A Pilot Web-Shared Controlling and Monitoring System for Real-Time Assessment of Civil Engineering Structures

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Summary

A Webshaker pilot project is initiated to demonstrate the feasibility of live web-based monitoring and control of experimental setups. Such experimental setups are relevant to real-time safety assessment of civil engineering structures. The developed framework allows for remote dynamic testing and monitoring of civil-infrastructure facilities. The Internet allows real-time worldwide access to the recorded response and associated live video/audio signals (Tele-presence). In this paper, the employed technologies are described in detail, and the pilot project is presented (http://webshaker.ucsd.edu). Feasibility of this technology for both practical and research applications is discussed.

Keywords: monitoring, remote control, safety assessment, data acquisition, www, CGI, shaking-table, video streaming, dynamics.

1. Introduction

In recent years, there has been an increasing interest in civil engineering applications related to monitoring, for real-time safety assessment of structures. This increase coincides with the rapid development of techniques employed in monitoring (fiber optics [1], large-scale sensors, micro-mechanics [2]), evaluation techniques (time-frequency analysis, statistical pattern recognition [3]), and communication capabilities (wireless technologies, remote control).

In this ambit, a pilot project at UCSD has been initiated with the goal of demonstrating the feasibility and cost-effectiveness of a web-controlled, real-time monitoring and control system for civil engineering structures. Emphasis is placed on the potential of the Internet for live on-demand experimental-testing, sharing of information, and optimization of resources, both for research and practice purposes. The project is developing through a number of actions, including:

1- The Webshaker pilot project, which consists of a web-controlled bench-top shaker.

2- A planned monitoring WebRing (http://monitoring.ucsd.edu), a website environment for linking monitored civil engineering structures worldwide.

3- A planned Webmonitoring Network, a web-based network of tools for real-time safety assessment (including signal processing, modeling, structural identification, risk evaluation, decision making).

At present, an effort is underway to instrument a building on the UCSD campus, and allow worldwide access for conducting real-time dynamic tests, by remotely controlling a dynamic shaker. A digital video camera will transmit live video, and the structural response will be made available using accelerometers. The user will be allowed to run dynamic tests, perform basic signal processing operations, and browse and download from a database of archived data. At present, a small-scale pilot effort (http://webshaker.ucsd.edu) consisting of a facility for remote controlled shake table testing, demonstrates the feasibility of conducting such control/monitoring experiments over the Internet.

In this paper, the technology setup involved in the Webshaker Project is first introduced along with the related implementation details. The feasibility of this technology for both practical and research applications is demonstrated.

2. Layout of a Web-based Monitoring and Control System

The outline of the setup employed in the Webshaker Project is represented in Figure 1. It is convenient to distinguish three different environments: 1) the instrumentation domain; 2) the server-side domain; 3) the client-side domain.

2.1 Instrumentation Domain

Sensors and actuators, along with the analog conditioning system, belong to the instrumentation domain. Sensors convert a mechanical signal (e.g., acceleration, displacement, strain) to an analog electrical signal (e.g., voltage). Conditioning consists of all devices and tools that modify, amplify, and eventually convert the electrical signal (originally generated by the transducer) to an analog one (suitable for recording or digitizing). The digitization is done via an Analog to Digital (A/D) converter that is often (but not necessarily) a data acquisition board installed on the same computer that operates as the server. The control of actuators (e.g. motors, electromagnetic shakers) operates along the same lines, but in the opposite direction.

2.2 Server-Side Domain

The server-side domain allows for interaction between the instrumentation and the client-side domains. It consists of software and hardware that can be physically located in a single computer or a networked set of workstations.

Sending pre-formatted HTML documents under request is the main task of a web server. For remote control applications, the necessary client/server interactivity is made possible by using Common Gateway Interface (CGI) programs. CGI is a protocol for exchanging information between client and web-server, and between web-server and programs. CGI programs can be written in any scripting language such as pearl, C, or Visual Basic. Some recent commercial data acquisition programs (such as latest versions of LabVIEW) also have CGI capabilities when run by an

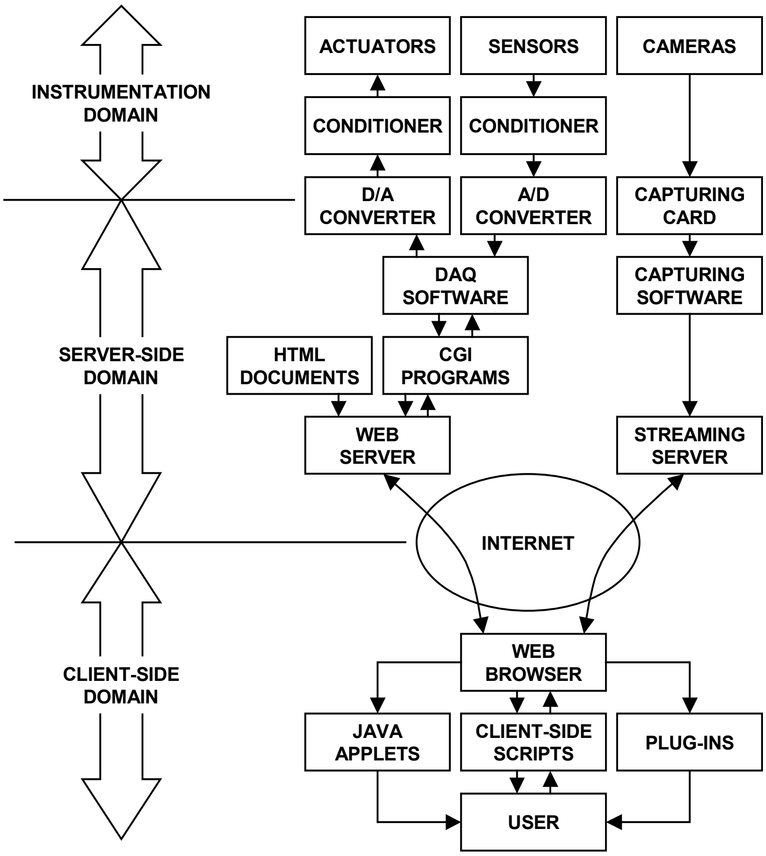

Fig. 1. Layout of Internet monitoring and control system.

appropriate web-server, and can be utilized for data acquisition (DAQ), signal processing, and generation of the CGI output page. Unfortunately, most of the DAQ programs, commonly provided with the I/O devices, are not Internet ready. In this case, special CGI scripts must be created to allow for the generation of the output web page, and for control/interaction with the DAQ application. The latter task can be achieved either: 1) by using the DAQ application as a subroutine of the CGI program, or 2) by utilizing the DAQ program as a free-standing resource that runs in parallel, and exchanges information through shared buffers or files.

2.3 Client-Side Domain

The most essential aspects of the interactivity of a remote monitoring/control system (such as sending the request for running a shaker and receiving the output from an accelerometer) are based on server-side programming capabilities, such as CGI. Some simple operations can be more conveniently carried out on the client-side (i.e., running on the user computer, rather than on a server). The strategies employed for client-side programming in the current Webshaker project make use of Java Applets, Scripts, and Plug-ins.

Java Applets are executable applications, embedded in an HTML page and running in the browser environment. These are written in Java languages and compiled to a machine-independent byte-code. The Applet can be utilized for instance to perform an interactive graphical representation of the returned signals, allowing the user to zoom into the graph and perform basic analyses.

Scripts can be embedded in an HTML page and executed on the client-side, in order to perform basic interaction tasks such as simple elaborations, checking of request forms before submission, and esthetical improvements. The most common language utilized is JavaScript as it is supported today by most Internet web-browsers.

Plug-ins are helper components that allow for reading certain types of files, otherwise unsupported by a browser. For example, Real Player and Window Media Player are common plug-ins that allow for playing a streamed video. The user must have the plug-ins downloaded and installed.

3. The bench-top shaking-table facility

The basic elements of experimental Tele-observation and Tele-operation/control are currently operational within the pilot framework (http://webshaker.ucsd.edu), of the newly developed UCSD Webshaker project (a tool that allows users worldwide to run a preset shaking-table test on an existing model). The facility is currently used as a learning environment for applications in Dynamics including Mechanics, Structural Dynamics, and Earthquake Engineering courses.

The instrumentation side of the Webshaker set-up consists of a small-scale model attached to a bench-top shake-table (Fig.2), and monitored with displacement (LVDT) and acceleration transducers. The facility was designed to operate with different models. The current model (Fig. 3) consists of a single degree of freedom (SDOF) aluminum frame bolted to the table. This model represents a scaled version of a single-story building.

Fig. 2 Overview of small-scale Webshaker setup.

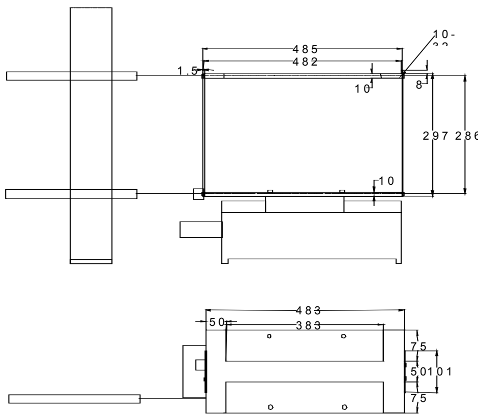

Fig. 3 Schematic of SDOF model on shake-table

Attached to the base and first floor of this model are two LVDTs to record the displacement while an accelerometer mounted on the base of the structure records the acceleration of the shake table. All measurements are taken in the direction of the shaking. The instruments allow the user to observe the model deformation induced by the base excitation.

3.1 Hardware Components

In detail, the experimental hardware is composed of the following items:

- APS Electro-Seis electro-magnetic shake table (Figs. 2 and 3). This is a single-degree-of-freedom (SDOF) table that allows the reproduction of ground motions with a zero to 200 Hz frequency range, and a 158 mm (6.25 in) maximum displacement. The maximum testing mass capability is 23 kg (50 lb). The table operates through an electro-dynamic actuator, which transforms the input voltage signal into a dynamic force.
- APS model 124 power amplifier, which amplifies the signal from the data acquisition (DAQ) card before it is passed to the shake-table.
- Two Macro Sensors DC 750-3000 LVDTs (Fig. 3), with a measurement range of ±76.2 mm (±3.0 in), corresponding to a ±10 V voltage range. The LVDTs incorporate a dedicated miniature circuit to provide signal conditioning for the basic LVDT sensor, and require only external DC power for excitation.
- Endevco accelerometer, model 7705-1000. This is a capacitive accelerometer, with charge sensitivity approximately equal to 100pC/m s-2, 0 to 1000 Hz frequency range, and 0.3% maximum transverse sensitivity.
- National Instruments PCI-MIO-16E-1 analog I/O board with the following characteristics: 1.25 MS/s, 12-bit, eight double-ended analog inputs, 2 double-ended analog outputs, ± 10 V output range.
- Sharp color CCD video camera with an Osprey 100 video capture card.

3.2 User Interface

Using a standard web-browser such as Internet Explorer or Netscape Navigator, users can:

- Select a dynamic base excitation and operate the shake-table by clicking the "Run Experiment" button.
- Download the output of the experiment (acceleration and displacement time histories recorded by the installed accelerometer and LVDTs). The output files generated from the experiment can be viewed using either a Java Applet with zoom-in capability or in the form of raw data.
- View a real-time streaming video of the shake table and the mounted test structure using Real Player or Windows Media Player.
- Conduct a numerical simulation of the executed experiment. The graphical result of the numerical simulation is superimposed on the plot of recorded data from the live experiment for comparison.

3.3 Software components

The employed server computer is a PC running Microsoft Windows NT Server 4.0. The software consists of a multi-tasking structure where IIS 4.0 Web Server, LabVIEW, Matlab, Real and Windows- Media Players are running at the same time. These applications control the Web interface, execution of the experiments, data elaboration, and video capturing/streaming operations. Coordinating these tasks is conducted in the Web Server environment, by making use of HTML and pearl scripts. Among the functions of this application are to:

- Make available the Web interface and interact with remote users. A pooling scheme allows up to five users to conduct independent experiments at the same time by assigning a priority to the users' requests.
- Generate the input signals, according to the user's desire, and store in a common directory.

- Send requests to the LabVIEW Virtual Instrument (VI) to run an experiment, collect the results of the experiment, and transmit to the remote user.
- Send request to Matlab for generation of graphical output in jpeg format and transmit to the remote user.
- Address and interface the streamed video signals.
- Call executable subroutines for advanced data elaboration.

3.4 Video capturing and streaming

In addition to the displacement and acceleration transducers, a digital video camera allows for real-time video transmission of the experiment. Typical computer cameras (such as the one used here) can capture as many as 30 frames per second, with a 512x492 effective pixel resolution (in the current configuration this corresponds to about 2-mm spatial resolution). This amount of data can easily be recorded on computer disk with the plug and play technology. For quantitative applications, capture rates of 100 frames per second or more are needed, as is sufficiently high spatial resolution (for comparison the currently installed LVDTs with the 12 bits DAQ card allow a 0.03 mm resolution in a 150 mm range). A high-speed capture and high-resolution video requires more expensive cameras and high speed buffering boards. As these technologies become more available and less expensive, quantitative digital video data is expected to become a mainstream tool and an integral component of the data acquisition system. Therefore, for now, the digital camera is used only for qualitative purposes (viewing the shake table and model motions).

Using video-streaming technology, a live or recorded video signal can be sent to a remote user near real-time. Commercial video-streaming technologies (e.g., RealPlayer http://www.realplayer.com or Microsoft Windows Media Player http://www.microsoft.com/windows/mediaplayer) allow for transmitting the best possible signal using the limited available Internet bandwidth. Today, this type of streamed signal is only suitable for qualitative purposes. The Webshaker setup includes both of these commercial packages for capturing and serving the video signal.

3.5 Execution of Experiments

Following the server request, The LabVIEW Virtual Instrument (VI) uses the PCI-MIO board as an interface to drive the shake-table and to acquire signals from the instrumentation. There are two types of base motion available for the experiments: a) harmonic and, and b) earthquake-like motions. For the harmonic motion of the shake-table, the user specifies the base motion amplitude (mm s^{-2}), frequency (Hz), and duration (sec.) of a sine wave. Once the user has specified the characteristics of the sine wave, the VI converts the sine wave into a series of discrete points with a voltage for each time step. Acceptable values of frequency range from 0.5 to 20 Hz, which encompass the range of frequencies of interest for earthquake engineering applications. The other form of input signal is an earthquake-like motion. These motions are constructed by scaling accelerograms from historic earthquakes, such as the 1994 Northridge earthquake. Limits are placed on the amplitudes of shake-table motion in order to ensure that the structure remains elastic during testing. For the harmonic motion, this is accomplished by limiting the maximum voltage to one-volt. For earthquake-like motions, the maximum voltage was experimentally fixed in order to contain the peak displacement within a 4-cm limit.

Upon clicking the ‘Run Experiment’ button, the user selection of base excitation is sent to the server. Pearl scripts generate an input file with the parameters specified by the user, which is then read by the LabVIEW VI. The VI in turn constructs and sends the input voltage signal to the shake table. While the shake table is running, the same VI simultaneously acquires data from the LVDTs and the accelerometer, located on the model. The analog signals from the sensors are sampled and digitized at 200 scans per second by the data acquisition card. The electric signals are converted to displacements and accelerations.

In addition, the VI performs some basic signal processing in both the time domain (e.g., filtering) and frequency domain (e.g., Fourier analysis), and sends back the results to the server in ASCII format. These data files are then sent to the remote computer. A Java Applet is embedded in the HTML (*Ptolemy*, http://ptolemy.eecs.berkeley.edu), to process and produce graphical representations of the data on the user’s web page.

A numerical simulation can be performed along with the live experiment, to compare the actual and predicted responses of the model. The numerical simulation calculates the response of a SDOF linear structure, subjected to a known base acceleration, using the classical Newmark predictor multi-corrector algorithm with the average acceleration technique [4]. The recorded acceleration from the accelerometer is used as input and the predicted relative displacement of the first floor with respect to the base is returned (Fig. 4).

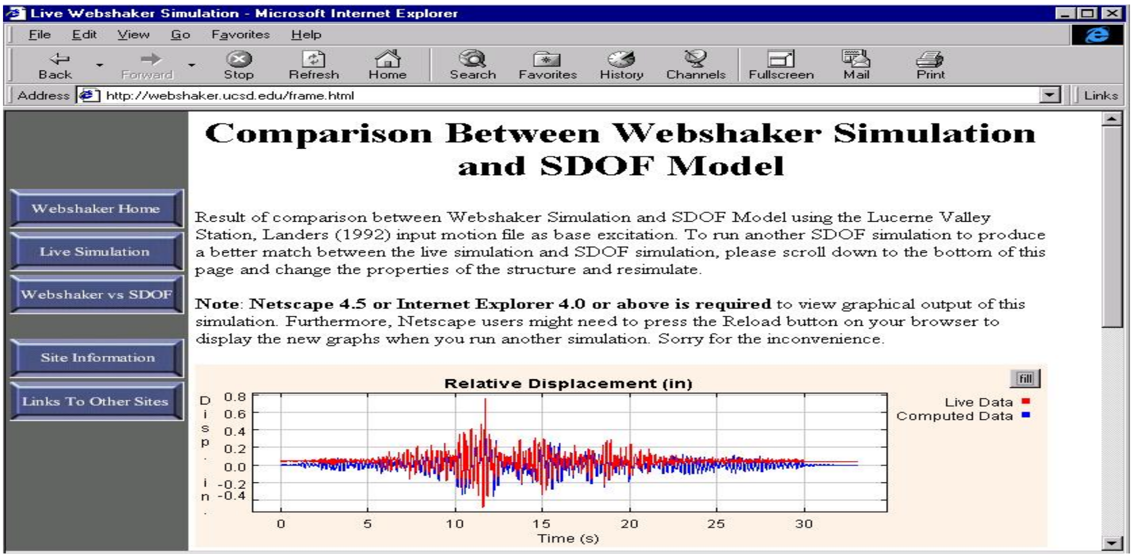

Figure 4. Sample Comparison between first floor recorded and computed response.

4. Conclusions

As damage detection techniques become more refined and reliable, permanently installed monitoring systems for civil engineering structures are becoming more feasible. New sensor developments (e.g., in micro-mechanics and wireless) will allow for reduced installation costs. The Internet and related technologies (such as remote control, video streaming, and database administration) will allow convenient dissemination. The Webshaker Project (http://webshaker.ucsd.edu) demonstrates that: a) a remote testing system is feasible based on commercially available technologies, and b) the system layout is versatile and suitable for general large-scale applications.

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