Remote direct manipulation:
A case study of a telemedicine workstation[1]

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Abstract

This paper describes our experience with the design of a remote pathologist's workstation. We illustrate how our effort to apply direct manipulation principles led us to explore remote direct manipulation designs. The use of computer and communication systems to operate devices remotely introduces new challenges for users and designers. In addition to the usual concerns, the activation delays, reduced feedback, and increased potential for breakdowns mean that designers must be especially careful and creative. The user interface design is closely linked to the total system design.

1. INTRODUCTION

Direct manipulation has been described as a visual representation of the world of action with rapid, incremental and reversible actions (Shneiderman 1983). The objects and actions of interest are shown continuously, users generally point, click, or drag rather than type, and feedback, indicating change, is immediate. However, when the devices being operated are remote, these goals may not be realizable and designers must spend additional effort to cope with slower response, incomplete feedback, increased likelihood of breakdowns, and error recovery. The problems are strongly connected to the hardware, physical environment, network design, and the task domain.

We studied these problems in the context of a remotely controlled microscope system used by pathologists to make diagnoses based on seeing microscope slides of tissues, blood, or other specimens. Our task was to redesign an existing system (developed by Corabi International Telemetrics, Inc.) to enhance its usability and provide for future extensions. This paper presents our solutions to some of the problems and discusses the extension of direct manipulation principles to an environment that includes remote control. We describe the Corabi Project and show examples of user interface design issues and then outline principles of remote direct manipulation.

2. THE CORABI TELEPATHOLOGY WORKSTATION

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Telemedicine is the practice of medicine over communication links. The physician being consulted and the patient are in two different locations. Corabi International Telemetrics developed the first telepathology system (Weinstein, Bloom and Rozek, 1987 and 1989) that allows a pathologist to render a diagnosis by examining tissue samples or body fluids under a remotely located microscope. The transmitting workstation consists of a high resolution camera mounted on a motorized light microscope. The image from the camera is transmitted via broadband satellite, microwave or cable. The consulting pathologist sits at the receiving workstation where she/he can manipulate the microscope using a keypad and look at the high resolution image of the magnified sample. Both physicians talk by telephone to coordinate control of the system and to request slides that have to be manually placed under the microscope.

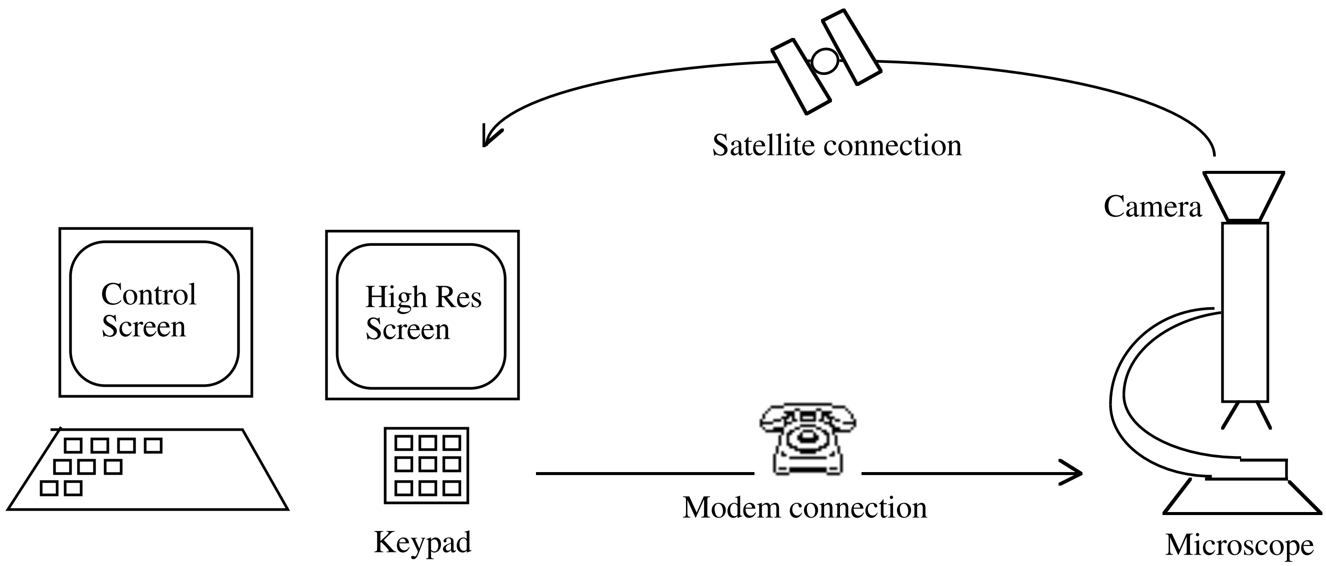

Figure 1: Simplified diagram of a telepathology system.

The system also allows the pathologist to store the results, recall the case at a later time, ask for second advice and manage the patient's records. During a work session the pathologist alternates between selecting cases to work on and performing a diagnosis. To conduct the diagnosis the pathologist goes back and forth between reading the patient record, choosing the slide to be viewed and entering the diagnosis.

Practically, the pathologist sees a high resolution screen displaying the analog image from the microscope, and a control screen (a PC display). The control screen only displays alphanumeric data and is used for database management tasks on the patient records, as well as to establish connections with the remote site and display status data during the connection. In the original system a third monochrome screen was used to display a small scanned global image of the whole specimen. To control the microscope the pathologist uses a keypad (with arrows keys and function keys) as well as a large number of buttons and toggles mounted on the rack holding the circuitry. The microscope controls include:

- magnification (three or six objectives),
- focus (coarse and fine bidirectional control),
- illumination (bidirectional adjustment continuous or by step), and
- position (2-dimensional placement of the slide under the microscope objective).

Our overall task was to redesign the database access, navigation among the tasks, and remote control of the microscope during the diagnosis. According to the principles of direct manipulation, our first step was to group related displays and controls that were originally dissociated such that all alphanumeric displays (all displays except the high resolution one) and controls are found on the control screen and can be manipulated with a pointing device. The control screen becomes the central part of the user interface.

3. TYPICAL PROBLEMS OF REMOTE DIRECT MANIPULATION

The architecture of a remote environment such as described above introduces several complicating factors that rarely occur in direct manipulation environments:

<u>Time delays:</u> The network hardware and software cause delays in sending user actions and receiving feedback: *transmission delays*, i.e., the time it takes for the command to reach the microscope (in our case, transmitting the command through the modem), and *operation delays*, i.e., the microscope itself does not respond right away. These delays in the system prevent the operator from knowing the current status of the system. For example, if a positioning command has been issued it may require several seconds for the slide to start moving. As the feedback appears showing the motion, the users may recognize that they are going to overshoot their destination, but it will also take a few seconds to have the stopping command take effect.

<u>Incomplete feedback:</u> Devices originally designed for direct control may not have adequate sensors or status indicators. For instance, our microscope can report its current position but it is so slow to provide it that it cannot be used continuously. Thus, it is not possible to indicate on the control screen the exact current position relative to the start and desired positions.

<u>Feedback from multiple sources:</u> Incomplete feedback does not imply that there is no feedback at all. The image received on the high resolution screen is the main feedback to evaluate the result of an action. In addition, the microscope can occasionally report its exact position allowing recalibration of the status display. It is also possible to indicate the estimated stage position during the execution of a movement. This estimated feedback can be used as a progress indicator whose accuracy depends on the variability of the time delays. To comply with the physical incompatibility between the high resolution feedback (analog image) and the rest of the system (digital) the multiple feedbacks are spread over several screens. Thus, the pathologists are forced to switch back and forth between multiple sources of feedback, increasing their cognitive load.

<u>Unanticipated interferences:</u> Since the devices operated are remote, and may be also operated by other persons in this or another remote location, unanticipated interferences are more likely to occur than in traditional direct manipulation environments. For instance, the slide under the microscope may be moved (accidentally) by a local operator. As a result, the positions indicated may not be correct. A breakdown may also occur during the execution of a remote operation, without indicating this event properly to the remote site. Such break-downs require additional information and actions that allow for the cancellation of actions to prevent their

completion.

Our proposed solution to these problems is to make explicit the network delays as part of the system, without compromising the overall system usability. The user needs to see a model of the:

- starting state of the system,
- action that has been issued, and
- current state of the system as it carries out the action.

In addition we believe that it is preferable to provide spatially parametrized positioning actions (i.e. move of a distance +x,+y or to a fixed point (x,y) in a two dimensional space), rather than providing temporal commands (i.e. start moving right at a 36° angle from the horizontal). In other words, the users specify a destination (rather than a motion) and wait until the action is completed before readjusting the destination if necessary. In general, we try to turn the remote environment as much as possible into a direct manipulation environment by applying the same basic principles.

However there may be obstacles to implementing these principles. We will highlight the problems involved by discussing the redesign of the slide position control, because it illustrates the additional challenges of dealing with remotely operated devices.

4. SLIDE MOVEMENT CONTROL - A DESIGN EXAMPLE

To provide a visual representation of the world of action it is certainly helpful to present a global view of the slide to the pathologist on the control screen. Since the specimen itself only occupies a small part of the slide, the global view lets the pathologist know what parts of the slide need to be observed and if the specimen under the slide is made of one or several separate parts. A red rectangle shown on the slide indicates the position of the microscope objective and tells what portion of the slide (the stage) is being viewed on the high resolution screen. Markers can be also placed on the map to indicate points saved. The rectangle can be selected with a pointing device and used to move the stage to another position on the slide. Similarly a saved point can be selected to be retrieved. These actions are handled with direct manipulation principles, making them easy to learn and to remember. Unfortunately, several problems blocked the extension of these principles to the control of all movements of the slide.

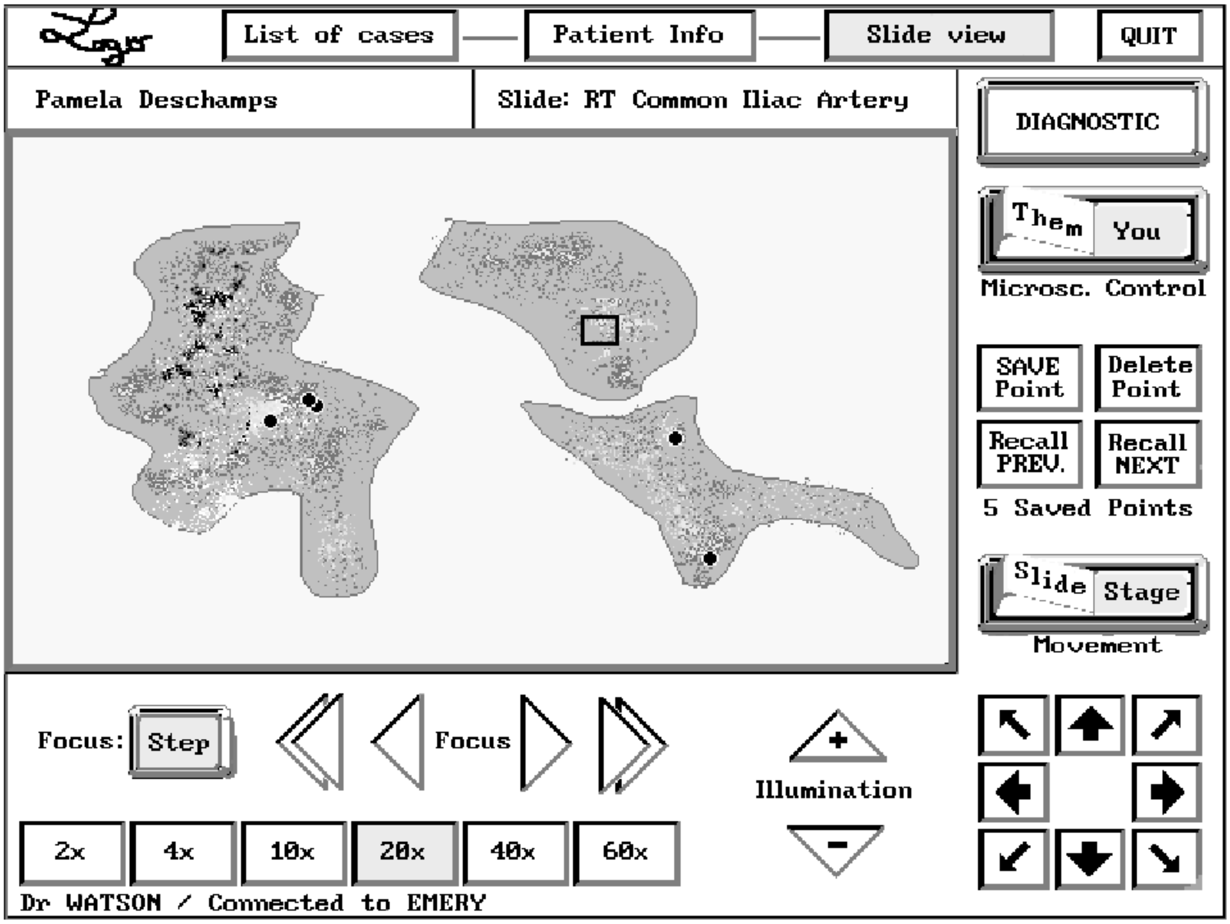

Figure 2: the control screen, showing the global view of the slide
and the stage position mark.

The first problem is that the microscope movements require very precise and smooth moves when using a high magnification. This makes it very difficult to use direct manipulation of the rectangle (then very small) on the global slide view. Of course we envisioned using zoomed images of the global view of the slide. Despite the fact that this technique would require the user to zoom and pan the global view before actually controlling the slide movement, we were faced with the problem that there was no practical way to obtain a useful zoomed image. The microscope was too slow to scan a full slide, it could not guarantee a precise and consistent placement of the slide to have the scanning done in advance by a technician, and the stored image was space expensive.

What we could provide, however, was the fine control of the slide relative to its current position (i.e. specify a direction and distance) rather than in an absolute manner (i.e. specify a position). The global view of the slide is used only to give feedback about the position of the stage. Thus, it can not be used as an object that can be manipulated (moved) directly with respect to all levels of magnification. But the spatial representation provides more control for the pathologists because it indicates where the part visible on the high resolution screen is located with respect to the whole specimen. Since the saved points are displayed as well, this may provide additional, implicit feedback, for instance, about regions that have been scanned already. This information is only implicitly given because it can only be derived by connecting the displayed data with the specific activities performed by the pathologists, e.g., when they choose a systematic strategy for scanning a slide.

The example shows that the device characteristics were of paramount importance in the user interface design. This is a very common problem: Remotely controlled devices often fail to provide any usable feedback at all. For example, current home automation user interfaces are constrained by the fact that home devices do not return status information to the central control [Plaisant, Shneiderman and Battaglia, 1990]. As a consequence, the conceptual design of the user interface can not be done without sufficient and often detailed knowledge about the specific devices and architecture of the overall system.

5. FROM DIRECT MANIPULATION TO REMOTE DIRECT MANIPULATION

The concept of remote direct manipulation can be rooted in two different domains which, so far, have been treated independently. Direct manipulation originated in the context of personal computers and is often identified with the desktop metaphor and office automation. The other root is in process control where human operators control physical processes in complex environments. Typical tasks are operating power plants, flying airplanes, or steering vehicles. If the physical processes take place in a remote location, we talk about teleoperation or remote control.[2] To perform the control task, the human operator may interact with a computer which may carry out some of the control tasks without any interference by the human operator. This is captured by the notion of *supervisory control* (Sheridan, 1988). Although supervisory control and direct manipulation stem from different problem domains and are usually applied to different system architectures, there is a strong resemblance.

Traditional direct manipulation can also be interpreted as a teleoperation, especially with high-speed networking and multi-tasking environments. Files that appear on a screen may come from a remote PC and the software may be distributed throughout the network. Messages and documents can be sent to or retrieved from remote machines, printers, or file servers. Even the letters on a display may be composed of font descriptions stored in a remote location from where the keystrokes are issued. Thus, the essential components of a teleoperation environment such as sensors, displays, controls, remote effectors or tools, and communication links are involved.

Remote direct manipulation (as well as supervisory control) can not be taken as a design criterion which is either fulfilled or not. One interface can be slightly more direct than another. Similarly, the control can be felt to be more or less remote. Thus, remote direct manipulation denotes a range of possible solutions rather than a binary variable. Direct manipulation is still an imprecise and subjective concept[3], although it has proved eminently useful in stimulating designers, revising existing systems, training designers, and in comparing systems. The connection between direct manipulation and supervisory control seems promising.

6. CONCLUSIONS

We believe that there are great opportunities for the remote control of devices if proper remote direct manipulation interfaces can be constructed. The notion of user control seems to play a

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2 These notions are often used as synonyms. There are, however, more subtle distinctions, for instance, between remote control and remote manipulation.

3 Cf. the summary in Hutchins, Hollan, and Norman (1986)

key role. It requires designers to provide adequate feedback in sufficient time to permit effective decision making and operation. A thorough task analysis as well as detailed knowledge about the technical environment are indispensable means to come up with creative solutions that put the user into control. The designers have to understand the system architecture, its strength and weaknesses *and* the users' needs to achieve a good conceptual design.

In domains such as office automation and process control, as well as in many others, the design of human-computer interfaces and the development of general models of human computer interaction rather than the improvement of devices are regarded as the major challenge for researchers.[4] However, devices are not yet sufficiently well designed to allow for their smooth integration in a remote environment according to the principles of remote direct manipulation:

- shorten time delays,
- provide extensive feedback of status,
- coordinate available feedback, and
- reduce possible interferences.

The development of these new integrated and remotely controlled environments also provides a stimulus for new applications. Remote controlled environments in medicine could enable specialists to provide consultations more rapidly. Home automation applications are being developed to allow more than remote operation of telephone answering machines by including security and access systems, energy control, and operation of appliances. Scientific applications in space, underwater, or in hostile environments can enable new research projects to be conducted economically and safely.

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[4] Cf. Rasmussen, Goodstein (1988), Sheridan (1987), Uttal (1989), and Van de Vegte, Milgram, Kwong (1990)

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