An Internet-based Educational Platform for Earthquake Engineering Laboratory Experiments

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Abstract

Shake table constitutes a versatile tool for educational purposes and small scale research projects in earthquake engineering and structural dynamics. Hands-on activities involving shake tables are effective tools for learning concepts in structural dynamics and earthquake engineering. For nearly ten years the University Consortium of Instructional Shake Tables has worked toward improving educational opportunities related to earthquake engineering. More recently, the suite of educational opportunities has expanded to include the use of teleoperation experiments for education at the undergraduate level. Through a partnership with an NSF-sponsored cyberenvironment project referred to as the Network for Earthquake Engineering Simulation (NEES), we are working to enhance earthquake engineering education around the world. The development of teleoperation and teleparticipation exercises for bench-scale instructional shake tables based around the NEES suite of tools will allow future civil engineers to learn fundamental concepts in structural dynamics.

1. Introduction

In 1999, twenty-three universities affiliated with the three national earthquake centers in the USA (MCEER, PEER and MAE) cooperated in the acquisition of shake table laboratory stations for each of their institutions through NSF support. Thus, the University Consortium on Instructional Shake Tables (UCIST) was founded and a series of hands-on equipment was developed and implemented in the classroom (Dyke et al., 2003).

Since that time, UCIST has expanded to over 100 universities within the US and abroad. Moreover, additional funding has been obtained to further this effort to utilize the latest cyberinfrastructure capabilities developed by the NSF-funded National Network for Earthquake Engineering Simulation (NEES) for expanding these exercises to universities that are not able to acquire shake tables. With this partnership, a recent focus of UCIST is to develop high quality teleparticipation and teleoperation experiments for use in the classroom.

UCIST has been focusing on leveraging the geographically-distributed network of world-class experimental facilities, its connecting cyberinfrastructure, and its extended community of engineering and cross-disciplinary faculty from academic programs across the nation to provide undergraduates with exceptional learning opportunities (Dyke et al., 2007a-d).

Students using the teleoperation tools have indicated that they enjoy using this technology for classroom experiments. One student stated “I liked how we actually ran a real experiment and were able to run it from our dorm rooms even though the shake table was someplace else, and actually view it through live streaming video.” Another student felt “[It] Was very hands on, and many people learn better by doing and seeing than just calculations." This type of feedback has encouraged us to expand the use of these experiments to reach broader audiences and a variety of students.

Two lead institutions and five additional deployment sites are cooperating in these activities. However, national dissemination of the project is our goal, and these initial efforts are expected to lead to the development of a collaboratory in earthquake engineering education. Evaluation of the modules developed is ongoing (Turner et al., 2011). UCIST has endeavored to enhance the education of undergraduates through the procurement of these shake tables, the development of curricula, and the dissemination of these tools to other institutions. Additionally, outreach activities targeting K-12 students and the general public were encouraged, and a wide range of undergraduate research opportunities became available. Execises and documentation are available on the NEEShub (nees.org) in the group space for this project at https://nees.org/groups/benchshaketables.

2. Architecture and Implementation

The essential equipment for learning experiments in earthquake engineering and structural dynamics is the bench-scale earthquake simulator, or shake table. This instrument, based on similar larger scale research facilities, has the capability to reproduce the motion of the ground during an earthquake, allowing for examination of structural behavior and of the performance of both conventional and innovative techniques under controlled conditions.

The bench scale uniaxial shaking table has a 18"x18" plate, which slides on high precision linear bearings and is driven by a Kollmorgan Silverline Model H-344-H-0600 motor fitted with a 1000 LPR IP 40 encoder. The earthquake simulator uses unit gain displacement feedback, and control is achieved using a CompactRIO real-time system made by National Instruments. The Shaker IV interfaces with a PC through the CompactRIO controller using real-time software implemented in LabVIEW. The CompactRIO is a real-time controller from National Instruments (NI, http://www.ni.com/). The CompactRIO is a combination of a real-time controller, Reconfigurable IO Modules (RIO), FPGA Module, with appropriate general data acquisition capabilities and an Ethernet expansion chassis.The system is linked to a PC and shared variables in Labview are used to allow for remote control and teleparticipation. The operational range of the simulator is 0–20 Hz.

Figure 0 Shake Table Experiment.

This shake table is a powerful tool for high fidelity and controllable reproduction of seismic motions. Accelerometers are included for measuring the responses of the structure and NI boards are used for recording the measurements. Data can also be streamed in real time to remote users for viewing and analysis. A prior NSF-funded cooperative project to establish similar shake tables at universities across the country facilitated the dissemination of the proposed project to universities nationwide (Dyke et al., 2003).

NEES cyberinfrastructure tools now make it possible for earthquake engineering researchers to remotely participate and control experiments, facilitating new testing methods such as distributed hybrid testing where various components of a single structural system are tested at geographically distributed sites. Video and data can be transferred in real time to laboratories and users around the country for analysis and simulation. These teleparticipation capabilities are being employed here for educational uses by UCIST through the development of a series of new educational exercises. These exercises will allow a broader set of students and institutions access to use the shake tables for education and training, and will facilitate national dissemination of real-time online laboratory experiments to offer state-of-the-art laboratory experiences previously unavailable to undergraduate students.

Remote operation of the UCIST shake table using the NEES cyberinfrastructure was first accomplished by the authors in December 2004. More recently, an expansion of this effort has been undertaken involving teleparticipation by adding functionality to stream data and video through existing NEES cyberinfrastructure tools (Dyke et al., 2007a-c). The UCIST PC is configured as a TCP/IP server to receive commands. Commands to the shake table originate by the remote user through the graphical user interface running at the client (remote) end. The NEES Real-time Data Viewer (RDV) is then used to view the time synchronized streaming video and data from any PC over the internet.

The components that allow for teleoperation and teleparticipation are illustrated in the diagram shown in Fig. 2, and include:

- A remote PC with internet access provides commands for teleoperations through a front end Graphic User Interface (GUI), which is integrated with the Real-time Data Viewer (RDV) as the Teleoperation Control Panel.
- RDV is a NEES tool that allows viewing of synchronized data and streaming videos. The telepresense of the platform is achieved by RDV.
- The Ring Buffered Network Bus (RBNB) program, running on a Data Turbine PC, buffers and streams data and video to the RDV.
- The main functions of the UCIST PC includes: 1) receiving teleoperation commands from Remote PC by the TCP server; 2) controlling the shake table according to the commands received by the TCP server; The control is achieved by the control server through a compactRIO; 3) streaming DAQ data to the Ring Buffered Network Bus (RBNB) server by the DAQ daemon program;
- An Axis web camera provides streaming video to the RBNB.

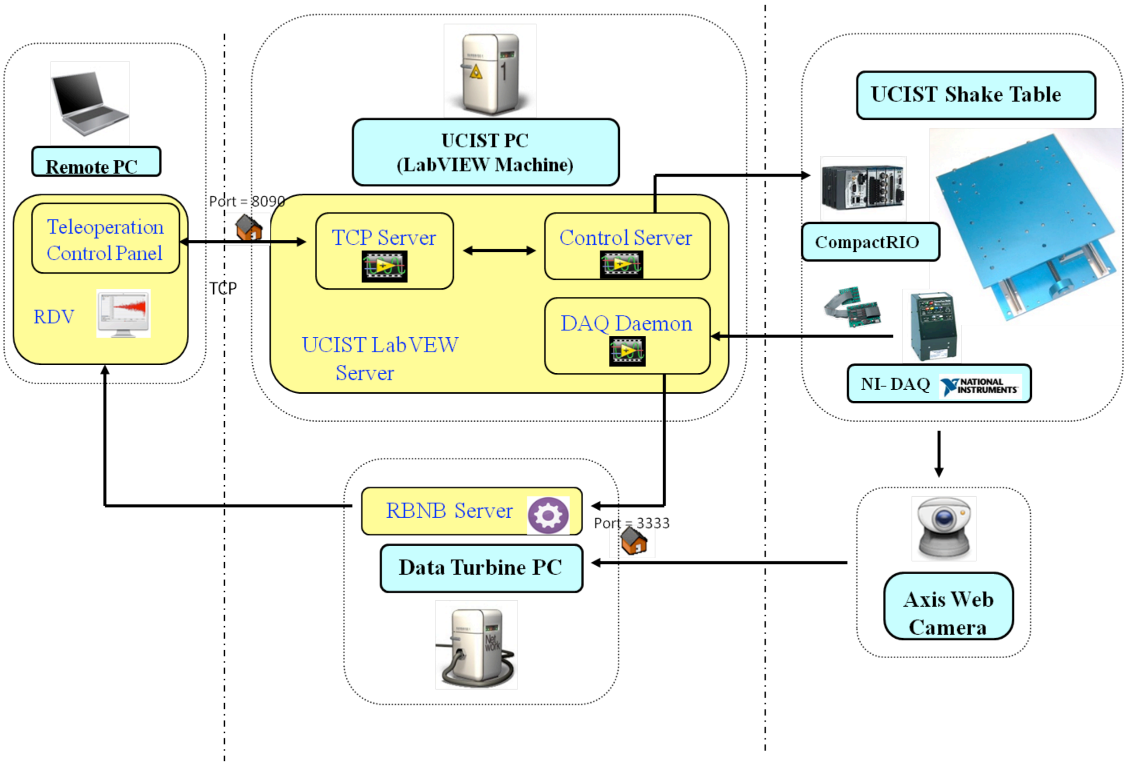

Figure 2 System Architecture.

Two views of the control panel for remote operation are showin in Figure 3. A view of the portal seen by a remote user while streaming data and video from the RBNB using the NEES Real-time Data Viewer (RDV) is shown in Fig. 4. The Teleoperation Control Panel is the Java Applet located in the upper right corner of the RDV, which serves as the GUI of the TCP client. The GUI client provides remote user a direct means to control the experiment by choosing simulation patterns and adjusting the corresponding parameters (eg. frequency and amplitude for sinusoidal pattern). Different simulation patterns are available for various experiments and purposes, including running sine, chirp sine waves, random patterns, and simulation of real earthquakes etc. Fig. 3 shows the Teleoperation Control Panels with two patterns: sinusoidal and chirp sinusoidal.

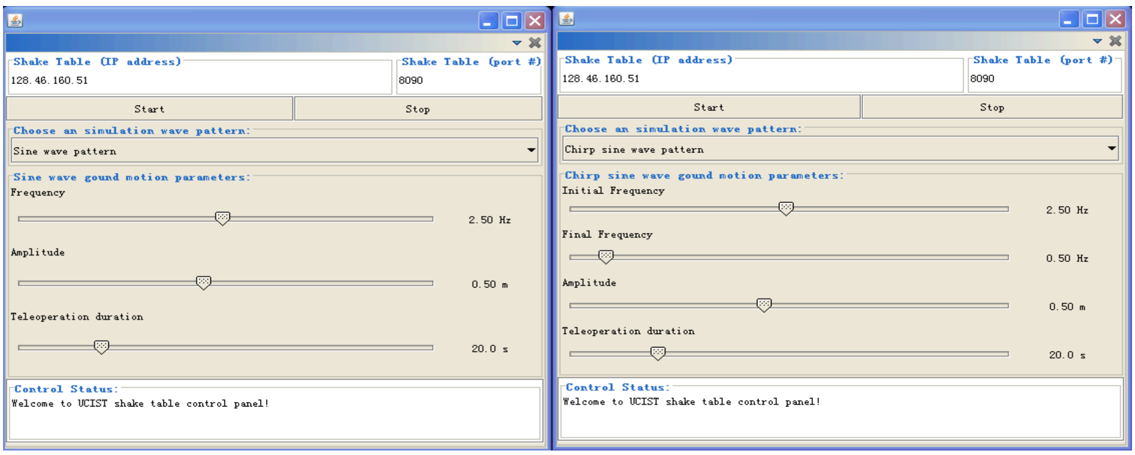

Figure 3 Two Views of Teleoperation Control Panels for Java Plug-in.

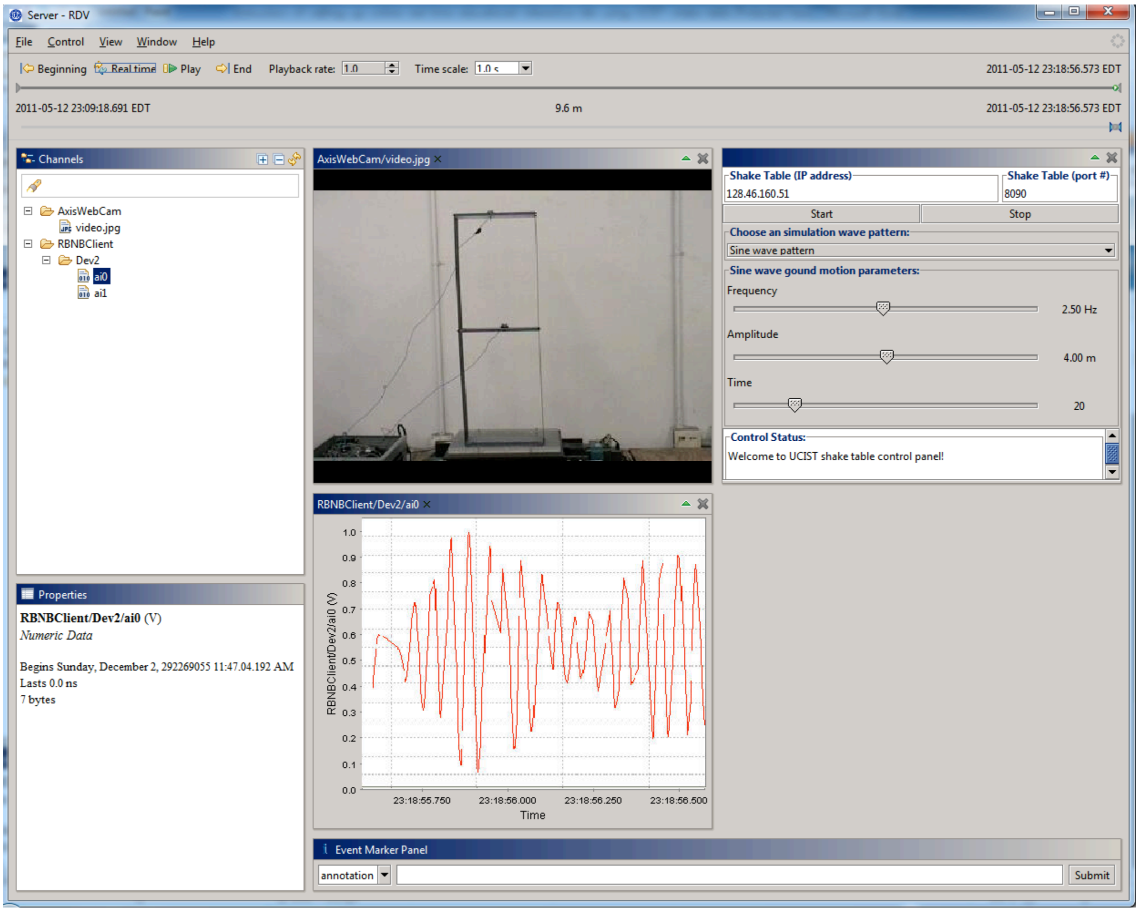

Figure 4 Real-time Data Viewer with Control Panel Integrated at Purdue Deployment Site.

3. Instructional Materials Developed to Date

Several early experiments that use this shake table lab station are available on the NEEShub for downloading and implementation. Experiments consider structural dynamics, soil-structure interaction, bridge design, torsional responses of structures, etc. Most of the modules contain laboratory manuals for instructors and students, drawings for building experimental components, and sample data. These experiments have been used at several institutions across the USA.

Freshman Level Introduction to Earthquake Engineering Module

A freshman level module was developed which consists of a series of eight lectures. Students are introduced to structural engineering topics, mathematical modeling of dynamic behavior, MATLAB simulation tools, and NEES capabilities and research through a series of lectures. Then the students use the teleparticipation tools to conduct an experiment using the shake table. A one-story (single-degree-of-freedom) structure with low inherent damping is used. The students are introduced to structural engineering and vibration concepts as they are asked to model the structure and analytically determine the natural frequency and response at various sinusoidal excitations, through a series of three homework assignments. The module culminates with the students conducting experimental tests online to observe the structure's actual natural frequency and response to various sinusoidal excitations. Students write a report documenting their experiences during the module and performing relevant computations. This experiment has been implemented at the University of Connecticut and Washington University in St. Louis (Dyke et al., 2007b-c).

Senior Level Design Exercises

Two additional exercises have been developed for integration into a senior level structural dynamics and vibrations course. These exercises focus on understanding both time and frequency domain behavior of discrete parameter dynamic systems.

In the first exercise the students use the shake table to experimentally observe transient and forced vibration of a single degree of freedom (SDOF) dynamic system. A SDOF system representing a one story building is used as the test specimen. Accelerometers are placed on the base (shaking table) and on the floor of the building. The input is a sinusioidal excitation, but the frequency and amplitude can be controlled by the user. The students use teleoperation tools developed within this project to remotely control the shake table. Streaming video is available, and the students use RDV to view the data and video in real time. Using the resulting frequency response function the students are also required to compute damping levels. The students also compare a numerical model to the experimental data.

In the second exercise the students have a multi-degree-of-freedom (MDOF) system. Their objective is to design a vibration absorber for a 2 story building model. The vibration absorber consists of a pendulum that can be adjusted to 'tune' it to the natural frequency of the primary system. The mass and length of the pendulum can be varied within a wide range of values (see Figure 5). The students are also expected to build a numerical model of the system and compare the experimental behavior of the system to the theoretical model.

Webinar for Engaging Faculty in Instruction Using Teleoperation

A webinar entitled "Learning and Teaching Using Teleoperated Shake Tables" was held on August 31, 2009 with logistical support from NEESinc and NEESit. This event was designed to engage faculty in the use of these shake tables for instruction. Approximately thirty individuals attended this online workshop, which is archived at https://www.nees.org/news/webcasts/. The workshop focused on the experiments and teaching modules developed, as well as the evaluation outcomes from these exercises.

3. Future Plans

Our vision with the teleoperation experiments is to develop an international collaboratory of bench-scale earthquake engineering facilities that will engage a broad range of students by creating a series of shared laboratory exercises available for remote operation via the internet. Implementation of the array of opensource cyberinfrastructure tools developed for NEES research will enhance the learning process at the undergraduate level. The operation and management of the NEES network has recently been relocated to Purdue University under the name NEEScomm. One of Purdue's strengths in information technology is in the development of hub technology, allowing the user to utilize simulation tools through a web portal without necessarily installing or supporting the software locally. NEEScomm is moving toward integrating education, outreach and training efforts of the NEES network into NEEShub, and will be generating what will be called the NEES Academy. Through the partnership of NEES and UCIST, the teleoperation tools for the shake table developed by UCIST are being incorporated into NEEShub.

We are planning other opportunities to explore the use of these teleoperated shake tables for education. For instance, prepared videos about the experiments might be created for faculty to use to engage students in experiments or to use with large classes. Interactive exercises within the NEEShub framework culminating in the use of a teleoperated shake table learning experience would be attractive as materials to supplement course lectures. We also anticipate formalizing some of the additional educational exercises that have been developed around the use of the shake tables. Undergraduate researchers will also be engaged in the REU program for research and development activities.

Conclusion

Bench-scale shake tables are an engaging tool for educating students at all levels about the importance of earthquake engineering. The use of modern internet capabilities such as teleoperation represents an exciting new alternative in the education of our students. This project is one example of using such innovative capabilities for learning and teaching. Students anywhere are able to perform real-time exercises in structural dynamics and earthquake engineering. The integration of typical sensors used in real world applications is also a helpful component of such exercises. A partnership between UCIST and NEES was developed to engage a broad group of students in learning exercises through the use of teleoperation. Faculty guidance in the use of such tools is available through a webinar. Through this partnership, UCIST is extending its reach to impact students across the US, and potentially around the world.

Further information about the UCIST and these teleparticipation exercises, as well as all of the educational modules are available at https://nees.org/groups/benchshaketables. For more details on how to participate in or partner with this educational collaboratory please contact Prof. Shirley Dyke at sdyke@purdue.edu.

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