Internet Accessibility of Data and Video in Real Time Demonstrated for a Highway Bridge Testbed

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Abstract

In engineering education, visualization and timely access to real world data is often difficult or impossible yet valuable for teaching students. This paper presents a novel system for real time monitoring of traffic induced vibration on a freeway overpass. By extending software developed by the Network for Earthquake Engineering Simulation (NEES) Cyberinfrastructure Center (NEESit) (http://it.nees.org), data from six accelerometers is synchronized with video of the bridge traffic. The data and video is made available for real time viewing on any computer connected to the Internet. Additionally, all information is automatically stored on a repository database for sharing, archival, and further analysis.

Such systems open the possibility for telepresence and collaboration to a much broader audience. The hardware used consists of off the shelf components. The custom software used is made freely available by NEESit for use in research and education. This low barrier to entry allows more researchers to open up and share their research to benefit engineering education. The barrier to participate and contribute to such research is much lower. A participant needs an Internet connected computer that is able to run Java applications. The ease of deployment and rapid implementation time line opens up exciting opportunities for participation in experiments to further engineering education.

I. Introduction

Despite the value of using experiments and data from live testbeds in engineering education, educators face many challenges in bringing such experiences into the classroom. Often, cost and logistics are controlling factors that prevent educators from using experiments in their curriculum. This stems from both direct experimental costs as well as associated expenses, such as transportation to the site of the experiment. In particular, civil engineering experiments can be logistically complex and often occur far from where students are studying. During testing, student safety and increased liability are also a concern. Despite these challenges, the value of experiments in engineering education is undeniable.

The popular growth of the Internet has caused a revolution in sharing data that could not have been envisioned in 1969 when Advanced Research Projects Agency Network (ARPANET) came on line. Engineering educators and students are now able to rapidly access vast amounts of information. The majority of engineering information available on the Internet consists of static content, such as reports, images, and videos. Relevant experiments at the core of research and education are also shared through the Internet. However, this content is often only available in an abridged, published form. Data analysis, curation, and publishing can take in excess of one year, delaying access to the information. Furthermore, such publications often require subscriptions that limit access to this information.

The work presented here solves these problems by providing open real-time access to raw data from real engineering experiments using readily available software and hardware. Using the NEESit software suite [**?**] along with National Instruments (NI) LabVIEW™, real-time data and video is collected and synchronized. This data and video is then accessible through the Internet for viewing in real-time using Real-Time Data Viewer (RDV). In addition, the data is periodically archived in a standard format to the NEES central data repository, NEEScentral (http://central.nees.org).

II. Background of Preceding Work

As previously mentioned, civil engineering experiments are often only accessible to a small, select group, but the earthquake engineering community and others have been actively working to improve accessibility of data from and participation in experiments. To this end, NEESit developed a set of tools known as the NEESgrid Software Suite [**?**] to improve accessibility and participation in earthquake engineering experiments by creating a virtual laboratory through the Internet. The main goals were to allow storage of data in a

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standard format in a centralized data repository and to enable real-time access to experimental data for remote participation and simulation.

The Multi-site Online Simulation Test (Mini-MOST) experiment [**?**] served as an early test of the NEESgrid Software Suite in a lab environment. The experiment uses a physical model, a steel beam, in conjunction with an analytical model to explore the seismic loading on a one-story building. The response of the physical model is coordinated with the simulated analytical model by NEESgrid through NEESgrid Tele-Operation Control Protocol (NTCP). This experiment functioned as both a learning tool for students as well as NEESit software developers. The experiment represented a step forward for the NEESgrid software by demonstrating its successful, reproducible use for remote participation and simulation with a relatively inexpensive experiment.

In 2002, researchers at the University of California, San Diego (UCSD) deployed Webshaker [**?**], a website (http://webshaker.ucsd.edu/) that allows students to conduct shake table tests on two simple structural models. The site uses a single-degree-of-freedom (SDOF) system and a two-story shear frame excited by a uni-axial shake table with instrumentation installed to measure floor displacements and accelerations (Fig. **??**). The website has been successfully used for over 5 years to provide a more comprehensive understanding of dynamics for undergraduates students. Over this time frame the website has proven the importance of including experimental reinforcement in illustrating concepts of dynamic systems and has received consistent positive feedback from students.

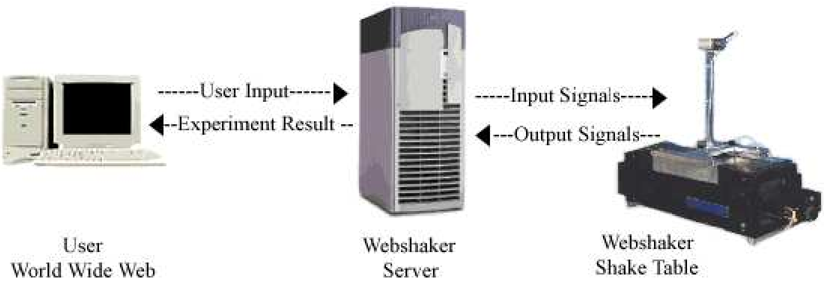

Fig. 1. Logical Flow of Webshaker

During the fall of 2007, approximately 90 students that were enrolled in undergraduate earthquake engineering conducted a real world dynamics experiment using iSeismograph [**?**]. The iSeismograph software enabled the students to capture synchronized data from the accelerometer and camera of an Apple MacBook laptop computer using the NEESgrid Software Suite to evaluate the natural frequency and damping of a cantilever beam. This project served as the first hands-on exposure to data acquisition for many of the students. Since the iSeismograph software is integrated with NEESgrid Software Suite, students were able to archive their data to NEEScentral. This also allowed students to view and analyze data sets taken by their peers for different configurations of the experimental setup. The experience provided a valuable, hands-on, experience that integrated the theory learned in class with hands on experimentation using readily available equipment. The use of simple hardware and the existence of comprehensive documentation [**?**] allows this experiment to be easily reproduced or customized by engineering educators throughout the world.

Fig. 2. Students Conducting Experiment Using iSeismograph

III. Structural Health Monitoring of Voigt Bridge

A monitoring system was deployed on the Voigt Drive / Interstate-5 (I-5) bridge (Fig. **??**), located on the main UCSD campus in San Diego, California, USA to demonstrate the ability to monitor a real large-scale structure with video and other instruments on an ongoing basis. The system incorporated an accelerometer sensor array and an integrated camera monitoring framework [**?**], [**?**]. Built in 1964, the Voigt Bridge is a two-lane, 2-way bridge approximately 90 meters in length, and carries traffic between the two portions of the UCSD campus that are divided by I-5. The single-column bent, 4-span, reinforced concrete box girder structure has a skew angle of approximately 32 degrees and a construction style typical of a large number of highway overpasses in California. Cap beams (lateral diaphragms) 1.8 meters in thickness, are situated over each of the columns and provide additional stiffness to the girders. This particular bridge was chosen as a testbed due to its proximity to the campus, an important consideration for convenient long-term maintenance and accessibility.

Fig. 3. Voigt Bridge

The bridge deck consists of five hollow box sections as shown in Fig. **??**. The northern most box section is conveniently accessed by manholes in the sidewalk. Due to this ease of access, the majority of the testbed hardware was located in the northern box section. Electrical power was provided to power the testbed. Internet connectivity for the testbed was provided by a high-speed wireless bridge to a nearby node of the UCSD campus network. Signal wires run from the main data acquisition system throughout the bridge to transmit the measured parameters.

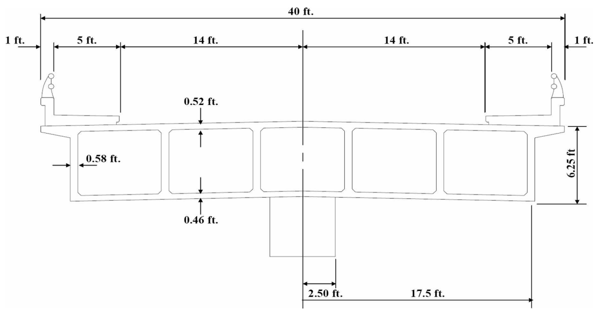

Fig. 4. Cross Section of Bridge Deck

A web portal (http://healthmonitoring.ucsd.edu/) was established to provide secure access to the data being collected on the bridge. On-line visitors have the ability to query for data containing peak accelerations, and to view the recorded accelerations and video signals[**?**]. Using the web portal a user is able to select a time frame and an accelerometer number from which to query, and a web page returns basic features of the archived data, including number of data points, maximum, minimum, and average acceleration for each hour. Further, links are provided to view the acceleration time histories, Fourier amplitude spectra, and video, as well as to download the archived vibration data and images. The portal has over 1000 1-minute records archived in this database.

IV. Real Time Access Testbed

The web portal setup in the initial monitoring of Voigt Bridge provided a revolutionary way for anyone with Internet access to view ongoing monitoring of a real, large-scale structure for the purpose of education. The system presented here was inspired by the success of the initial monitoring of Voigt Bridge. The primary goal of this testbed was to free the data provided by the initial system from a proprietary, project specific format. The NEESgrid Software Suite developed by NEESit provided the tools needed to achieve this by providing a framework to collect numeric and video data in a documented standard format using modular software. This promotes the use of the monitoring effort in education by enabling the use of standard tools for visualization and preserving historic data in a publicly available archive in a standard format. Instead of learning a new system to access each data set an educator as well as students can now access and visualize data from numerous experiments using the same tools. As the use of NEESgrid and NEEScentral continues to expand, students will have access to a greater variety of data allowing them more options to explore engineering principles without having to learn multiple software packages and user interfaces.

A. Monitoring Hardware

The monitoring system was assembled from common off the shelf components. A conventional computer running the Microsoft Windows XP operating system was used to run the real time portal (Fig. **??**). The computer connects to the Internet through a wireless bridge that was deployed for the first phase of structural health monitoring. To allow data acquisition and video capture, the computer was equipped with a high speed universal serial bus (USB) 2.0 interface and an Institute of Electrical and Electronics Engineers (IEEE) 1394 firewire interface. The USB 2.0 interface was used to connect a NI USB-6009 data acquisition device. The USB-6009 supports 14 bit analog input from up to 8 single ended inputs and also provides a 5 volt power supply. The USB-6009 was connected to 6 high sensitivity Crossbow CXL01LF1 accelerometers, which were mounted along the length of the bridge in a vertical orientation to capture traffic induced vibration of the bridge. Since each accelerometer only required 4 mA of current, it was possible to power them directly from the 5 volt power supply provided by the USB-6009, which is capable of providing up to 50 mA. This eliminated the need for an external power supply for the accelerometers, thus simplifying the hardware requirements. The IEEE 1394 interface was used to connect a Prosilica FB1394B fiber bridge to enable communication with the video camera, a Sony XCD-X710CR, over distances that are not possible with standard IEEE 1394 cables. The Prosilica FB1394B fiber bridge connected directly to the controlling computer, drawing power over the IEEE 1394 connection, while the Prosilica FB1394B located near the camera was powered by a power supply and provides power for the camera. The camera is installed atop a light pole on the west side of the bridge to provide video of traffic on the bridge deck. This system provides an example of a state of the art real-time monitoring system constructed of conventional, inexpensive hardware.

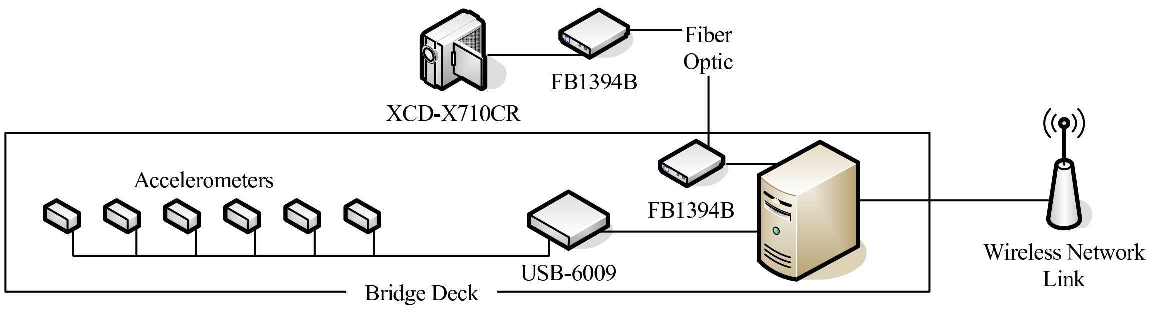

Fig. 5. Logical Hardware Layout

B. Monitoring Software

The software component of the monitoring system consisted of three main pieces which serve the following logical functions: capture of data from hardware; transmission of data into a ring buffer; and extraction of data from the ring buffer for presentation and archival (Fig. **??**). NI LabVIEW^{TM} was used to capture readings from the accelerometer and video from the camera. The Ring Buffered Network Bus (RBNB) Data Turbine component of the NEESgrid Software Suite provided the ring buffer to synchronize and temporarily store all the data streams in preparation for viewing and archival. Real-Time Data Viewer (RDV), another component of the NEESgrid Software Suite, provides a platform independent method for visualizing the captured data. Data Turbine Utilities provided the needed bridge between for communication between LabVIEW^{TM} and RBNB as well as providing archival capabilities. Using these software packages, a data acquisition system based on documented standards was quickly deployed.

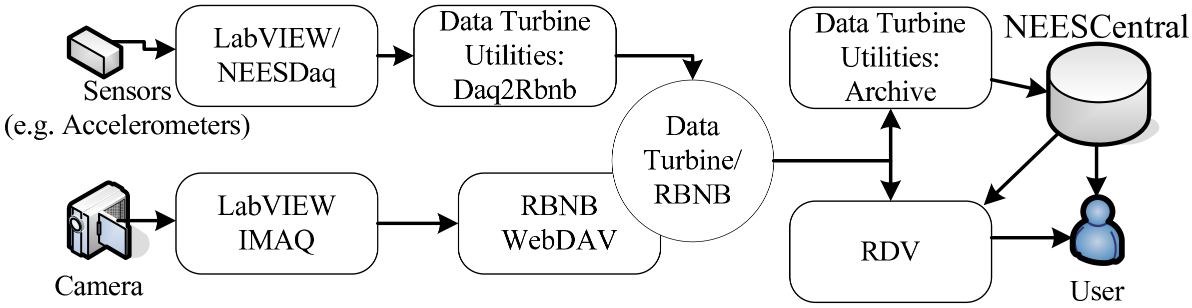

Fig. 6. Logical Software Data Flow

Creare, Inc. provides RBNB (http://www.creare.com/rbnb/index.html), the central piece of the NEESgrid Software Suite (Fig. **??**). The role of RBNB is to synchronize and temporarily store data from multiple streams. Two methods were used to input data into RBNB, using software application programing interfaces (APIs) and using the Web-based Distributed Authoring and Versioning (WebDAV) plug-in to transfer files directly into the ring buffer. RBNB acts as a mediator for all data so that multiple data sources can asynchronously publish data to the buffer freeing the user from the complications typically associated with synchronizing multiple data streams. In a similar manner, it allows data to be asynchronously retrieved from the buffer for presentation or permanent storage.

NEESdaq, a component of the NEESgrid Software Suite provided by NEESit, is a ready-to-use software program written in LabVIEW™ that is designed to retrieve data from data acquisition hardware. Once the data is retrieved, metadata is added to describe the data before passing the data on to the next component. This metadata includes a time stamp, a description of the data source, the units of the data, as well as other pertinent information. The data is passed to RBNB using the Daq2Rbnb functionality of Data Turbine Utilities, where it is synchronized and inserted into the ring buffer (Fig. **??**).

Custom code was written in LabVIEW™ Image Acquisition (IMAQ) to capture images at a specified frame rate from the video camera. RBNB provides WebDAV functionality that allows data files, in this case video frames, to be added to the ring buffer simply by writing the file in a network folder. The video code took advantage of this to accelerate the development time frame, by eliminating the need to develop code to communicate directly with RBNB. RBNB captures and timestamps each frame written to the WebDAV folder and synchronizes the video frames with the numeric data streams.

V. Data Access and Management

As previously mentioned, this effort focused on making experimental data more accessible. By systematically loading the experimental data into RBNB it becomes possible to process the data with standard tools provided by NEESit. The NEESgrid Software Suite solves two main issues with experimental data, visualization and archival, for all data that is loaded into RBNB. Data can be archived from RBNB using the archive functionality of Data Turbine Utilities. For visualization, RDV can be used to view data in real time as well as re-play archived data.

A. Data Management and Storage with NEEScentral

In addition to the other functionality provided by Data Turbine Utilities, the archive functionality allows data to be extracted from RBNB and archived to a project on NEEScentral using a documented, standard format. The data archive was run hourly, during daylight hours, to upload a one minute snapshot of data from RBNB to the NEEScentral website. If desired, a longer time frame could be specified. Once the data is uploaded to NEEScentral, the researcher is able to control access to the data for dissemination to only a select group specified by the researcher or to make the data publicly available (Fig. **??**). With the data archived to NEEScentral the researcher is also freed from the concerns of long term data management. The NEEScentral data repository provides reliable long term data storage.

B. Viewing Data with RDV

The NEESgrid Software Suite provides RDV to visualize data in a number of ways. Data can be viewed in real-time by connecting directly to the RBNB server. Archived data can be replayed through connecting RDV to NEEScentral (Fig. **??**). RDV is also capable of playing back recorded data from files stored on a local storage device. Aside from the other benefits of the NEESgrid Software Suite, the visualization capabilities of

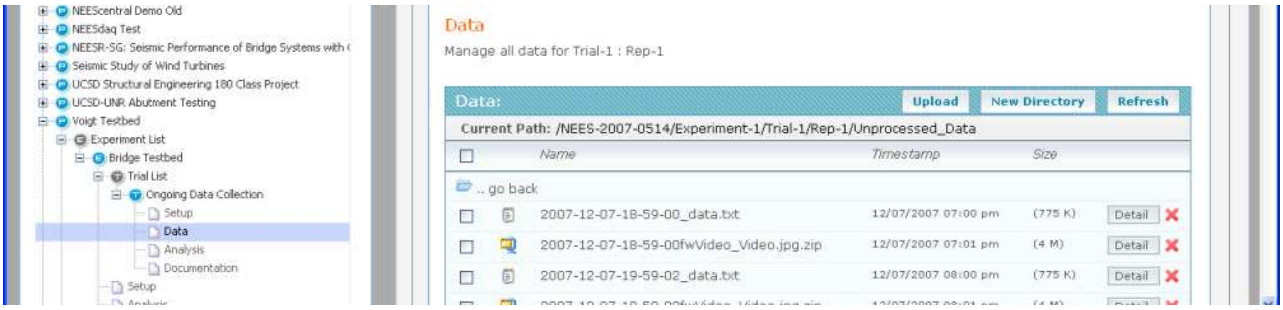

Fig. 7. Data on NEEScentral Website

RDV provide a compelling argument for the value of the NEESgrid Software Suite in engineering education. RDV is also platform independent, thus minimizing the requirements for the student accessing the data. The student merely needs an Internet connected computer that is able to run Java applications.

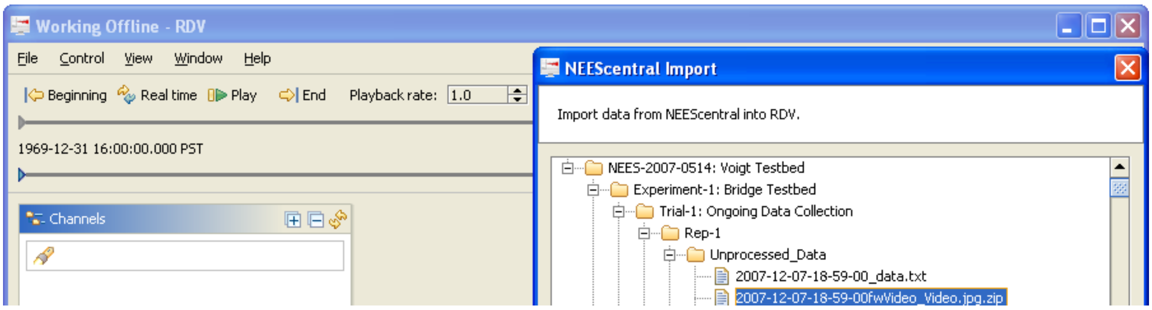

Fig. 8. Importing Data into RDV from NEEScentral

VI. Testbed Operation

The monitoring system began full time operation in late 2007 and has been operating nearly continuously since its launch. The testbed has provided valuable information regarding the use of the NEESgrid Software Suite for continuous monitoring. In collaboration with NEESit, upgrades to the NEESgrid Software Suite were implemented to allow the automation of long term monitoring outside of a controlled laboratory environment. The ongoing archiving of data has produced an extensive record of traffic induced vibration for Voigt Bridge (Fig. **??**). This system at Voigt Bridge is a test platform that illustrates a simple real world monitoring system implemented using the NEESgrid Software Suite. Students throughout the world have access to the data from Voigt Bridge. Furthermore, the hope is that educators will use this as an inspiration to set up their own experiments, allowing students to access data from real-world, ongoing experiments. Such systems allow students to have access to continuous data from experiments that they may not be able to physically visit.

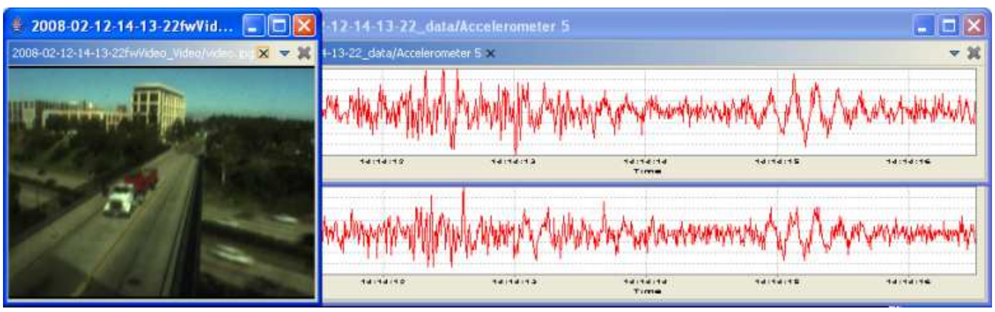

Fig. 9. Replay of Truck Crossing Voigt Bridge Using RDV

In the same way that the Internet revolutionized communication by providing a standard protocol to connect network throughout the world, this open approach to data provides the possibility for a revolution in the experimental process by encouraging open sharing of data. The NEESgrid Software Suite provides a standard and open protocol for sharing of experimental data. Data can be easily made publicly available through archiving on NEEScentral. These tools offer convenience for the experimentalist as well as providing a path for the experimental data to provide illumination beyond the scope of the initial experiment. Through open data sharing students and experimentalists will be able to access far more data than has traditionally been available thus allowing for data mining and comparative studies not possible through traditional means of dissemination for experimental data.

VII. Conclusion

This investigation represents the first use of the NEESgrid Software Suite to provide real-time ongoing access to vibration data and video outside of a controlled lab environment for monitoring an in-service civil structure. The system serves as a demonstration of the simplicity with which engineering data can be shared and archived in a standard format. This represents the next step in the evolution of the NEESgrid Software Suite and structural health monitoring. As the power of computer systems increase and prices decrease such systems will become easier and more affordable to deploy. The authors hope that this will serve as a model to inspire others to develop tools for bringing data from real engineering experiments into the classroom.

VIII. Acknowledgments

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