TELEMICROSCOPY

Gary Fan, Phil Mercurio*, Steve Young and Mark Ellisman
U.C. San Diego and *San Diego Supercomputer Center

While many of us have used a computer network to send E-mail, how about using it to remotely control an electron microscope? That's exactly what Telemicroscopy refers to.

Up to now electron microscopy (EM) has been conducted typically in a darkened enclosure, with the operator sitting in the dark for hours staring at a dim phosphor screen. This paradigm was not, however, closely followed during the telemicroscopy demonstration at the SIGGRAPH 1992 meeting in Chicago, where microscopic images were acquired on-line over the Internet high-speed computer network from the intermediate-high voltage electron microscope located at the San Diego Microscopy and Imaging Resource. Stereo-pairs were displayed on a color projection screen in front of many spectators and camera crews.

The rational behind such effort is not, however, to avoid the dark which we microscopists are adapted to, but to improve the accessibility and effective usage of the limited number of electron microscopy resources. As we know, establishing and maintaining a state-of-the-art EM resource involves considerable initial cost and continued support of staff with special skills and knowledge. Since the relatively high costs limit the number of such facilities, effective usage of these resources is crucial. By developing a system through which researchers can mail in their specimens and examine them remotely without leaving their own laboratory (or office), we expect to increase the utilization of these unique resources and reduce travel related cost significantly.

To operate an electron microcope remotely and interactively obviously requires that (1) the microscope be remotely-controllable, and (2) that images be immediately available to the user so that fast feedback is possible. These conditions are met to some degree at the present: modern electron microscopes are invariably equipped with an internal microprocessor which, in addition to coordinating functions of various components and peripherals, interpreting user operations and executing microscope parameter changes, can also accept external commands through, typically, a serial port; on-line digital image acquisition devices, such as slow scan CCD camera systems, make high quality images immediately available for computer manipulation and network transmission; high-speed comp[uter networks, although not yet widely available, do exist and are expected to expand rapidity in the next few years as the nation's information highway (see *Time*, April 13, 1993, page 50) and *Science*, May 21, 1993, page 1064) promoted by the High Performance Computing and Communication Initiative recently passed by the U.S. Congress, shapes up. Thus all the major elements required to conduct microscopy from a remote site are in place. What remains is to link these to enable "telemicroscopy".

Our prototype telemicroscopy system consists of the following:

1) The Microscope: A JEM-4000 EX electron microscope, with a side-entry stage, was modified for the telemicroscopy project. This microscope possesses an internal microprocessor which supports communication to the outside-world over a serial communication port (4800 baud). The available commands allow emulation of all panel operations. The four axes of the goniometer; x, y, z and tilt, are driven by four servo motors coupled to position encoders. The motor-encoders are controlled by a dedicated IBM compatible PC which can also be controlled externally.

2) Digital Image Acquisition Devices: The viewing and recording devices for telemicroscopy are a side-entry TV system and a 1024 X 1024 pixel slow scan CCD camera with a custom-made, bottom mount lens coiupling to the microscope. The CCD system can achieve single-electron sensitivity in the high gain mode. The insertion and retrieval of the pneumatically activated TV camera can also be controlled remotely through the serial port of the microscope. The TV camera is intended for live-viewing by a local operator who will assist the remote user at least in the early stages of the telemicroscopy development. It may also be used to acquire relatively rapid, preliminary views across the network. The slow scan CCD camera will be the high resolution image acquisition device for the remote user. The camera head can be rotated through 180 degrees so that the image can be oriented in a desired way on the computer screen. This feature is useful, for example, in stereo-pair acquisition where the tilt axis should be oriented vertically on the computer screen for stereo viewing.

3) Local Host: A Sun SPARC Station 2 computer serves as the local host, which houses the image acquisition hardware and executes programs for (1) communication with the remote user; (2) controlling all the microscope operations and the stage movement and (3) acquiring images using the TV and the CCD camera and, if requested, sending them to the remote station over the network. The host computer is connected to the FDDI computer network via a fiber-optic cable, which has a bandwidth of 100 megabits/second.

4) Remote Workstation: Currently only UNIX based platforms are supported at the remote site. Any computer with good networking and image handling capability and a reasonable amount of processing power should be fine. For example, a Macintosh Quadra series (-700, -800, -900 and -950) computer with 30 megabytes or more memory should be adequate, and we expect to support this platform in the future.

5) Software: This is an important part of the telemicroscopy system. Since the user does not see the actual instrument, the software plays the role of a virtual microscope with which the user interacts. Mainly two applications, CAP/CON and GridBrowser, are running at the local and remote sites, respectively, talking to each other through the computer network. A network utility, Intercom, allows voice communication between the local and remote sites using the audio capabilities of the workstations to send segments of digitized speech over the same network, which is a great help especially in case of trouble.

The prototype was demonstrated at the 1992 SIGGRAPH meeting in Chicago, Supercomputing 1992 and various other occasions. Prior to a demonstration, a low magnification image of a large region of the specimen area is pre-mapped by montaging. The remote user browses through the low magnification sample using GridBrowser. When an area of interest is found, the user may issue a command to acquire a higher magnification image of that area. GridBrowser sends a message with the coordinate information to the local server, CAP/CON, to take the following actions: (1) moving the stage to the coordinates of the location; (2) inserting the focusing screen to determine the illumination, and, if necessary, adjusting the illumination level; (3) retrieving the screen and capture an image with the CCD camera with the proper exposure and (4) sending the image with a "task completed" message to GridBrowser, for display at the remote user site. In addition to requests for single images at different levels of magnification, the remote user can use GridBrowser to acquire a nxn montage of images, stereo pairs or tomographic tilt series, and the tomography data set can be sent over the network to the San Diego Supercomputer Center for 3-D reconstruction.

Telemicroscopy is the first step towards a distributed EM resource, a laboratory without walls. We expect that such a system will increase our access to specialized instruments, high-performance computation, and expertise concerning new techniques in microscopy. It will also make possible collaborations and interactions between scientists as they each view and analyze data at their respective locations. ■

I half a spilling checker
It came with my PC.
It all ways show four my name
mistake I cannot sea.
I've run this poem threw it;
I'm sure you please to no.
It's litter perfect in its weight.
My checker tolled me so.
- - - Delbert E. Philpott

Advertisers, Please Note:

The development of this newsletter has been an interesting challenge. And we have reached the point where our fixed costs are reasonably constant.

In a hope to increase total advertising revenue, we are decreasing our rates - with a continued hope that this vehicle will be attractive to you. Effective with our next (September), issue our (one or two color) rates are:

1/8 Page:	$350
1/4 Page:	$600
1/2 Page:	$900
1 Page:	$1,800
Inserts:	$1,500

And will continue to print high quality inserts (one or two color) at attractive pricing.

Rates for copy in the "New and/or Interesting in Microscopy" section will continue at $5 a word - with a 20 word minimum.

And we will improve on the "reader response" card feature as properly started with this issue.

- - - Don Grimes, Editor

PS - And for those who advertised in this issue, we will offer a 20% discount for our next issue!!!