SEM Remote Control with a 3D Option

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Remote control of a scientific instrument is a topic gaining more and more attention between instrument users and operators. The project presented in this article reports results obtained from two distinct research efforts. The main outcome from the first research was the realization of an application to remote-control a Scanning Electron Microscope (SEM), while the main outcome from the second research was the implementation of a procedure to reconstruct 3D surfaces.

The remote control application is a server/client application [1], and [2]. The server/client structure is comprised of two different applications. The server application, resident on a computer locally, is connected to the instrument and it works as middleware between the instrument and the client. The client application is implemented on the remote user's computer, and is able to control the instrument through a TCP/IP connection. The main aspect of this server/client application is that it has been designed not only for working on local networks but, in particular, for providing good performance when used over the Internet. The remote commands implemented on the client application concern the connection to the server application, the connection to the microscope, the management of microscope controls, communication with the local operator, video streaming of specimens' images, and the management of the 3D surface reconstruction engine. Excluding the video streaming, the communication between client application and the microscope is practically in real-time.

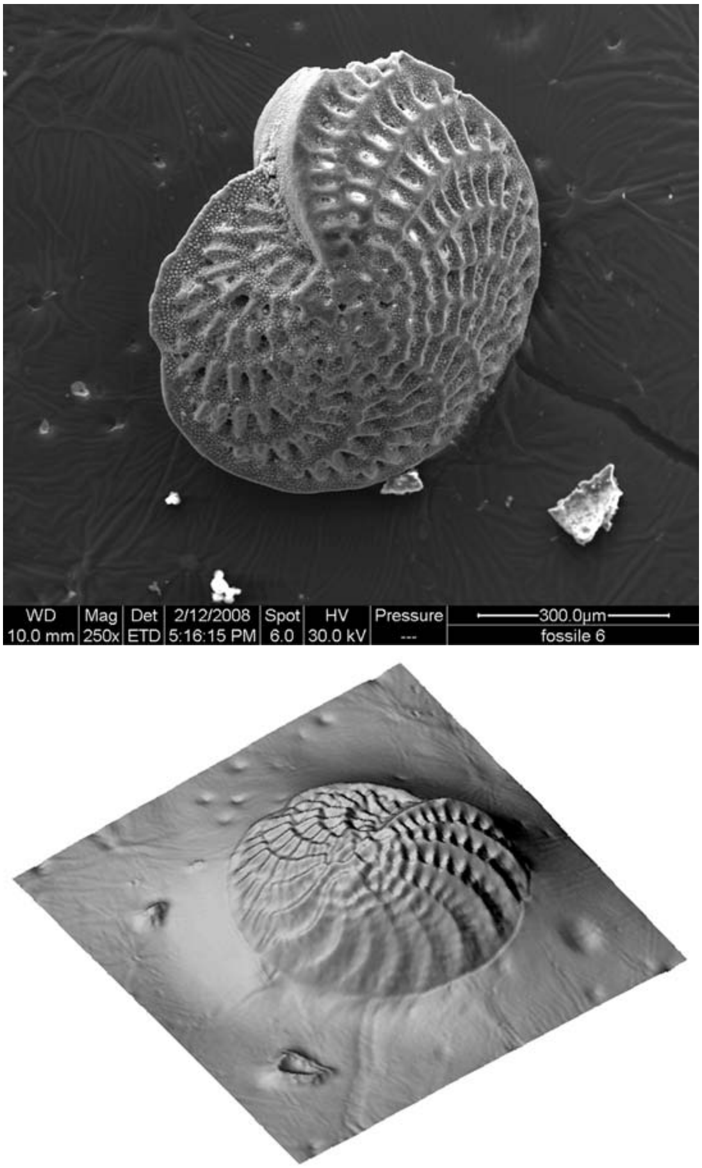

FIG. 1a, top: The image of a shell fossil with the Scanning Electron Microscope operating in high vacuum. 1b, bottom: The fossil foraminiferan surface 3D reconstruction obtained by the method briefly explained in this paper.

The procedure for 3D surface reconstruction was originally designed as a local application [3] and was modified during work for providing remote control functionalities. The 3D tool extracts the third dimension from back-scattered electrons [3]. This method for reconstructing the depth map in the SEM is founded on a 4-Source Photometric Stereo (PS) technique, which is based on the so-called reflectance map that uses several images of a surface, taken from the same viewpoint but under different lighting directions, to estimate the relative surface depth at each image point.

The image acquisition process may require specific instrumentation (4-sector, independent channel axial BS detector), or a strictly standard SEM configuration with specimen rotation/translation. In this last case, an alignment procedure had been developed [4] to simulate different lighting conditions in a standard SEM. It is necessary to rotate the specimen under the fixed detector and to acquire four images sequentially of the same specimen view after imposing three 90° rotation steps on the specimen. A sequence of four pictures of the same area will be obtained, each of them apparently illuminated from a different lighting direction. All these microscope operations are executed via remote control without any delay utilizing the 3D reconstruction tool available in our remote control application. Fig. 1a and Fig. 1b show an example of 3D reconstruction using this technique.

The results demonstrate that it is possible to remotely control an SEM on a public network, both for conventional and non-conventional operations, even if the video streaming is affected by network limitations. Starting from this point, a new research project was undertaken. The topics of this project are several: on one hand, it is important to obtain real-time video streaming on a public network. On the other hand, it will be useful to realize a distributed architecture where it is possible to share instruments through tools for conventional and non-conventional operations on a public network.

Real-time video streaming on a public network will be best handled via new internet communication protocols; new telecommunication network features, like wide band and low latency; and exploiting standard video coding techniques tuned and adapted to the nature of the video signals being encoded. The current implementation is based on H.264/ACV [7] standard encoder optimized for fast encoding of the RGB digital signal coming from the SEM.

The development of a distributed architecture requires a complete revision of the way the remote control was implemented in previous projects. In fact, despite the good results obtained with

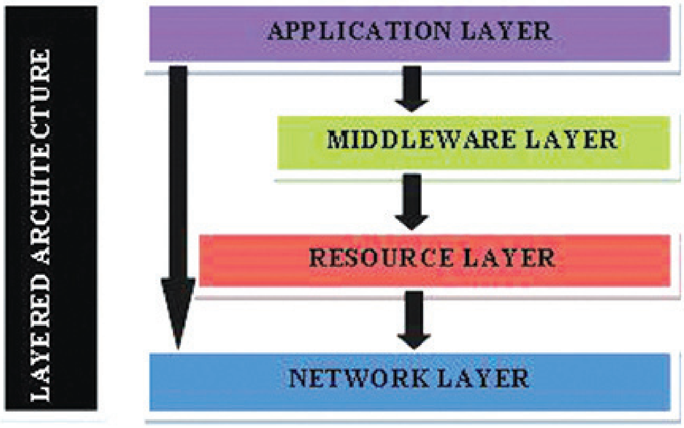

FIG. 2: Example of layered structure.

the server/client application, some aspects restrict the utilization of remote control. The main problems are that the server/client application requires that remote clients install the client application on their own workstations, and that it is necessary to implement a server/client solution for each instrument when sharing more than one instrument. In order to overcome these limitations we identify distributed computing protocols, more commonly known as Grid technology, as the available technology to reach our goals. The first phase has been a research effort concerning the state of the art of this technology, in order to identify the best solution. The features of Grid technologies are explained in [5] and [6]. The main property is that Grid architectures are layered structures. Fig. 2 shows an example of a possible layered structure. The advantages of applying Grid technology on different instruments are listed below:

- Security access;
- Security connection;
- Real-time interaction;
- Interoperability;
- Real-time streaming video;
- Concurrent access by multiple users to the same resource;
- Public network availability.

In this Grid example, every layer has a dedicated role, and implements the solution to these questions. In particular:

- Network layer connects all resources and contains the interfaces implementing local control and managing the security aspects;
- Resource layer groups resources such as computers, storage systems, instruments, sensors, electronic data catalogue, data base;
- Middleware layer is the layer where there are all the tools that allow the interaction between the grid resources available;
- Application layer is the only one accessible by the user. Here are the User Interfaces of the available applications.

Among the several advantages provided by Grid architectures, there is a point particularly relevant to remote control of microscopes: instrumentation security. It is obtained by observing that layers containing the application interfaced directly with the instruments are completely hidden to unauthorized remote users. Only the layers with Graphical User Interfaces (GUI) of the applications pertaining to remote control of the instruments by authorized researchers, with conventional and non-conventional operations, are available to those specific remote users. Moreover, Grid architecture is accessible through an electronic certificate, that improves the security of Grid shared resources. Another favourable point is that the layered structure allows an easier configuration of the remote control operation, because it is possible to develop a unique GUI to remote control different specific instruments. When the remote client accesses the Application Layer, and selects the resource to use, just the commands related to it will be enabled. In this way, it is easier to include other options, like the 3D surface reconstruction engine, which are not specific for the instruments, but is an option developed *ad hoc* for improving the instrument's performances and experimenting with new technologies and applications. ■

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