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A FRAMEWORK FOR SHARING ONLINE LABORATORY RESOURCES

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ABSTRACT

Numerous online laboratory resources have been and continue to be developed by many educational institutions around the world. These resources include both remote laboratories, which are based on actual experimental devices accessed remotely, as well as virtual laboratories, which represent software simulations of experiments. In the vast majority of the cases, the remotely accessible online laboratories reported on in the literature represent stand-alone systems, which are typically difficult to share by large numbers of learners dispersed at various educational institutions. This has led to the existence of many functionally similar, but independently operating systems developed in many places.

This paper will identify the common features of such online laboratory resources. Then, the framework for a network of interconnected resource managers, which facilitate the efficient implementation and deployment of as well as the subsequent search for and shared usage of online laboratory resources (e.g. remote experiments, virtual experiments, game-based environments, etc.), will be presented. A centralized resource repository is presented that enables the publishing of information on the existence and availability of specific resources through the network. Finally, an example is given that illustrates the issues relating to joining, publishing, searching for and accessing online laboratory resources in that framework.

KEY WORDS

Online laboratory resource, remote experiment, resource manager, resource sharing, search, virtual experiment

1. INTRODUCTION

1.1 Motivation for this work

Laboratory work exposes students to practical issues and physical instruments and is, therefore, important in engineering and science education. Certain types of experiments can be delivered solely by online means. Successful applications of online laboratory systems with varying degrees of interactivity have been reported by many educational institutions (1, 2, 3, 4, 5, 6, 7, 8 and 9). One of the prominent advantages of online laboratories is their flexibility of delivery. They allow the students to not only work at their own pace but from any location and at any time they choose. Recently, studies of educational outcomes have started to appear in the educational literature, which provide increasing evidence for the educational viability of such online laboratory resources (10, 11, 12 and 13).

Typically, the remotely accessible online laboratories reported in the literature represent stand-alone systems, and it is rather difficult for potential users to locate them and then make a decision about which online laboratory resources best satisfy their requirements. In this context, there is an increasing need for a framework to connect such online laboratory resources as well as search for and share these resources.

1.2 Some related work

Recently, many research efforts have been made to provide technologies or infrastructures to support the sharing of distributed online experimentation systems. MIT developed iLab (14), a shared architecture to support batched experiments across institutional boundaries. A method to guide the learning resource recommendation according to the student's learning status was described (15), which focuses on how to organize learning materials based on domain ontology. In order to find suitable learning materials that best match the students' needs, a multi-attribute evaluation method was proposed (16). Based on connecting similar learners to form a small community, shared common needs for learning resources can be identified during different learning processes (17). Building upon these concepts, this paper discusses a framework that enables the search for and communication between distributed online laboratory systems.

First, an analysis of the common features of online laboratory resources is presented. Then, the general software application used for managing these resources at different universities is discussed. A framework to search for and share online laboratory resources by connecting and exchanging resource information with these software applications is described. Finally, two cases are illustrated to explain issues relating to joining, publishing, searching for and accessing online laboratory resources in that framework.

2. ONLINE LABORATORY RESOURCES

In order to efficiently share online laboratory resources amongst many users, the common features of these resources must be identified, thus establishing a unified way to represent them. The information describing an online laboratory resource can be separated into a field feature and a deployment feature, in addition to a name and a description.

Each online laboratory resource is associated with a specific field feature, which includes a domain (e.g. engineering, science, medicine, etc.), a discipline (e.g. mechanical engineering, electrical engineering, etc.), a sub-discipline (e.g. statics, dynamics, solid mechanics, etc.) and a subject (e.g. vibrations, gears, inertia, etc.). For example, Figure 1 shows a remote experiment for demonstrating the deflection of a cantilever beam under transverse loading (18). This experiment is related to the subject of "beam" in the sub-discipline of "statics", which in turn is part of the discipline of "mechanical engineering" in the domain of "engineering". These dependencies can be organized in a hierarchical structure, and any laboratory resource can then be placed uniquely in this structure. A portion of this hierarchical tree structure is depicted in Figure 2.

The existing online laboratory interfaces were implemented in many languages. In addition, due to their implementation or other factors, they exhibit different technical characteristics, and they can be classified into three categories:

- Remote experiments (19, 20 and 21) involve the operation of a real, remotely located, physical system (i.e. experimental devices equipped with actuators and sensors to manipulate and monitor them), including visual and data feedback from the remote site (i.e. involving some type of "real presence" to the remote site).
- Virtual experiments (22, 23) represent interactive simulations accessed through graphical user interfaces (often involving realistic three-dimensional graphics animations) but provide no visual or operational link to a real physical system.
- Game-based experiments (24, 25), through immersive environments provided by computer game engines, can facilitate rich interaction and collaboration between team members in conducting experimental procedures.

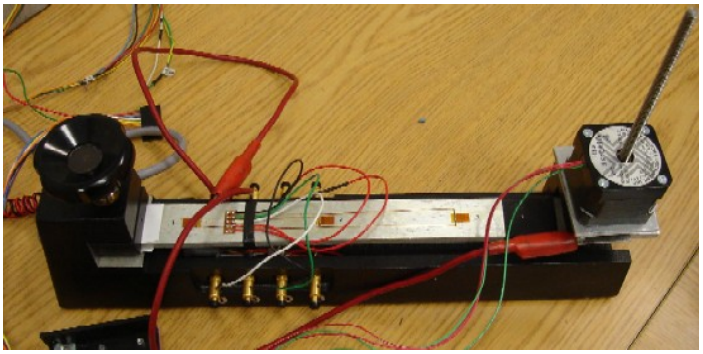


Figure 1: Remote experiment with a cantilever beam

In addition, some online laboratories provide video or audio support, and furthermore these resources may have special access policies (e.g. usage fees, copyright or other restrictions, etc.). Building on the analysis of these common features, a coding scheme was developed, which allows the identification of suitable online laboratory resources on the Internet more efficiently than by applying one of the commercial search engines. A more detailed description of this coding scheme can be found elsewhere (26).

3. RESOURCE MANAGER

Most online laboratory systems 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. Often, software tools such as Common Gateway Interface (CGI) (27), Hypertext Preprocessor (PHP) (28), Java Server Pages (JSP) (29), ASP.NET (30) and Active Server Pages (ASP) (31) are used on the server side to establish management functionality for the various experiments that reside locally at a particular institution. In this paper, the software tool used to manage the online laboratory resources is referred to as resource manager (RM), which performs the following functions:

- **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 congestion.

These functions and software modules for online resource management are used to operate several remote and virtual experiments developed at Stevens Institute of Technology (SIT, see Figure 3).

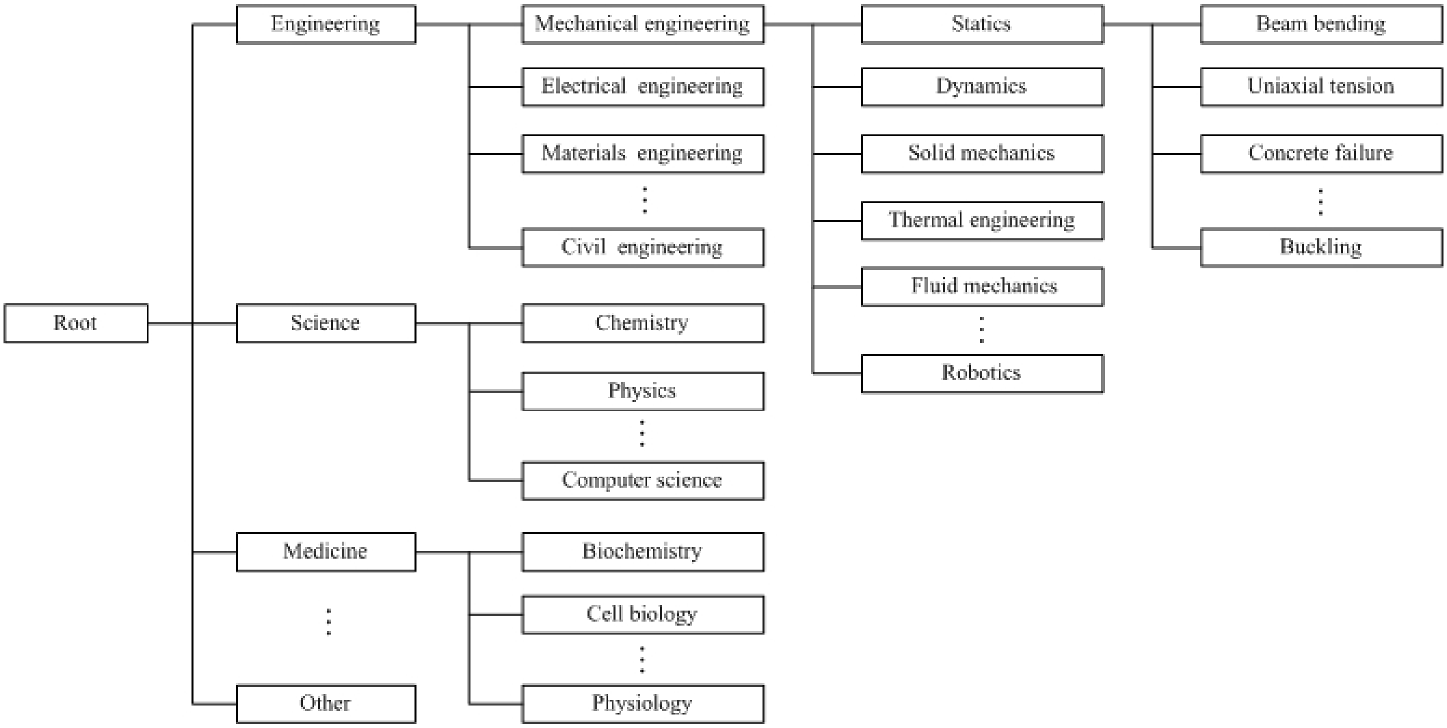


Figure 2: Part of hierarchical tree structure for identifier “field”

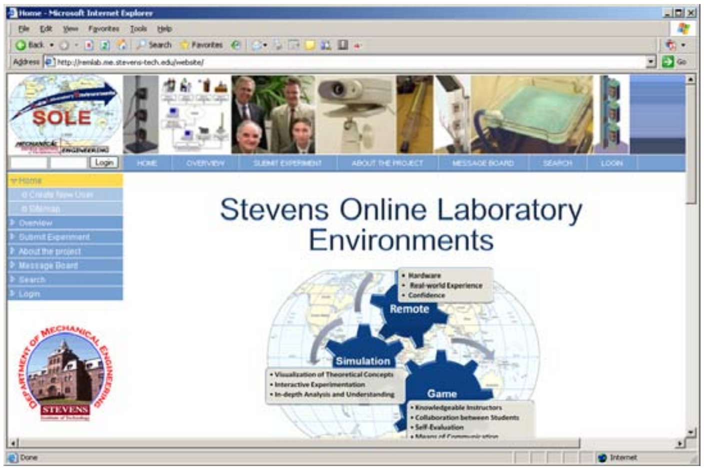


Figure 3: Stevens online laboratory environments

4. NETWORK OF RESOURCE MANAGERS

Computer networks are used as the interconnection of two or more computers in order to share files and folders, applications, or resources like printers, scanners, web-cameras, etc. They can be divided into two major categories: server-based and peer-to-peer networks(P2P) .

In P2P networks, there are no dedicated servers or hierarchy among the interconnected computers. All of the computers on the network handle security and administration individually. Each computer can act as both a server (sharing resources) and client (using resources). There is no centralized control over the resources (e.g. files or printers). Individual users simply share the resources whenever and with whomever they want. Typically, all computers are equal in the sense that no computer has a higher priority for network resources.

Unlike P2P networks, sever-based networks provide for centralized control of network resources. Sever-based networks are also known as client/server networks because of the clearly defined distribution of roles between client computers and server computers. The client computers use the resources available on the network while a dedicated server provides the shared resources and handles security and system administration for the entire network.

Comparing these two network models, the P2P network architecture lets all clients provide resources, including bandwidth, storage space and computing power. Thus, as additional nodes are integrated into the network and demand on the system increases, the total capacity of the system also increases. This concept exactly matches the goal at hand to efficiently utilize all online laboratory resources available around the world. Currently, there are several different architectures for P2P networks:

- **Centralized**: Napster (33) and other similar systems have a constantly updated directory hosted at a central location (e.g. the Napster website). Nodes in the P2P network issue queries to the central directory server to find which other nodes hold the desired files.
- **Decentralized but structured**: These systems have no central directory server, but they have a consistent protocol to ensure the network structure. "Structured" means that the P2P overlay topology (i.e. the set of connections between P2P members) is controlled and that files are placed not at random nodes but at specified locations that will make subsequent queries easier to satisfy. There is a growing literature on such structured P2P systems which support a hash-table-like interface (34, 35 and 36). One drawback is that such systems only directly support exact-match search.
- **Decentralized and unstructured**: These are systems in which there is neither a centralized directory nor any precise control over the network topology or file placement. Gnutella (37) is an example of such designs. The placement of files is not based on any knowledge of the topology. To find a file, a node queries its neighbors. The most typical query method is flooding, where the query is propagated to all neighbors within a certain radius. This search mechanism is extremely unscalable, thus generating large loads on the network participants.

Beyond building the network to connect the online laboratory resources distributed around the world, how to find the resource is a key issue that needs to be considered in this framework. The concept underlying commercial search engines (e.g. Google 38) and file-sharing programs (e.g. Napster) can be used for that purpose. Both Google and Napster employ a centralized index, which makes it fast and efficient to locate available resources on the Internet and in the P2P network, respectively. The work presented here was inspired by the approach employed by search engines and file-sharing programs. A centralized repository is used to host an index of available online laboratory resources and communicate them between resource managers. This system enables its users to efficiently find and collaboratively use online laboratory resources that are distributed all over the world.

Figure 4 depicts the overall network structure, including four representative sample institutions. This architecture corresponds to a centralized P2P network. In this framework, each participating institution offering or using resources can be considered a peer. If a peer wants to find a desired online laboratory in the network, a corresponding query has to be sent only to the resource repository. This process avoids the query having to be propagated through the entire network, wherein there would be no guarantee that a peer with the desired resource even existed. In addition, the widespread propagation of queries would cause a high amount of traffic in the network, and hence such networks typically exhibit very poor search efficiency. After finding the desired resource from the centralized resource repository, direct communication between the peer to use the selected resource and the peer offering it can be carried out.

5. EXAMPLE

In this section, the key issues for sharing online laboratory resources using the network framework described above will be described based on an example. The four general steps involved are as follows:

- **Join**: How to add a resource manager to the network?
- **Publish**: How to deposit information on the existence and availability of a resource into the resource repository?
- **Search**: How to find an online laboratory resource meeting certain user requirements?
- **Access**: How to access an online laboratory resource?

Step 1: Join

Figure 5 depicts a sample network, including five resource managers: RM A, RM B, RM C, RM D and RM E. At the outset, the resource repository already "knows" (i.e. has information on the existence of) RM A, RM B, RM C and RM D. These four RMs may "own" (i.e. be directly associated with) or not "own" experiment stations (i.e. remote and/or virtual experiments). Then, another institution wants to join the existing network. This step can be accomplished by registering the new RM (here RM E) with the resource repository using Web services such as discussed in detail elsewhere (39).

Step 2: Publish

Subsequently, RM E uses the Web service of the resource repository to report the information on the experiment stations "owned" by it to the resource repository, and the resource repository inserts this information into a database that indexes all existing online laboratory resources. Then, RM E is "known" to the resource repository, indicated in Figure 5 by a double-arrow line. The status of "known" implies that the resource repository can communicate with the RM. In particular, it can periodically query the information on the resources "owned" by the RM.

Step 3: Search

One of the important services of the network of resource managers is a feature enabling the search for a desired resource with certain characteristics. Minimizing the message volume and improving the resource search efficiency are important issues when deploying the search algorithm in P2P networks (40). As shown in the example in Figure 6, a user logged into RM B initiates for instance a search for experiments involving a "beam" by sending a message to the resource repository. After querying the indexed resource database, the resource repository replies with a list of online laboratory resources that meet the search condition. Comparing the approach described here with decentralized P2P networks, only two messages are generated in this search process. Also, a customized and efficient search algorithm based on the field and deployment features describing the online laboratory resource was implemented to meet our needs. The search interface indicating a sample search is shown in Figure 7. The right side represents the input screen for the search criteria and results and the left side is a pop-up window for field selection.

6. Step 4: Access

The user logged into RM B can carry out the beam experiment by directly communicating with RM D, which “owns” the desired beam experiment. Direct communication between users and experiment resources are especially valuable for high-bandwidth or low-latency communication, such as video streaming or real-time control (the framework shown here does not make any provision for this direct communication).

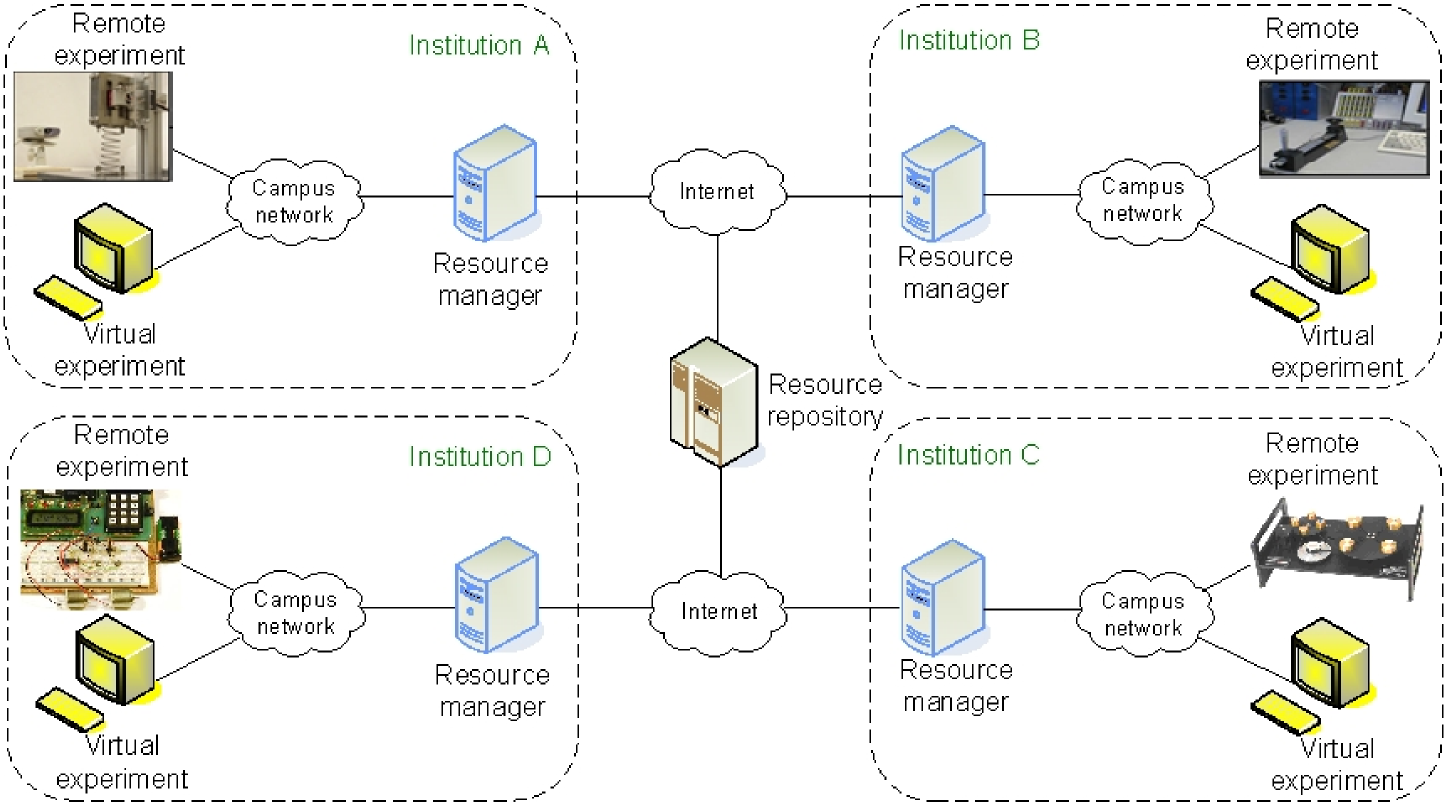


Figure 4: Proposed P2P network topology with a centralized resource repository

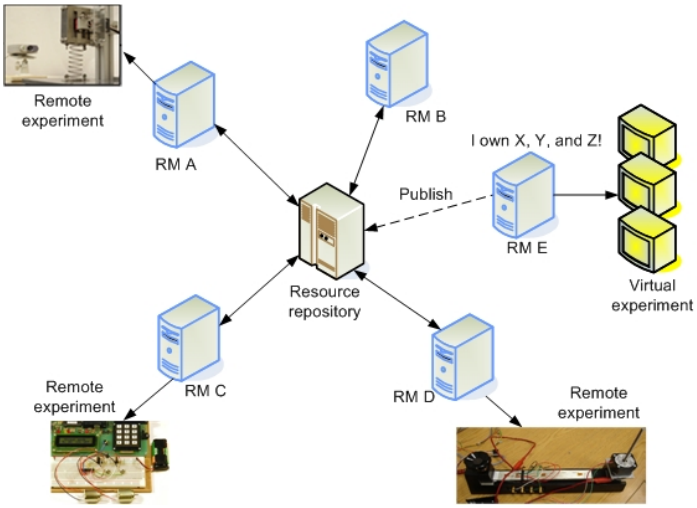


Figure 5: Publishing of online laboratory resources

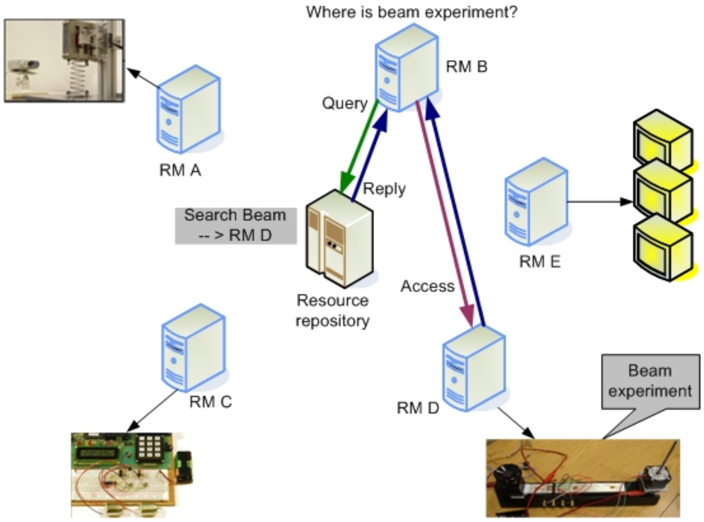
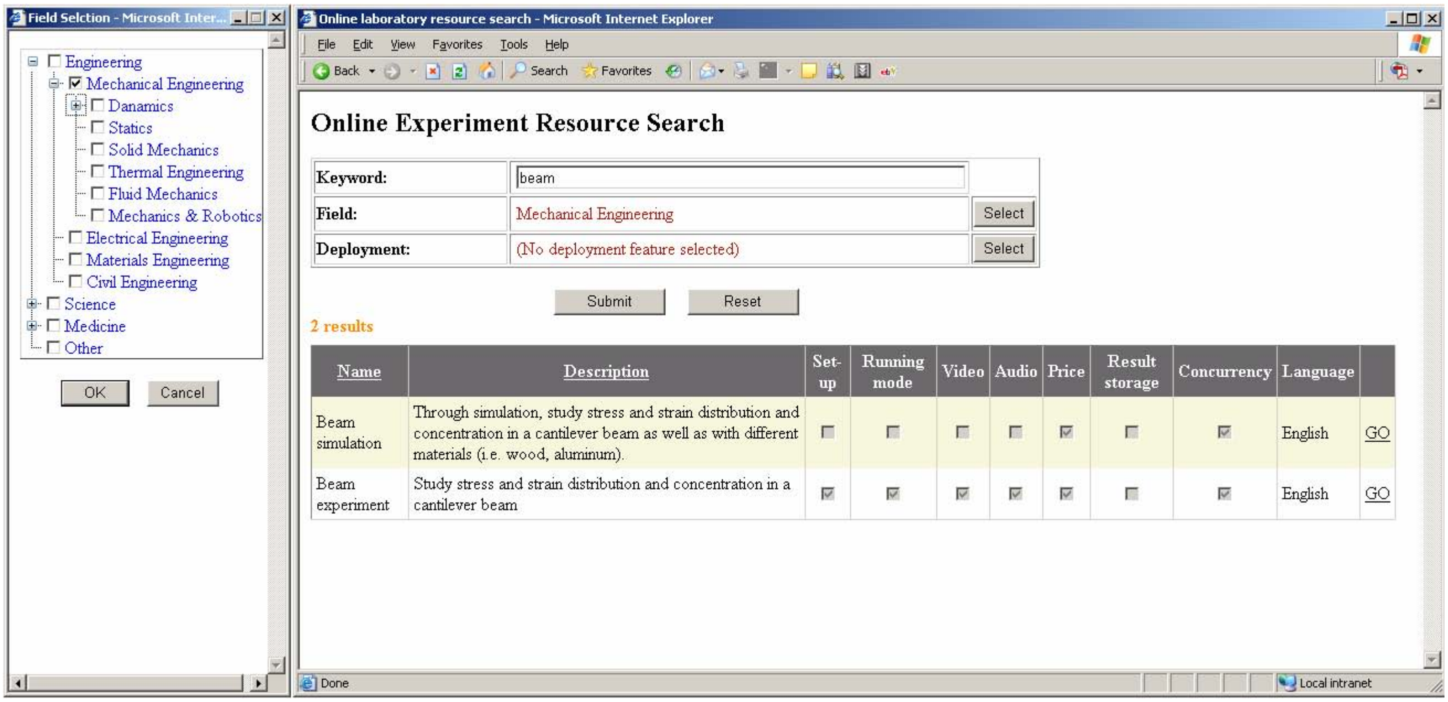


Figure 6: Searching for online laboratory resources



- ☐ Engineering
  - ☑ Mechanical Engineering
    - ☐ Danamics
    - ☐ Statics
    - ☐ Solid Mechanics
    - ☐ Thermal Engineering
    - ☐ Fluid Mechanics
    - ☐ Mechanics & Robotics
  - ☐ Electrical Engineering
  - ☐ Materials Engineering
  - ☐ Civil Engineering
- ☐ Science
- ☐ Medicine
- ☐ Other

OK Cancel

Online Experiment Resource Search

Keyword:	beam	
Field:	Mechanical Engineering	Select
Deployment:	(No deployment feature selected)	Select

Submit Reset

2 results

Name	Description	Set-up	Running mode	Video	Audio	Price	Result storage	Concurrency	Language	
Beam simulation	Through simulation, study stress and strain distribution and concentration in a cantilever beam as well as with different materials (i.e. wood, aluminum).	☐	☐	☐	☐	☑	☐	☑	English	GO
Beam experiment	Study stress and strain distribution and concentration in a cantilever beam	☑	☑	☑	☑	☑	☐	☑	English	GO

Figure 7：Screenshot of the search interface

CONCLUSIONS

This paper describes the common features of online laboratory resources, which are separated into a field feature and a deployment feature, in addition to a name and a description. Then, a P2P network of interconnected resource managers, which are located at different institutions and facilitate the efficient implementation and deployment of as well as the subsequent search for and shared usage of online laboratory resources, is presented. A centralized resource repository with a search index is described that enables the publishing of information on the existence and availability of specific resources in the network. This centralized index renders the search for available online laboratory resources in the P2P network efficient.

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