Oxford CyberSEM: Remote Microscopy

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Abstract. The Internet has enabled researchers to communicate over vast geographical distances, sharing ideas and documents. e-Science, underpinned by Grid [1] and Web Services, has enabled electronic communications to the next level where, in addition to document sharing, researchers can increasingly control high precision scientific instruments over the network. The Oxford CyberSEM project developed a simple Java applet via which samples placed in a JEOL 5510LV Scanning Electron Microscope (SEM) can be manipulated and examined collaboratively over the Internet. Designed with schoolchildren in mind, CyberSEM does not require any additional hardware or software other than a generic Java-enabled web browser. This paper reflects on both the technical and social challenges in designing real-time systems for controlling scientific equipments in collaborative environments. Furthermore, it proposes potential deployment beyond the classroom setting.

1. Introduction
Microscopy can take the young into a microscopic world that can’t be seen with the naked eye. When 6- or 7-year-olds see 'hundreds and thousands' through a simple light microscope, or an ant or a fly or sugar grain magnified 20-fold, their eyes light up with excitement. However, by the time they reach senior school, the things that they are taught about the microscopic world are often out of reach, either because the light microscopes available to them are not powerful enough, or because the topics of study are beyond the resolution of a normal school microscope. Lessons and assignments rely on textbook images, and the opportunity for hands-on discovery of the microscopic world, and the fascination that this can bring, is lost.

The increasing access that schools have to the Internet, the availability of low-cost, fast links (e.g. broadband) and improvements in image compression and access security make it certain that within this decade, access to remote instrumentation and experiments will increase. Oxford University has developed a prototype that gives control of a dedicated scanning electron microscope (SEM) to schools over the Web. A full-scale dedicated Jeol 5510LV SEM is installed in Oxford and is undergoing road-tests over the Internet by a small number of schools to solicit feedback on its usability. The overarching vision includes the development of lesson modules and supporting documentation, including detailed lesson plans, in collaboration with science teachers in secondary schools to integrate use of a sophisticated microscope into the curriculum. The remote operator can change the microscope magnification, move around the sample, focus and capture images directly onto his/her computer at a range of resolutions. The remote operator can choose between a set of samples, selected as most appropriate for student learning in the 14-18 age group. At present, most samples are focused on the biology curriculum and include leaves, rat skin, E. coli, sperm, bacteria,
salmonella, rat kidney, radiolarians, trachea, lung and pollen, but plans are in place to broaden into the physics and technology curricula.

2. Design Considerations

Designed with schoolchildren in mind, CyberSEM does not require any additional hardware or software other than a generic Java-enabled web browser readily available across schools in the UK. Consultations were carried out with the various stakeholders to ensure that non-microscopists can operate the SEM with minimal training and technical knowledge. The design incorporated additional features beyond the base functionality for enhancing a sense of co-presence. Live video of the room housing the physical microscope is streamed continuously to allow the user to observe the actual movements of the gears as samples are manipulated. Furthermore, the local control software at the SEM’s console is left permanently running on the display to convey a sense of co-presence. This allows the remote users to simultaneously view the updated images on the console as samples are being manipulated through the remote interface.

![Figure 1: CyberSEM Java applet with SEM controls and live video streams](image)

2.1. System Architecture

Conceptually, the architecture and design of the backend systems and the interfaces are relatively simple. A centralised Linux server, `websemserver`, hosts the web site containing the booking system and classroom lessons plans. Two hardware-based video servers from FlexWatch are used: one to capture the current view of the sample in the microscope and a second one to stream live video of the physical room itself, the latter enabling collaboration between remote and local users. All communications with the video servers are restricted by a firewall. Both the video streams can only communicate with `websemserver` in order to reduce any broadcast traffic on the departmental network and to further minimise security risks by prohibiting direct access to them.
Figure 2: CyberSEM architecture

Websemserver also hosts the client application comprising of three Java applets that are downloaded to the user’s desktop. The applets are consolidated into a separate window when launched on the user’s machine, as shown in Figure 1. The rows of buttons at the top of the window comprise the control applet with the two video windows comprising the remaining two. Based on Web Services, the applets communicate directly with Apache and Tomcat\(^1\) executing on the Linux server. All control commands are forwarded from websemserver to a dedicated computer controlling the physical SEM. Video streams from the two hardware-based video servers are intercepted by websemserver and tunnelled back through Apache to the respective applets in the client application. This also ensures that schools would only need to trust a specific port on a specific machine at the University, reducing concerns about external systems serving materials that are inappropriate for schoolchildren.

2.2. Graphical User Interface

As mentioned earlier, the underlying goal of the project was to provide schools with facilities for incorporating a sophisticated electron microscope into their curriculum, without the associated capital or maintenance expenses to them. The aim was to develop a simple application that can be executed in schools using standard hardware and software. The user interface had gone through a number of iterations, having consulted both teachers and learners. It originally consisted of sliders and dials to control magnification, focus, contrast and brightness. However, they proved to be quite difficult to use given the fine granularity provided by the SEM. Additional buttons were incorporated for setting the level of granularity for each of the respective controls. However, these not only reduced the available real-estate for the live video windows, these proved to be somewhat confusing given that each function operated at vastly different ranges. The current version requires the user to press the button corresponding to the desired functionality and subsequently move the mouse pointer up or down to modify the settings. Whilst counter-intuitive to some of the adults, it proved to be readily adopted by the pupils following an initial trial.

The design also considered using a token system so that multiple users from multiple desktops, and optionally at multiple sites, could control the SEM during the same session, i.e. the user with the token would control the SEM whilst others would merely observe. However, this was not something the teachers perceived as being useful in their classroom. Rather, it was suggested that only a single computer should have control over the SEM. This allows for greater interaction amongst the pupils as they gather around the main display and take turns to operate the SEM. It also ensures that only one site has control and temporary responsibility over the expensive microscope at any one time. Additionally, it reduces the risk of damage through abuse by competing users.

An image capture button was incorporated to be able to take a snapshot of the current view of the active sample. In addition to the image, it embeds the magnification level along with the voltage

\(^1\) Apache Tomcat is the servlet container that is used in the official Reference Implementation for the Java Servlet and JavaServer Pages technologies.
information that can be included as part of a pupils report for submitting subsequent exercises developed as part of the lesson plan.

3. Deployment Challenges
Deployment raised several challenging issues. Whilst the system was designed to operate over even moderate speed broadband connections, complex firewall policies, especially in UK secondary schools, posed a major problem. This is partially due to strict rules regarding live video streaming. Collaborating with University’s computing services, departmental computing services, schools and their respective ISPs, firewall policies were relaxed to allow streaming from websemserver. However, video signals were still being blocked. A specific solution to this general problem was finally discovered by allowing direct access to port 80 not only to websemserver, but additionally from specific computers in the schools. Whilst not technically simple, this requires coordination across a number of organisations with the additional burden of oversight by a number of authorities.

Manipulation of the samples within the video window raised additional technical challenges. Intercepting mouse events, whilst not highly challenging, required reverse engineering of proprietary video libraries. However, any interruption or errors in the network stops the streams in the applet windows. Restarts buttons had to be incorporated as a temporary measure to circumvent the problem. The system also had to take into account that the state of the SEM, retrieved via manufacturer’s APIs, may not necessarily reflect the true status of the microscope.

4. Conclusions
CyberSEM was initially funded by the Department of Trade and Industry through its e-Science programme and by the electron microscope manufacturer Jeol. The project engineered facilities that allow samples placed in a SEM to be examined and manipulated via the Internet through a simplified, easily usable set of instrument controls. Aimed at schoolchildren, consultations were carried out with various stakeholders to ensure non-microscopists could operate the SEM with minimal training and technical knowledge. The next phase of the project is to integrate further feedback received from the various field-test users and develop a production version of the prototype with advanced security and functionality. This will enable CyberSEM to be used in outreach programmes from museums during field trips organised by schools for further public engagement of science. Furthermore, the production version will be designed and associated protocols tuned such that the capabilities are readily transferable to more sophisticated microscopes available at characterisation facilities for commercial use by Small and Medium Enterprises (SMEs) and large industries alike. CyberSEM not only aims to return the excitement back into science, it also hopes to inspire and train the next generation of young scientists towards ensuring that UK companies maintain an edge in an increasingly competitive global market.

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Reference
[1] Foster, I and Kesslemann C (2003) The Grid 2: Blueprint for a New Computing Infrastructure, Morgan Kaufmann Publishers, ISBN 1558609334.