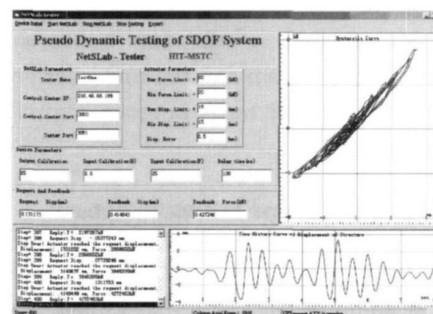


Fig. 6. Interface of tester program.

## 4 Conclusions

NetSLab platform has been utilized for the organization and communication of the remote pseudo-dynamic testing. One of the main issues for remote testing is to carry out the control of NetSLab network platform to the testing equipment. Aiming at the operation of MTS actuator system currently widely used in structural testing, the method of the acquisition board control was used to develop the testing system with the advantage of relatively simple operation and programming. The efficient data transmission and control of the testing system was validated by a collaborative testing on LAN. The results also prove that the developed testing system is adequate for applications across the Internet.

The application of network platform may be limited or affected sometimes by the network environment. The telecommunication capability of NetSLab on China Education and Research Network were validated by actual testing between Hunan University and Harbin Institute of Technology in China. Developing application packages for more complex testing and various purposes is still underway. Although the application of NetSLab breaks through the limitation of firewall on China Education and Research Network, it also brings a good many issues about network technology considered, such as the security and the management.

The collaborators of this key project plan to carry through a hybrid control testing about a multi-span bridge with several single piers. The column model of each pier will be carried out in physical testing or simulation analysis by testers in single distributed laboratories. The result of the whole testing will be integrated by the simulation analysis and testing control program through network platform. There are two key issues that should be considered carefully. One is the integration and coordination of the single testing system through network platform. Specially, the collaborators had better specify an opened standard and versatile interface between network platform and testing control system similar with OpenFresco (Open Framework for Experimental Setup and Control) de-

veloped by the University of California at Berkeley in America, which enables users to connect network platform and testing control system conveniently by applying this interface. Another is the accuracy of hybrid simulation, including the simulation of the boundary condition in the simulation analysis, the realization of the boundary condition on the physical specimen, the coordination between the simulation analysis and physical testing control program, and so on. In this part, advanced special analysis software can be applied, such as OpenSees (Open System for Earthquake Engineering Simulation) developed by the University of California at Berkeley in America. These issues will be solved step by step in the further research.

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