A Grid-Based Research Environment for Civil Engineering

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Abstract: The flow of information brings a tremendous change in the civil engineering industry as well as the politics, economy and culture of a society. The civil engineering field with the information revolution sees the combination of digital technology and construction technology, such as development of integrated construction systems, electronic databases, document management systems, and simulations. As a result, the scale of constructed structures gets larger, multi-functional and complex. These core technologies and the development of extreme technology become an essential part of a nation's competitive construction strategy. However, related huge experiment facilities are too expensive for an organization, which makes the building and application of them difficult. In this paper, we propose a grid-based research collaboratory that connects fragmented construction experiment facilities and shares their technologies and information across the research community, which ensures the efficiency of the facilities. And based on this research, we propose a design for a real-time hybrid experiment collaboratory in Korea Construction Engineering Development (KOCED) civil engineering research project and describe our experiment with its prototype.

Key–Words: Grid system, Remote experiment, Collaborative computing, Civil engineering

1 Introduction

In order to bring the construction technologies, such as experimentation, interpretation, design, building and maintenance up to a global level, we distribute the huge research facilities across the nation [8]. Also, although we need each research facility, we experience the limitation of accommodating the facilities to many research institutes. We share the facilities and maximize the effectiveness of their use, through grid technology [7, 6]. By distributing the research facilities across the nation, we can expect a balanced development of all the regions nation-wide. By installing the facilities into universities, we can expect the combination of education and research. The KOCED grid system is huge research facilities, computing servers, and data repositories connected by a high speed information network and integrated to a grid system, which makes the facilities become one facility.

This effort of distributing huge research facilities and building a grid system resemble nation-wide policies of the U.S. and others. The Network for Earthquake Engineering Simulation (NEES) project of the U.S. is one of the examples of such an effort [9, 3].

KOCED is composed of the cores of each region that are connected by Internet. In order for remote users to use the cores, it is necessary to have an entry point. This entry point provides a platform for facilities and services from the cores of each region. For this, this contains managing, monitoring and storage tools, and plays a role as an internet protocol gateway for user and the core of regions. Additionally, this provides services and resource management for sharing data, and provides services for co-work. For an entry point to access to experiment data, there should be an interface, and the data streaming technology makes this possible. Also, for remote control of physical experimentation, it is required to have control protocol, and this protocol provides a standard interface for local facilities. The prototype of KOCED remote experimental environment was built with Globus Toolkit 3 [5] which is based on OGSA [4].

Fig 1 shows the civil engineering experimental facilities that are linked in the KOCED grid network across the nation. We plan to expand the grid coverage to include more experimental facilities.

This paper is organized as follows. In section 2, we discuss related work where we discuss NEES and our KOCED. In section 3, we explain the major services of KOCEDgrid , which is the grid system used

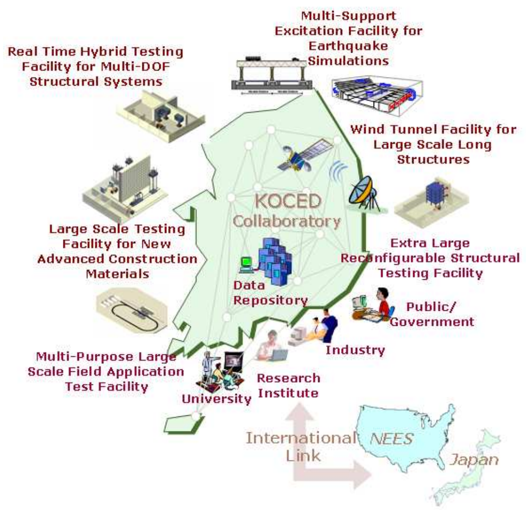

Figure 1: Civil engineering experimental facilities in KOCED grid

in KOCED. Then, in section 4, we shows the design, implementation and testing of the remote experimental environment of KOCEDgrid. Finally, conclusions are presented in section 5.

2 Related Work

NEES is a connection of nation-wide experiment facilities related to earthquake engineering. NEES is operated as a collaboratory, which is managed by a consortium, and is composed of a network system that enables the sharing of 16 future earthquake engineering facilities, teleobservation and teleoperation, sharing data, simulation, and co-work.

NEESgrid system is largely divided into NEEspop software that serves as a gateway to a tool site, TelePresentce Mode (TPM) software that provides a co-work environment, and Data Acquisition (DAQ) PC software that gathers data from a tool, along with a data model that enables data storage building.

G-Civil is a project in UK that enables remote access to processed civil engineering site monitoring data via an Internet portal [1]. The grid system of G-Civil allows people working in collaborative projects to access and manipulate data in real-time.

In Korea Construction Engineering Development(KOCED) project, each participating university locates a selected huge experiment facility. Using this facility, each university can perform research within the region, as well as remotely perform experiments. The remote access of facilities is restricted to the grid portal. This grid portal plays the role of connecting fragmented universities' facilities, sharing research data as a web service, see result graph in the section 4, and monitoring the process of research. Also, through camera and video connected to research facilities, it is possible to look into and modify the process of research, and prove services for a collaboration. Grid portal also performs the role of connecting users and facilities by the Data Acquisition System (DAQ), which receives data from research and sends them to users, local data/meta-data servers, or computer servers. In addition, this makes possible a remote control of facilities by means of a controlling system that receives the order from users and sends it to facilities.

Simulated data from research forms meta-data and is stored in local data storage facilities, and completed data are managed in a huge database system. This database provides an efficient searching mechanism for these data, manages meta-data, and informs storage place when data are managed redundantly. This construction of the database can be possible by development of application programs accompanied by existing data management systems, and by file transfer services through grid middle-ware.

Research can be performed through a single experiment facility. However, it can also be performed through a combination with simulation. In this case, we can use a computing server, which sends calculated results from simulation to facilities, performs real experiments, sends back results to a computing server that calculates based on the results, sends calculated results again to facilities, and so on. The computing server provides Application Program Interface (API), which can perform simulated streaming transfer, and controls API, which can modify facilities. This integration of the calculation grid function and facility grid function can be possible. It is the Job Scheduler program for grid middle-ware.

A remote user receives Web services for co-work, modifies research facilities, and sees simulated results through a grid portal, and looks into research results through local data storage. Also, he can examine research data and related information from other researchers through the database. Additionally, in order to manage data efficiently, it is required to have an accurate analysis and a modeling process of data.

3 Services of KOCEDgrid

KOCEDgrid system is modelled after NEESgrid in a sense that it is aimed to integrate and share the facilities. We investigated the NEESgrid system so that we can reuse some of the existing functions and improve the weak points of the system. First, we identified the major functions that the KOCEDgrid system should provide as follows: resource management, data management, remote experimentation, and collaborative research environment.

3.1 Resource Management

Resource management provides the following functions. First, it provides authorization to confirm the identity of users as well as the delegation of rights. Second, it allows users to locate the required resources when they need to use the experiment facilities and related data from remote sites. Third, it enables users to monitor the status of the resources for the effective usage and management of resources including experimental facilities. Finally, it includes not only facilities for experiments but also high-end computers with which researches perform large-scale scientific calculation and simulations. It allows researchers to allocate jobs to high-end computers regardless of their physical location and to see the results.

3.2 Data Management

The capability of generating and managing meta data in a pre-specified format is provided for the effective management and lookup of experimental data. Data generated in experiments and simulations are transferred to the database in a secure way. Users are allowed to look up data effectively in a pre-specified meta data. Access to the data from remote places is performed in a trusted way using standard secure protocol.

3.3 Remote Experimentation

3.3.1 Teleobservation

Teleobservation should provide the following two functions. First, users from a remote site should be able to see the experiment data. Second, the video and audio from where the experiment is being performed should be accessible from a distance in real time. Experiment data can be seen in a remote place with a visualization program based on real-time streaming. A synchronization mechanism is needed for synchronizing the experiment data and video in real time.

3.3.2 Teleoperation

The capability of controlling experiment facilities from a distance is provided: control of experiment facilities is different depending on the facilities. A control layer is independent from the experiment devices that are separated from the control layer that is dependent on the experiment devices. Separation of those two layers is made in order to reduce the cost in extending the grid system to include the new experiment equipment. The experiment device-independent control layer is implemented as control commmands and protocols that are general to experiment devices. In addition, the experiment device-dependent control layer converts commands from the device-independent layer to device-specific commands to control the experiment device, which can be extensible.

3.3.3 Remote Communication

In fact, it is very hard to take every control of experiment equipments from a distance. However, there should be a way to take some measure in a laboratory in case of emergency. The following actions cannot be performed from a remote site: displacement of experiment prototype, installation of sensors, and camera location changes for observation. To perform these actions, the following services should be provided: people who can assist in the experiment, a video communication system that connects people in the experiment facility and researchers in a remote site, and a wireless communication system.

3.3.4 Experiment Facility Scheduling

Since the experiment facilities are shared by researchers, users can look up the usage schedule of experiment facilities by others as well as apply for using the experiment facilities on line.

3.4 Collaborative Research Environment

3.4.1 E-Notebook

The grid architecture allows researchers to collect and organize data for collaborative research. The data includes not only text but also pictures, CAD, voice, video and application-generated data such as Word and PowerPoint. E-notebook enables collaborators to organize and look up the data.

3.4.2 Chat

Collaborative researchers should be able to do multiparty discussion through chat in real time. Researchers from remote sites should be able to discuss the experiment situation through chat as they observe the ongoing remote experiment.

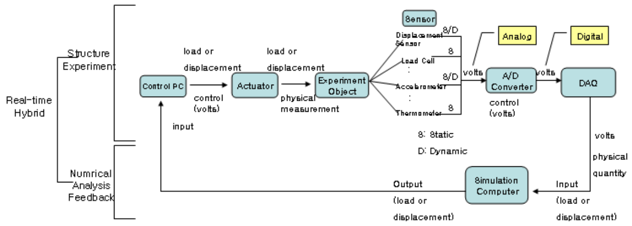

Figure 2: A hybrid experiment model

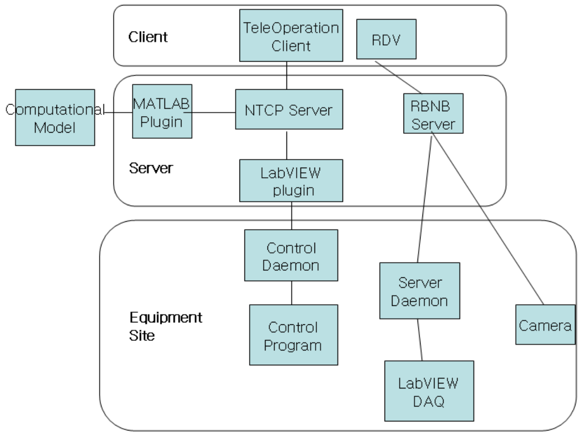

Figure 3: A software architecture for hybrid experiment

3.4.3 Scheduling

A scheduling function is provided to collaborative researchers so that they can form the community for collaboration. The scheduling is maintained for each collaborative research community. Each researcher can look up and modify the schedule of his community.

3.4.4 Integrated Research Environment

The system should allow researchers to perform the experiment in an integrated research environment. With a single sign on to a portal site that is a gateway to experiment facility grid, they should be able to use the resources and services in the grid with their access rights in an integrated environment.

4 Design and Prototype Testing of a Remote Experimental Environment

We designed a hybrid experiment and developed a prototype to test a remote experiment environment for construction research. Mini-WindTunnel and mini-Shaker experiments are other prototype examples of KOCEDgrid.

4.1 Hybrid Experiment Model

A hybrid experiment decomposes the entire test structure into independent substructures that can be modeled computationally or physically, located at different facilities, tested separately, and integrated via computational simulations. Fig. 2 shows a hybrid experiment model. A hybrid experiment consists of two parts: one part of a structure is modeled computationally and run on a simulation computer numerically. Another part is constructed and instrumented physically. The physical experiment's control system and the simulating computer communicate and influence each other's behavior over the course of the experiment. The physical experimental results acquired by DAQ are fed to the simulation computer for numerical analysis. The simulation computer, in turn, provides input to an actuator of the physical substructure by simulating the interactions between the physical and the virtual model. A hybrid experiment is performed by repeating each simulation step which sends feedback of the simulation to the physical equipment.

Fig. 3 shows a software architecture of the hybrid experiment model.

4.2 Design and Implementation of Prototype of Hybrid Experimental Model

Fig. 4 shows the prototype of a hybrid experiment model that is based on a simple steel framework to model the effects of an earthquake on a one-story building. The basic idea of this model is from the Mini-most experiment from NEESgrid [2]. The framework is tested pseudo-dynamically to examine the seismic response of the structures using models comprised of both physical and numerical substructures. This framework was split into three subassemblies - two physical experimental nodes and one computational node with MatLab numerical simulation. They are physically tested or numerically simulated at the same time at the different locations.

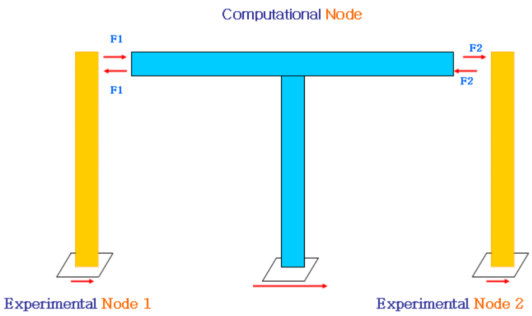

Figure 4: A Prototype of hybrid experiment model

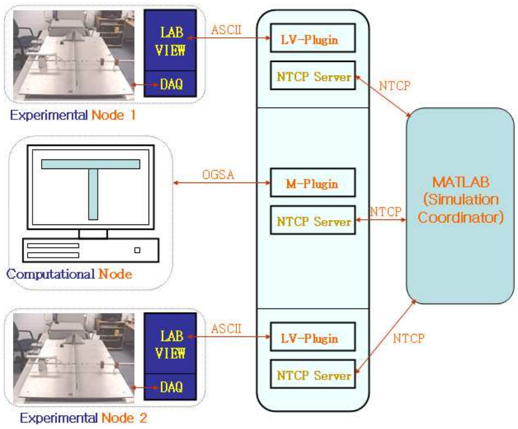

Figure 5: Software architecture of the prototype of hybrid experimental model

As shown in Fig. 4, components of the software architecture link these subassemblies together and enable the hybrid experiment. NTCP (NEESgrid Teleoperations Control Protocol) server communicates with the DAQ machine and the computational node to exchange system status information and controls.

The experiment with the prototype is performed by the simulation coordinator MatLab code which coordinates the entire experiment. The simulation coordinator provides overall management of the experiment. It repeatedly issues a set of NTCP proposals (a set of requested actions) based on the current simulation state. It collects information on the resulting state of all the substructures, and based on that resulting state, computes the next set of commands to send. The simulation coordinator communicates and interacts with the DAQ machine and two simulation codes

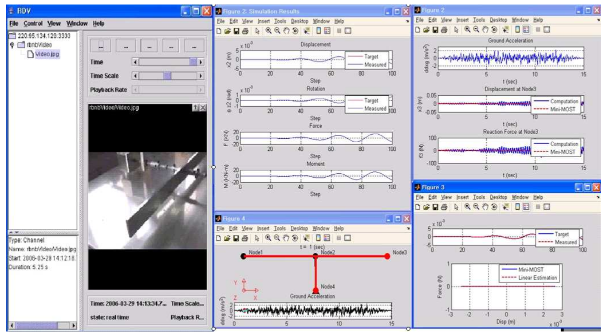

Figure 6: Screenshot of the Hybrid Prototype Experiment

through the NTCP protocols over the entire experiment.

The computational node automatically shows the experimental results such as Fig. 6 after all the simulations are completed successfully. The structural response to the force resulting from the interactions between the seismic wave input and the computational node are measured and visualized in graphs. The quakes of the prototype equipment during the experiment are shown in the form of video stream.

Our experiment with the prototype provided a good perspective on the overall collaborative architecture for a hybrid experiment using a physical equipment and a simulation computer.

5 Conclusion

In this paper, we described a grid-based research environment for civil engineering that is being developed in a project called KOCED. The paper identifies the main functions of a collaborative research environment including remote experiment and shows the design of hybrid test model and the implementation of its prototype. Each facility-based research will form a local cluster. A nation-wide grid will be formed based on these local clusters, which will integrate industry and academy. The integrated potential of Korean construction engineers and researchers will result in the rapid development of the Korean construction industry. Showing the real experiment from a remote large-scale experiment facility in a university class will provide a basis for quality distance learning. We plan to expand our grid network to include other new experimental facilities. We expect the facility for accessing experiment data in a grid system to be exploited by the construction researchers and engineers. We hope the presented model of integrating and sharing large-scale facilities will be applied to researchers in other academic fields.

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