Framework for Integration and Visualization of Structural State Data

A civil engineering structure, a building or a bridge, undergoes many changes during its lifetime. Some changes are slow, such as degradation of material over time, some are moderately fast, such as changes in the temperature of rooms in a building, and some are very fast, such as damage incurred in an earthquake. These changes start even as the structure is being built, making its initial state somewhat unknown.

Knowing the state of a structure is very important. In many cases, we are interested in improving the quality of life of people who use the structure. In other cases, we would like to change the purpose of the structure. Always, we strive to prevent loss of life due to natural or man-made structural catastrophes. Yet, establishing the state of a structure with certainty is a major challenge for civil engineers and architects. We often find that we lack critical structural state data.

Recent advances in electronic technologies make it seem there is data all around us. Devices that collect data, store it, and process it to some degree are all around us. In buildings, security systems collect video and still image data and track movement of people. Complex heating and ventilation systems are closed-loop control systems that require temperature and humidity data collected at many locations of the building to regulate their operation. Energy-saving systems track human usage and adjust energy consumption at optimal levels. Safety systems measure and control radiation levels in and around a structure. In many modern structures, motion-measuring instruments are used to actuate dampers that reduce vibration due to wind to increase comfort of inhabitants. Some buildings are instrumented to measure their response to seismic events. Structures with instruments that measure local deformation of structural elements and joints exist, but are very rare.

A multitude of data is collected in and around a structure, yet this data is not integrated at a single location. Data streams are separate from their sources to the control centers that use them. Such separation of existing, acquired, data is robbing us of a chance to better understand the state of a structure and to follow how it changes over time. Sensor data fusion methods and technologies exist. They are being used in the military and in many engineering disciplines, even in Civil Engineering. The principal reason why data fusion is not used to integrate acquired data at the level of a civil engineering structure is the scale of the data. Today, there are no suitable data frameworks to organize and store diverse structural state data and visualize it at the scale of the entire structure, the scale of structural elements, and the scale of structural materials. Development of such framework is a fundamental step toward integrating and visualizing structural state data, and deriving information necessary to evaluate the state of a structure.

Project Goals

The goals of the proposed project are to conceptualize, develop and implement a framework for gathering, classification and integration of structural state data collected in and around a structure, and to enable effective visualization and fusion of such data to define the state of a structure.

Project Objectives

To achieve the stated goals, the following objectives are defined:

1. Define types of structural state data. Structural state data is differs by:
    - Source: field or point data. Point data is acquired using sensors capable of monitoring a small, local region, such as strain gages. Field data may be acquired using field sensors, such as video cameras, or generated using a computer model that interpolates among several point-sensor data.
    - Scale: local, intermediate, global. Local structural state data are material-level stresses and strains. Intermediate data pertains to structural element deformation or forces, such as joint rotation. Global data, such as drift, pertains to the entire structure.
    - Type: discrete/continuous, analog/digital.
    - Location: where the data was taken.
    - Time: when the data was taken.

    These data attributes will be encapsulated using data type and meta-data concepts.
2. Define data structures for structural state data. An inheritance-based object-oriented data structure must be established to generate efficient meta-data to describe raw structural state data. Location and time are fundamental dimensions describing structural state data, and they should be used to integrate it. Therefore, a 4-dimensional database structure is needed to handle structural state data. Such 4D data structures are already used in construction management.
3. Define a data structure access paradigm. Access to a special and temporal database containing objectified structural state data is best accomplished using a visual access paradigm. A three-dimensional computer model of a structure is already a familiar visual paradigm used in structural analysis. This paradigm can be extended to allow access to structural state data by its location. Synchronized time-history displays can be used to present the time component of structural state data. A sketch of such data access tool is shown in Figure 1. Fusion of geometric and temporal data can be implemented using Virtual Reality Modeling Language (VRML). A distinct advantage of VRML is its scene-based data structure, and ability to display on a variety of platforms, from a conventional computer monitors to augmented reality (three-dimensional visors) and virtual reality (CAVE) platforms.

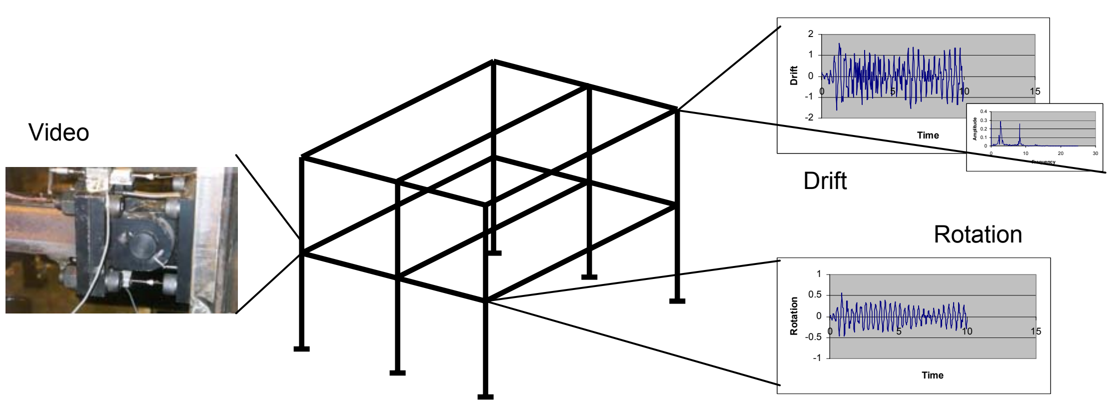

Figure 1. Virtual reality visual access to structural state database.

4. Verify using an experiment. Prototype implementations of structural state database and VRML access tools will be verified using an experiment. A small-scale plane frame structure will be instrumented using a variety of wireless sensors, simulating actual

structural monitoring instrumentation for strains, temperatures, rotations and drifts, and video cameras. This structure will be excited using a small shaking table, to simulate short-duration seismic events, and monitored over longer periods of time to simulate long-term environmental events. Data collected from this experiment will be processed and stored in the structural state database and displayed using a VRML-based 4D access tool.

Project Tasks and Schedule

The following tasks are planned in order to achieve project objectives stated above. They are defined in two groups to separate tasks for Project Year 1 and Project Year 2 and to insure planned project deliverables are ready for evaluation at the end of Project Year 1.

Project Year 1	Tasks	1. Review of data structures and access paradigms. 2. Define structural state data types and meta-data. 3. Design structural state data structures. 4. Implement structural state database prototype. 5. Implement prototype VR database access tool using VRML. 6. Link VRML access tool to structural state database. 7. Report on progress.
	Deliverables	1. Design of a meta-data for structural state data. 2. Prototype structural state database. 3. Prototype structural state VR access tool.
Project Year 2	Tasks	1. Build a model frame and install on a 1D shaking table located in UC Berkeley Structures Laboratory, 115 Davis Hall. 2. Instrument the model frame using CrossBow wireless sensors and Internet appliance moderate resolution video cameras. 3. Conduct long-term and short-term structural state monitoring experiments and store acquired data in the structural state database. 4. Refine implementation of structural state database. 5. Refine implementation of VR database access tool. 6. Report on progress.
	Deliverables	1. Improvements in structural state meta-data, database and VR access tool. 2. Example data collected on a physical frame model.

A Gantt chart showing planned duration and dependence of the proposed tasks is shown in Figure 2. This project, divided in two Project Years, is expected to take 24 months to complete.

Project Personnel

The research program proposed herein will be conducted at the University of California, Berkeley with Professor Bozidar Stojadinovic serving as the Principal Investigator and advisor to one graduate student researcher. A project advisory committee, consisting of Professors Gregory L. Fenves, Stephen A. Mahin and Arpad Horvat from UC Berkeley, Dr. Kim Mish from Lawrence Berkeley National Laboratory, and two researchers from Kajima chosen after a consultation with the Joint Oversight Committee of the CUREe-Kajima Program, will be assembled and consulted during the project.

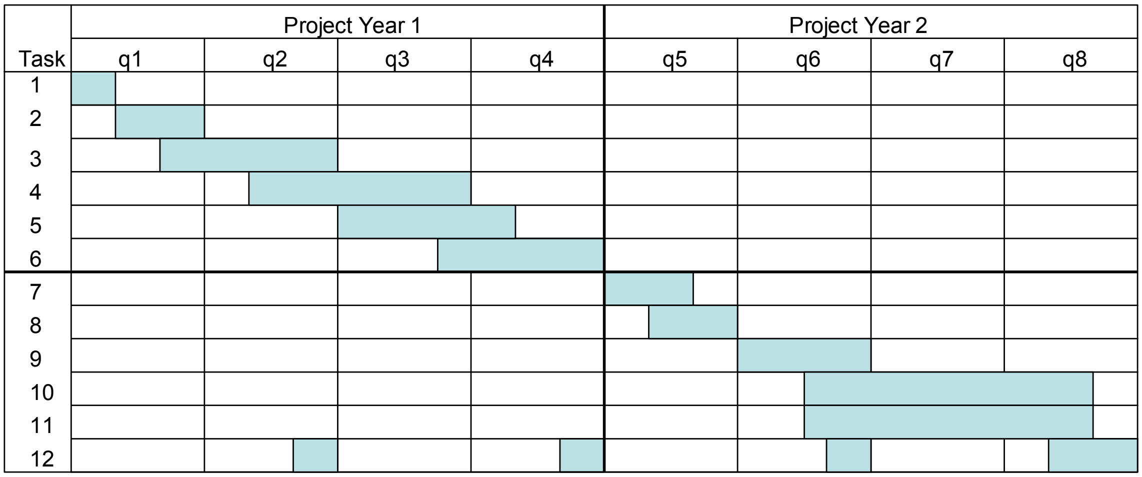

Figure 2. Project time-line.

Results and Applications

A direct outcome of the proposed project will be a prototype framework for gathering, integration and visualization of diverse structural state data. This framework will comprise a meta-data structure developed for structural state data, a database implementation on a personal computer using a common database tool, and a Virtual Reality access tool for the structural state database. Similar frameworks exist in construction management: this idea will be extended to structural state data in this project. The proposed framework will enable further work on raw structural state data processing and fusion to gain a more refined insight into the state of a structure and to improve monitoring of structures over time. Other extensions are possible. One direction may be the use of Virtual Reality tools to immerse the user in the structural state database and let him or her use visual data mining tools to discover more links between structural state data points. Another direction may be to use wireless sensor and computer networks to gain real-time access to processed structural state data. Such access may be very useful in emergency situations.

Collaboration and Integration with Kajima

The prototype structural state database and access tools to be developed in the proposed project should be of significant interest for the Structural Engineering and Building Environment Engineering Laboratories of Kajima Technical Research Institute (KaTRI). Access to this project will be provided through the proposed project advisory committee. However, closer collaboration involving a parallel project at KaTRI is even more desirable. Possible areas of collaboration and complementary work are:

1. Collaboration in structural instrumentation. Use of existing wired structural state sensors built into Kajima buildings and innovative use of wireless sensor networks.
2. Verification of the proposed database prototype in a large-scale structural test in Kajima's laboratories. Additional instrumentation to be used in this verification test can be treated as ancillary payload for a Kajima test planned for other research purposes.
3. Use of the proposed structural state framework in a real building built by Kajima.