A Scheduling System for Shared Online Laboratory Resources

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Abstract - **Online educational laboratories are increasingly deployed in traditional on-campus as well as Web-based distance-learning classes around the world. Recently, various educational institutions have attempted to leverage their online laboratory developments by broadly sharing them across institutional boundaries. While virtual experiments represent scalable software simulations, hardware-based remote experiments can only be used by one person or group of persons at a time. This paper describes the design and prototype implementation of a scheduling system for shared online laboratory resources, which can be employed to coordinate reservations of usage time for multiple geographically dispersed users. This scheduling system facilitates various priority levels for user requests, thus allowing different modes of usage, such as experimental demonstrations during a live class by an instructor and experiments carried out either individually by one user or collaboratively by multiple users. This software module can also be integrated into a more general resource management system, which enables the standardized description of and efficient search for online resources. Collectively, such tools have the potential for leading to fundamental changes in engineering and science laboratory education.**

Index Terms - Scheduling, Online laboratory, Remote experiment, Sharing, Virtual experiment.

INTRODUCTION

Laboratory work exposes students to practical issues and physical instruments and is, therefore, important in engineering and science education. With the Internet's rise in popularity, educational engineering and science laboratories that are accessible online are increasingly gaining acceptance for deployment in traditional on-campus as well as Web-based distance-learning classes around the world [1]. Successful applications of online laboratory systems with varying degrees of interactivity have been reported by many educational institutions [2],[3],[4],[5]. With the increasing number of users of these systems, a scheduling system will be useful in helping the owners of online laboratory resources to broadly share them across institutional boundaries.

The remotely accessible online laboratories reported in the literature can be classified into remote experiments [6],[7],[8] (based on actual physical setups) and virtual experiments (based on pure software simulations) [9],[10],[11]. While virtual experiments represent software simulations that are typically scalable (i.e. suitable for concurrent usage by multiple users), remote experiments based on actual hardware can only be used by one person or group of persons at a time. This paper describes the design and prototype implementation of a scheduling system for remote online laboratory resources, which can be employed to coordinate reservations of usage time for these resources by multiple geographically dispersed users.

First, a review of related scheduling systems and online laboratory technologies is presented. Then, the details of the logic behind the scheduling approach for shared online laboratory resources, the workflow chart for exercising a schedule, and the software module design are discussed. Then, the scheduling requirements are analyzed and a prototype scheduling system implementation for shared online laboratory resources is presented in conjunction with some sample usages.

RELATED WORK

Scheduling is part of daily life. Suppose that somebody is considering to take a bus at some arbitrary time, then this potential passenger may feel uneasy to wait for the next bus if the departure intervals are long. Fortunately, all bus carriers (e.g. New Jersey Transit [12]) provide time schedules so that passengers can plan their travel with ease in advance and need not waste time in waiting. Even in cases when some waiting is inevitable, a lot of technologies have been used to provide the estimated waiting time. For example, when the customer cannot get immediate assistance at Dell's support website [13], the length of the waiting list and an estimate for the waiting time are provided.

Recently, many research efforts have been made to implement online experimentation systems. The "Lab-on-Web" remote laboratory in Norway establishes user-friendly and efficient technologies for interactive, online operation of remote education laboratory equipment for electronic device characterization [14]. The "Telelabs Project" at the University of Western Australia combines laboratory equipment available via the Internet with automated assessment and performance monitoring techniques to enhance the students' learning experience [15]. MIT developed several remote-controlled experiments that are

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useful in learning heat transfer [16]. This laboratory also enables users to sign up for a specific time period to avoid time conflicts. Building upon these concepts, this paper discusses a scheduling system that enables users to conveniently make reservations for shared online laboratory resources.

SYSTEM DESIGN

I. System architecture

Most online laboratory resources are implemented based on dynamic HTML Web pages or JAVA applets to provide the students with a user-friendly interface for performing their laboratory tasks [17]. The goal of the work presented here was to develop a software module that will efficiently support and manage the sharing of remote experiments. Figure 1 depicts the typical three-tier Web business architecture that dominates commercial applications and was adopted for this project [18]. The three tiers of this architecture are client, resource manager and experiment station. With the rapidly increasing number of online laboratory resources, the resource manager component, which is used on the server side to establish management and coordination functionality for the various experiments that reside locally at a particular institution, needs to be given more attention. The resource manager (RM) represents a software module that performs the following functions [19]:

- Authentication is used in order to restrict access to the online experiments to authorized users. Also, it can help to avoid malicious attacks or abuse of the system.
- Status management is employed for determining the current availability of an experiment and guiding students in accessing it. Normally, a student can gain control over the experiment on a first-come first-serve basis, which is facilitated by queue management.
- Data storing is used to preserve the experiments' results for later usage by students and instructors.
- Scheduling is utilized to facilitate access to the experiments without conflicts and system congestion.

II. Scheduling a resource

When students prepare to conduct an experiment at a traditional on-site laboratory involving a unique experimental setup (i.e. one that cannot be duplicated for concurrent use by the entire class), they first need to find an available time slot and then register for that time slot. This may require them to estimate how long they will need to carry out the experiment. The scheduling system for online experiment described here also assumes that the students should finish their experiments in a limited time, just like they do in traditional on-site laboratories. The user interaction for scheduling a time slot is illustrated in Figure 2.

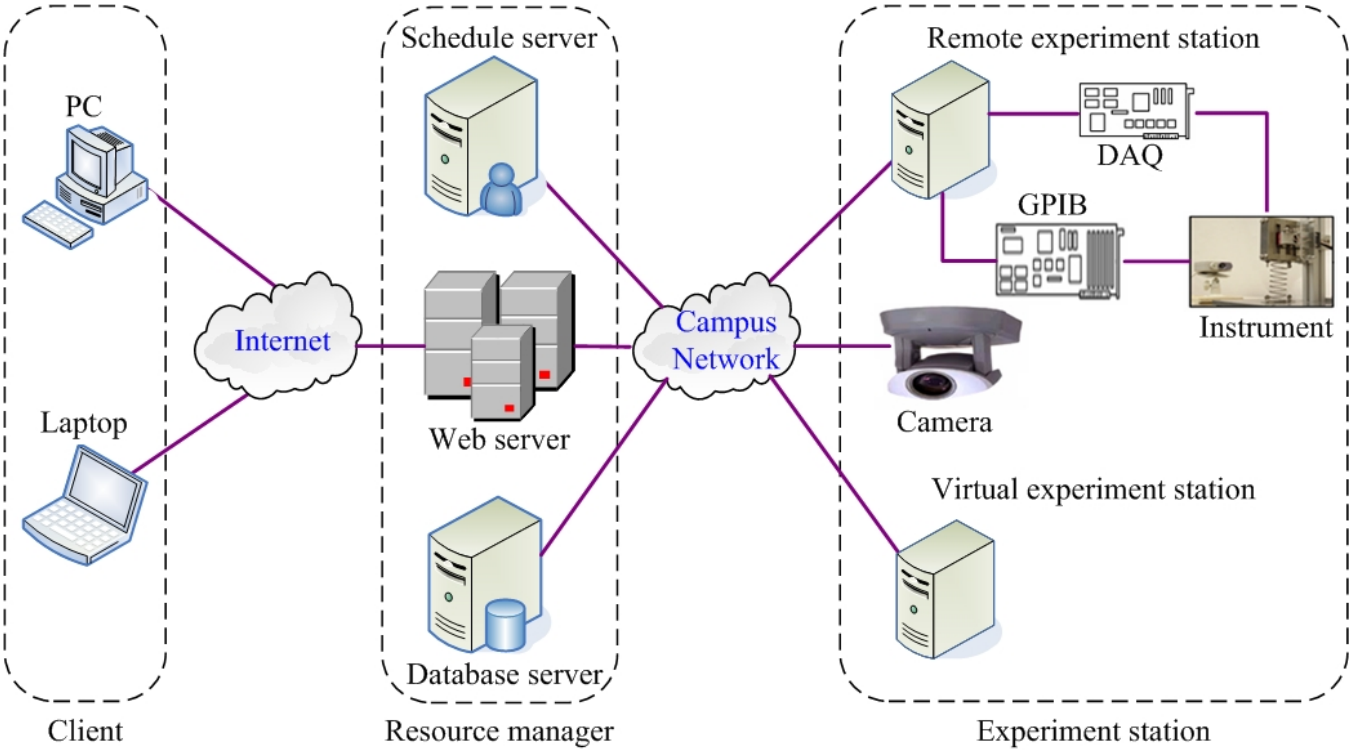

FIGURE 1
SYSTEM ARCHITECTURE

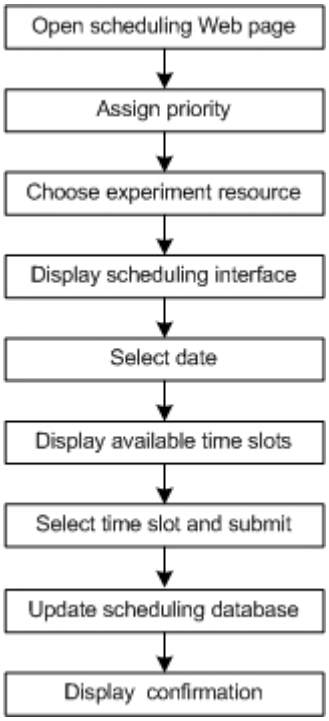

FIGURE 2
WORKFLOW FOR SCHEDULING A TIME SLOT

The workflow can be summarized as follows:

- The user opens the scheduling Web page
- The system assigns a priority according to provided user registration information (this priority is used for solving schedule conflicts for different users as discussed in more detail in a later section)
- The user chooses an experiment resource with the desired characteristics
- The system displays the scheduling interface
- The user selects the date for carrying out the experiment in the scheduling interface
- The system displays the available time slots for the selected resource on the chosen date
- The user selects a desired time slot from the available time slots and submits the request
- The system saves the user schedule information and updates the scheduling database
- The system displays a confirmation of the schedule to the user

III. Waiting online for a resource

For potentially large numbers of students using online laboratories, there will likely be a few students trying to access a particular experiment at the same time because they forgot to reserve a time slot. Therefore, one of the functions of the scheduling component of the RM is to resolve conflicts. The RM uses the workflow shown in Figure 3 to give the user a choice of waiting online when the resource is occupied by another user.

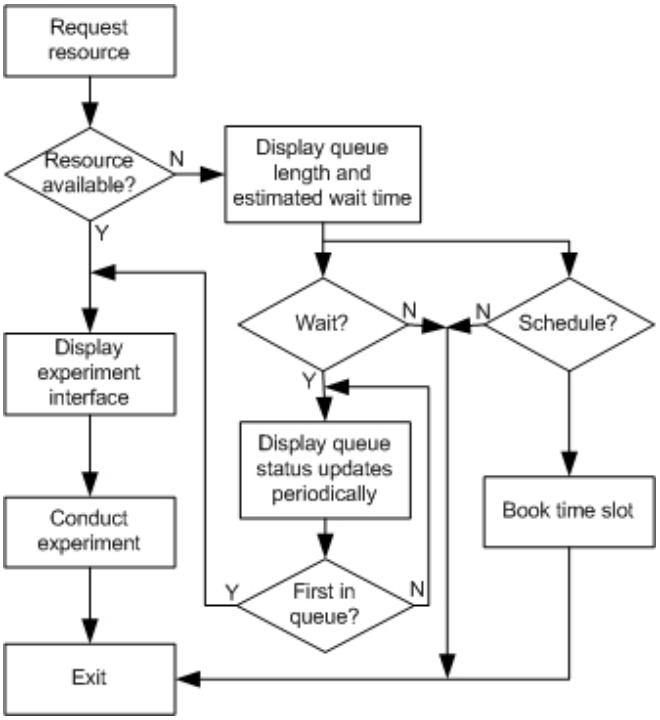

FIGURE 3
WORKFLOW FOR WAITING ONLINE

Normally, any user can conduct a particular experiment if nobody else is using the corresponding resource. If the user tries to access an online experiment and finds the corresponding resource unavailable, the RM generates a queue on a first-come first-serve basis to manage the users who want to wait for the resource to become available. Then, according to the queue length and estimated waiting time provided by the RM, the user has two choices. First, if the queue is short and the user does not want to find another time slot, the user can choose to wait online for the resource to become available. Otherwise, the user can directly schedule another time slot for using the resource later.

IV. Priority design

As mentioned at the beginning of the paper, the online laboratories discussed here are used for educational purposes. Providing students with convenient access to experimental resources is one of the different modes of usage of these resources. In addition, this scheduling system was designed with some integrated functionality for assigning different priority levels to the various user requests. These priorities are based on the following different types of users:

- Students: Their main objective is to utilize the resources to complete laboratory assignments using specific experimental setups. During the experimental procedures, they need to operate the instruments and

collect the resulting data according to the laboratory instructions.

- Instructors: Their most common resource usage is for experimental demonstrations during a live class. This type of usage may require control over the resource for a longer time and with higher priority. This means that all other usages of the resource must be subordinated.
- Administrators: They are responsible for maintaining the resources and avoiding their abusive usage.

All users of the system must register to obtain a user account. The users fall into one of the three groups listed above with different associated priority levels. In order to avoid malicious attacks on or abuse of the system as well as to manage the users, upon opening an account, the users must provide their names, e-mail addresses and usage objectives (i.e. research experiment, educational experiment, class demonstration, etc.). Upon registration, all users are automatically assigned the lowest priority, thus classifying them as students. If someone wants to obtain instructor priority level, manual verification by the system administrator is required before the account is reclassified. Then, registered users can use their accounts to log into the system and start usage sessions. Once a user logs into the system, the RM automatically assigns a priority level to the session according to the user's group affiliation. This means that different users have different limitations:

- A student can only reserve one time slot per day and cannot schedule a time slot that has already been reserved by another user.
- An instructor can schedule two or more subsequent time slots. If a user is already logged into the system when another user requests access, then this user is inserted into a waiting queue. If the second user is an instructor, then this instructor is inserted at the top of the waiting queue, i.e. before any students that might already be in the queue. As soon as the current user completes the work, the next user from the waiting queue gains access to the system.
- The administrator can change the priority level of a specific user account and block user accounts.

V. Software module design

The overall software architecture for the RM developed is shown in Figure 4. The system was realized using a multi-layer software approach that enables the various distributed applications (i.e. Web application, lab agent and experiment/camera controller) to interoperate with each other. Furthermore, the efficiency of the implementation and the reuse of several software modules were also key concerns during the development process. The main software modules are as follows:

- The first software layer is the graphical user interface (GUI), which presents the available information and actions to the user. The user interface was implemented such as to be accessible from all platforms that are able to process HTTP, thus making the system entirely platform-independent.

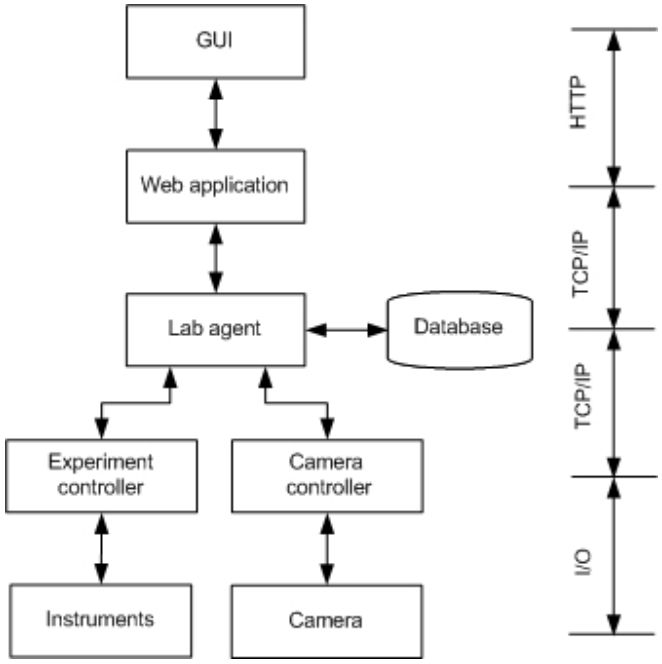

FIGURE 4
SOFTWARE STRUCTURE

- The second software layer is the Web application, which processes the requests from the GUI and posts back the results of these requests. The processes of 'experiment input form generation', 'scheduling request form generation', and 'schedule information check' are part of this layer.
- The lab agent forms the third software layer. It accepts the input from the Web application requested by the user and then generates a user input queue based on the user requests, including 'waiting online' requests and 'scheduling' requests. According to the user request, the lab agent transmits the request to the appropriate controller (i.e. experiment controller or camera controller). This layer makes the interactions between Web application, database and experiment controller transparent to the user. The Web application does not depend on the details of the experiment implementation, and the experiment controller does not depend on the details of the database operation. The separation of the database and instrument operations renders the development of the Web application and the experiment controller independent, thus improving the development efficiency and making the reuse of program modules easier.
- The instrument and camera controllers constitute the fourth software layer. They are used to control the real physical instruments such as the experimental devices, lights, cameras and microphones.
- The instruments and cameras represent the hardware components that perform the requested operations.

This RM was designed to manage the resources within an institution and to speed up the future development of

additional experiments. The experiment controllers together with their associated instruments can be considered as black boxes in the system, which have a common communication interface with the system. User inputs (e.g. experiment input data, scheduling requests, etc.) and experiment output (e.g. experiment status, experiment feedback, etc.) are processed by the lab agent via this communication interface. Because the communication is based on platform-independent TCP/IP connections, the scheduling functionality can be reused later for additional online resources to be developed in the future.

VI. Taking advantage of an appointment

After scheduling a time slot, the user needs to perform the experiment starting at the reserved time. Sometimes a user may fail to take advantage of the scheduled time slot because of unpredictable factors. In that case, the system offers the user several options as indicated in the process workflow shown in Figure 5:

- If the user tries to conduct the experiment at another time and the resource is not occupied, then the user can access the online experiment, but there is no guarantee for availability. This means that when the next time slot starts and the owner of that time slot wants to us his or her reservation, the system will not let the user continue to control the resource.
- If the user fails to access the experiment at the reserved time, the system gives the user a grace period. During that grace period, the system locks the resource for the user. After that grace period has elapsed, the system unlocks the resource and opens it up for other users.

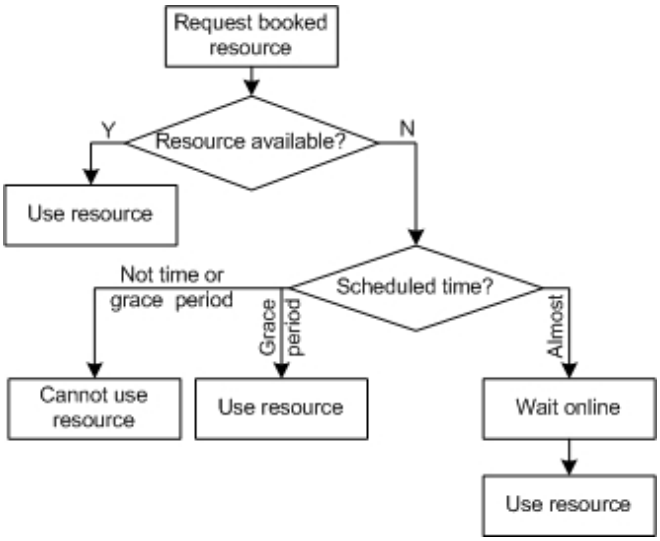

FIGURE 5
WORKFLOW FOR EXERCISING AN APPOINTMENT

EXAMPLE

Consider a student who is learning the theory of vibrations in a dynamics class. This student plans to first solve the homework problems in the textbook and then carry out the assigned experiment via the Internet. To avoid a potential time conflict with other students, this student chooses to make a reservation before beginning the experiment. Figure 6 shows the interface used for scheduling a time slot for an online vibration experiment. After selecting the date on which the student wants to conduct the experiment, the available time slots for the chosen experiment are listed. The student can select only one time period per day. If another student tries to access the experiment resource while this student is utilizing it at the reserved time, a status report for the experiment as shown in Figure 7 is displayed to guide the other student to either wait online or make a reservation.

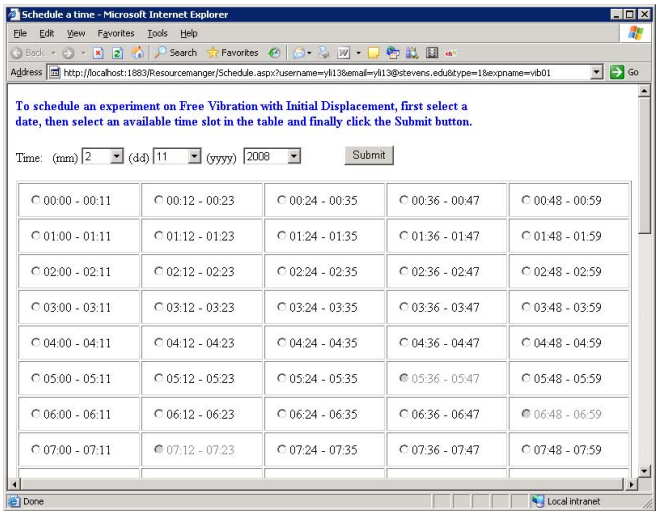

FIGURE 6
SCREENSHOT OF SCHEDULING A TIME SLOT

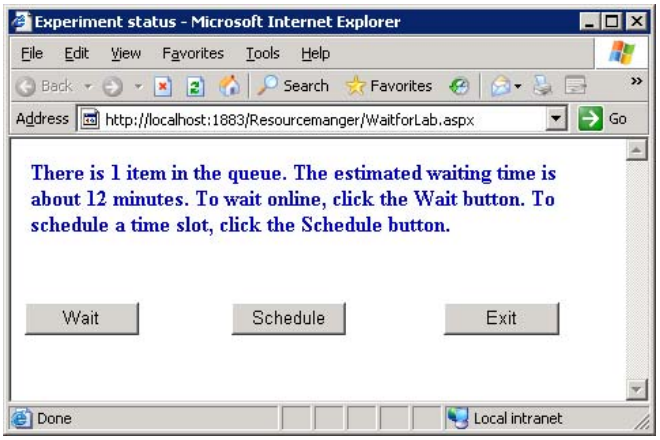

FIGURE 7
SAMPLE STATUS REPORT

The scheduling is not limited to one online experiment. After making a schedule for the vibration experiment, the student could also make additional reservations for other experiments involving for example a wind tunnel, a cantilever beam and so on. In order to help the users in better arranging their schedules, the RM provides a tool for viewing and editing all reservations made. A sample user interface is shown in Figure 8.

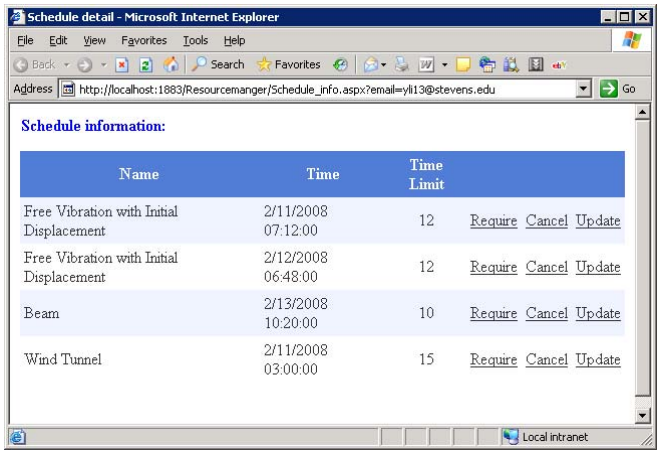

FIGURE 8
GUI FOR MANANGING ARRANGED SCHEDULES

CONCLUSIONS

The rapid spreading of broadband Internet access is enabling new methods of delivery for modern engineering and science curricula at educational institutions worldwide. Various online laboratories are beginning to play an increasing role in education and training. This paper described the design and pilot implementation of a scheduling system for shared online laboratory resources. This scheduling system can be employed to coordinate reservations of usage time for these resources by multiple geographically dispersed users and to avoid time conflicts between these users. Also, it provides integrated functionality for handling various priority levels for the user requests in order to facilitate different modes of usage. Furthermore, this system was designed in a platform-independent fashion that will accommodate the expected rapidly increasing number of newly developed resources in the future. This software module can also be integrated into a more general online resource management system, which enables the standardized description and classification of and efficient search for online resources [20]. Collectively, such tools have the potential for leading to fundamental changes in engineering and science laboratory education.

ACKNOWLEDGMENT

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