HVEM Control System Based on Grid: A Cornerstone of e-Biology

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Abstract. This paper proposes HVEM Control System, which is the cornerstone for teleinstrumentation infrastructure. The proposed system is oriented for people whose primary work is to get access to a remotely located instrument, a High-Voltage Electron Microscope (HVEM). Our system is implemented to fulfill all the necessary requirements in allowing the user to 1) control every single part of HVEM in a fine-grained manner, 2) check the HVEM and observe various states of sample, and 3) take their high resolution images of the sample. In that aspect, this paper suggests an HVEM Control System designed on the concept of the Grid and Web Service which satisfies various types of user groups, explains novel characteristics of our system.

1 Introduction

Many scientists use computing resources, storage resources and any other resources to perform real-time experiments. This science, which is performed through distributed global collaborations over the Interenet, is called e-Science[1]. Specially, scientists in e-Science need to access or control experimental devices remotely in a fine-grained manner, and this capability is crucial for remote experiments.

High-Voltage Electron Microscope (HVEM) allows scientists to see objects at a magnification greater than the actual sample. The type of HVEM referred in this paper is transmission electron microscopy (TEM), which produces an image that is a projection of the entire object, including the surface and the internal information. When tilt is needed, the Goniometer rotates to change the angle of the sample. When environments inside the HVEM such as voltage and focus are needed to be changed, FasTEM performs such operations which users command. It is the CCD camera that produces an actual image inside the HVEM. HVEM users control the HVEM in a fine-grain manner, observe the sample using the above subcomponents of HVEM, and take high-resolution images using storage resources. Since remote users want to perform the same tasks as offline users, the HVEM-Grid provides remote users with applications for controlling the HVEM, observing the sample, and carrying out other tasks remotely.

The objective of our system is to work towards an implementation of the vision of being able to use the HVEM of the Korea Basic Science Institute

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(KBSI)[2] remotely. This typically means that the remote users can carry out the realistically large scale research. Therefore, this requires functions that allow remote users to control subcomponents of the HVEM and to observe the sample. Specially, the functions include requirements of biologists such as memorization of some specific locations and recording/replaying the trace of the sample.

In this paper we describe the HVEM Control System, which has the capabilities listed above. This paper is organized as follows. Section 2 describes background material. Section 3 explains the architecture of our HVEM Control System. Section 4 shows experimental results. Section 5 summarizes our plans for future work and Section 6 concludes the paper.

2 Background and Related Work

2.1 Grid and Web Service

A Grid can be defined as a layer of networked services that allow users single sign-on access to a distributed collection of computing, data, and application resources. The Grid services allow the entire collection to be seen as a seamless information processing system that the user can access from any location. However, the heterogeneous nature of the underlying resources remains a significant barrier. Scientific applications often require extensive collections of libraries that are installed in different ways on different platforms.

Web service is an important emerging distributed computing paradigm that focuses on simple, Internet-based standards to address heterogeneous distributed computing. Web services define a technique for describing software components to be accessed, methods for accessing these components, and discovery methods that enable the identification of relevant service providers.

HVEM Control System utilizes Grid and Web service for the control of HVEM. By doing this, our HVEM Control System can support many other systems. A 3D-image construction service, which we are currently developing, gives us a good example. The service commands the HVEM to tilt the angle of the sample by 1 degree, take an image and repeat this process. Then, it builds a new 3D image out of taken images. Because HVEM Control System is based on Grid and Web service, it can support HVEM Control User Interface as well as other services such the 3D-image construction service.

2.2 Other Research

The National Center for Microscopy and Imaging Research (NCMIR) at the University of California San Diego(UCSD) develops 3D imaging and analysis technologies to help biomedical researchers understand biological structure and function relationships in cells and tissues. Its web-based tool[3] and EMWorkspace[4] are innovative and similar to our system. However, they have some major drawbacks. First, they can not support the HVEM of KBSI, which is really large-scale and newest. Second, GTCP[5] which EMWorkspace uses is not suitable for asynchronously operated microscopes. When operations are issued to such microscopes, it is needed to poll the status in order to verify success of operations. Although all clients can poll the status of the HVEM, it is to hard to guarantee consistency between clients. Therefore, there exists a Grid service that polls the status of the HVEM and manages the status in our system. Third, they do not have specific functions to biologists such as memorization of interesting locations, recording/replaying traces that remote users are interested in. These functions are necessary because they lead to efficient observation and experiments.

3 Architecture

3.1 HVEM Control System in 3-Tier Architecture

This section of the paper describes the architecture of the HVEM Control System. Our system has a 3-tier architecture[6] which utilizes Grid and Web Service. Grid and Web Service which is based on the XML messaging have many advantages suitable for integration with complex systems: platform independent architecture, interoperability, and flexibility.

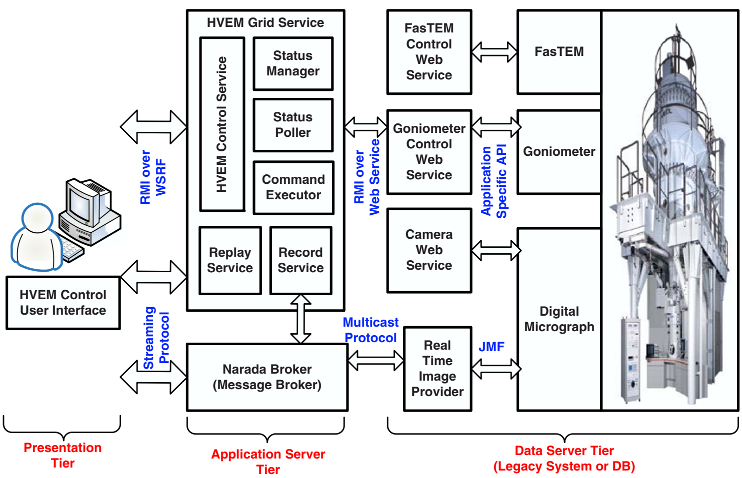


Fig. 1. System Architecture

Figure 1 shows the architecture of the HVEM Control System. HVEM Control User Interface (HVEM Control UI) program corresponds to the presentation tier of the 3-tier architecture. HVEM Grid Service based on Globus Toolkit 4[7] and Narada Broker[8,9] correspond to the application server tier. Remote Method Invocation (RMI) which is based on Web Service Resource Framework(WSRF), is used to communicate between HVEM Control UI and HVEM Grid Service.

HVEM Control Service is responsible of handling control requests from HVEM Control UI. Status Poller polls the overall status of the HVEM such as location of the angle, voltage value, focus and brightness. Then, it forwards such information to Status Manager, which manages the status of HVEM. Many operations for retrieving specific status are handled by the Status Manager, not corresponding subcomponents of the HVEM. This can alleviate the overhead of FasTEM and Goniometer. Command Executer routes users' operations to related Web services. FasTEM, Goniometer and Digital Micrograph, which are provided by manufacturers, are encapsulated in Web services, and those Web services correspond to data server tier. Applications which control Goniometer and FasTEM are termed Goniometer and FasTEM respectively, and Digital Micrograph is an application to manipulate CCD camera. We encapsulated those application specific APIs in Web services to provide only secure and reliable features.

Record and Replay services are tightly coupled with each other. If the Record service receives a start request, it starts to record real-time images from the Digital Micrograph to a stable storage device. It continues to record them until it receives a stop request. The Replay service transfers the saved video to the HVEM Control UI when it receives a replay request which the HVEM Control UI selects. Record and Replay services provide a good method to biologists because they tend to observe past samples.

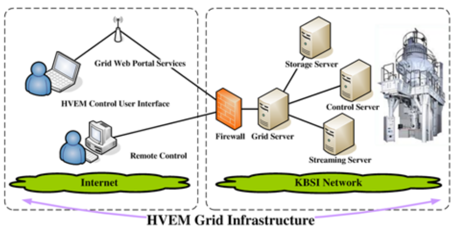
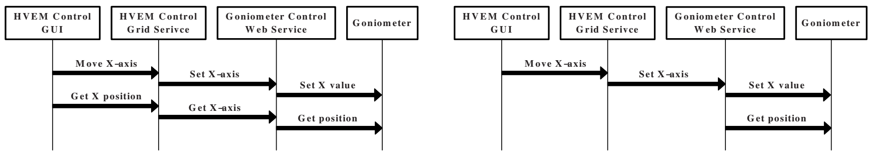


Fig. 2. HVEM Control System Network

Figure 2 outlines the HVEM Control System on the Network. HVEM Control UIs are located on internet, and legacy systems which manipulate HVEM and Web services which encapsulate legacy systems are on KBSI's site, which is protected by firewalls. HVEM Grid Service objects interact with HVEM Control UIs, Web services of HVEM legacy system (encapsulated experimental equipment) and other hardware resources such as storage devices. By doing this, HVEM Control System can be more secure, because unauthorized users are prevented from accessing legacy systems direct.

3.2 Control of Goniometer and FasTEM

Figure 3(a) shows the sequence to move an axis of a sample by HVEM Control UI. HVEM Control UI sends a request message of movements along X-axis to HVEM Control Service by RMI over WSRF, and HVEM Control Service transfers a request message to Goniometer Web service object which encapsulates



(a) Basic Sequence (b) Optimized Sequence

Fig. 3. Sequence to move an axis of a sample by Goniometer

the Goniometer control application. When the response for the request of movements along X-axis is delivered to HVEM Control UI, HVEM Control UI sends another message to request information of current location of a sample. The request message goes through the same way as before. A similar message flow is applied to control of FasTEM.

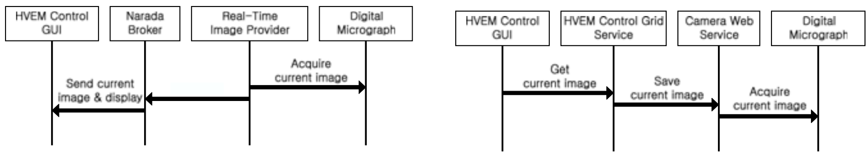
In general, we can control cameras and microscopes with small number of operations. However, we need many operations to control axis of sample and angle of stand in Goniometer. Usually, biologists start experiments after they complete the whole setting of the HVEM such as brightness, focus and voltage. During observation they move the axis or tilt the angle through the Goniometer to find specific parts of the sample. Then, they take an image. This suggests that most of operations are related to moving or tilting. Therefore, we can get chances to improve performance in that part.

Figure 3(a) shows that we need two operations to move an axis of the sample in Goniometer: changing the axis and reading the location of the sample. Therefore, it could suffer from overload due to too many operations when large number of HVEM Control User Interfaces access to it or moves an axis by trackball. Figure 3(b) shows the optimized sequence of control operations in application level. Unlike Figure 3(a), HVEM Control User Interface can complete two operations, which are operations to change the axis and to read the location, in one RMI call. It could be a useless operation to read the location when you intend to change the axis only. However, biologists look at the samples by changing the axis in most cases. In that case, the operation to read the location of sample is followed by the operation to change the axis. This feature makes the performance improvement larger.

3.3 Control of Camera

Control of camera consists of two parts: Real-Time Streaming Service and Snapshot Service. We begin by introducing Real-Time Streaming Service.

Figure 4(a) shows the sequence for Real-Time Streaming Service. Real-Time Image Provider gets video sources from Digital Micrograph by utilizing Java Media Framework (JMF). It transfers received images to the Narada Broker, which multicasts messages. Then, the Narada Broker delivers them to HVEM Control UI (and Record service if it receives a subscription request).



(a) Sequence of Real-Time Streaming Service

(b) Sequence of Taking Images of an Sample

Fig. 4. Sequences of Camera Control

Figure 4(b) shows the sequence of taking images of a sample. This sequence starts from HVEM Control UI. HVEM Control UI sends a request message of taking images of a sample to HVEM Control Service. Next, HVEM Control Service delivers the message to Camera Web service and the message arrives at Digital Micrograph finally. Digital Micrograph has a COM plug-in to process this requests. After plug-in completes the request, the result is delivered to HVEM Control UI through Camera Web service and HVEM Control Service, and HVEM Control UI can download the image.

3.4 Record and Replay

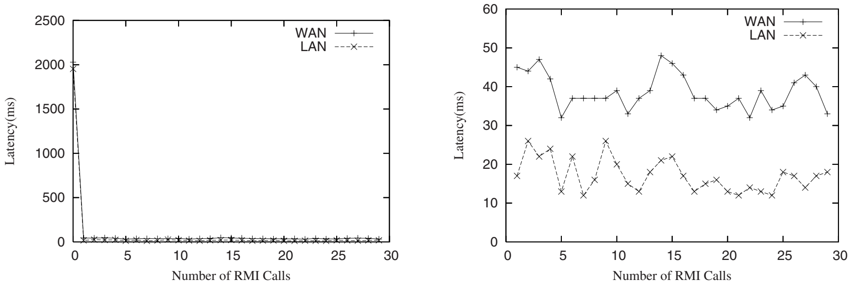
In order to record real-time images, HVEM Control UI sends a start request to Record service. Then, Record service subscribes an appropriate topic to Narada Broker. The topic should be related to real-time images from Digital Micrograph. After the subscription Record service starts and continues to save real-time images into stale storages as an appropriate format until it receives a stop request.

When a remote user wants to replay a specific video, HVEM Control UI sends a replay request to Replay service. Then, it transfers saved images to Narada Broker and Narada Broker delivers them to HVEM Control UI by the same way of the Real-Time Streaming Service. This capability leads to efficient research because many biologists want to watch past experiments during the current observation. Note that sequence diagrams of Record and Replay services are skipped due to the page limit.

4 Evaluation

The machines used in this evaluation were a Pentium IV 2.80GHz PC in Seoul National University (SNU) and two Pentium IV 3.0 GHz PCs in KBSI, running Linux 2.4.18. RMI service server is located in KBSI, and RMI clients are in SNU and KBSI when the experiments run in WAN and LAN environment respectively.

Figure 5 shows latencies of RMI which performs optimized operation of Goniometer Control. We measured latencies when RMI is called 30 times continuously. Figure 5(a) shows all results from first to 30th call. The latency of first call is larger than others, because loading RMI library takes some time in Java VM. Figure 5(b) excluded the first latencies. In this case, the average latencies



(a) Including first RMI call (b) Except fisrt RMI call

Fig. 5. Latencies of RMI with Optimization in Application Level

are 38ms and 17ms for WAN and LAN respectively. It may take at least 76ms in WAN environment without the optimization because it needs two RMI calls to move axis of sample (changing the axis and reading the location). This is good advantage to reduce the latency to 38ms by the optimization and allows biologists to control the Goniometer with a reasonable speed.

5 Future Work

HVEM Control System is a part of our three-year project, and it is the objective of the first year. Currently, we are developing an image processing system, which is the objective of the second year. It is a kind of workflow systems, which receives a job specification from remote users, carries out the job, and then stores results of the job. Usually, biologists tend to take many images of samples and build 3D images based on the 2D images. To do this, users tilt the angle of samples by some degrees (between 0.5 and 1), focus the lens of the CCD camera, and take a high-resolution 2D image. Until 2D images are enough to construct 3D images, this process is repeated, and then 3D images are built. The objective of the system that we are developing is to automate this workflow. Thus, this system requires to control the Goniometer, the FasTEM, and to take an image through the CCD camera, and our HVEM Control System provides those functionalities.

6 Conclusion

This article has proposed the system to control HVEM at remote site. Our HVEM Control System is implemented based on Grid technology and Web services. Initial version of the system was assembled by basic components, and we optimized flows of messages. Then, we presented reasonable results and our results showed that our system will be a very useful research method to biologists. We are convinced that our HVEM Control System will be a core software infrastructure in research work of scientists at remote stations.

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