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Usability Experiments for the Redesign of a Telepathology Workstation

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Abstract

Dynamic telepathology uses a remotely controlled microscope to allow a pathologist to view samples at a remote location. However, time delays introduced by remote operation have made use of a commercial dynamic telepathology system difficult and frustrating. This paper describes experiments to evaluate and redesign the user interface. We also make recommendations for further automation to support the pathology process and increase the usefulness of the system.

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ABSTRACT

Dynamic telepathology uses a remotely controlled microscope to allow a pathologist to view samples at a distant location. However, time delays introduced by remote operation have made use of a commercial dynamic telepathology system difficult and frustrating. This paper describes experiments to evaluate and redesign the user interface. We also make recommendations for further automation to support the pathology process and increase the usefulness of the system.

INTRODUCTION

The first real-time, telepathology system has been developed (Weinstein et al., 1987, 1989, & 1990), and commercialized by Corabi Telemetrics, Inc. It allows a pathologist to render a diagnosis by examining tissue samples or body fluids under a remotely controlled microscope.

Weinstein showed that telepathology was possible and that diagnoses can be rendered from remote sites using a video monitor. Design efforts are now aimed at optimizing the workstation to ensure its successful use for pathology services. This case study illustrates some of the difficulties encountered in the design of a remote control interface that has to deal with time delays and accommodate hardware not intended for remote operation.

One goal of human-computer interaction research is to reduce the perceptual and cognitive resources required to understand the interface or to reduce the motor effort required to operate the interface (Shneiderman, 1992). A well-defined user interface is critical for the development and acceptance of medical workstations. Lessons should be learned from related efforts (Foley et. al., 1990 & Beard, 1991). Many previous medical workstations have failed because the user interface was poorly designed. Although there are clear overall benefits of telepathology for the health system, more attention should be given to the design of interfaces to minimize operational complexity and additional training. It has been shown that remote diagnosis is possible, but the design of a satisfactory work environment remains a challenge.

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The original microscope user interface has caused significant problems when time delays are present. Pathologists issue motion and focus control commands from a custom keypad. The original design used an arrow button to begin a microscope movement and a stop button to end it. The main problem with such commands is that it is hard to estimate how early to press stop. Worse, the stop location may not even be on the screen when users need to press stop. Of course, it's possible to backtrack to the approximate location where stop was pressed, but this takes time. Overall, pathologists considered this interface hard to use and frustrating.

The most obvious solution would be to reduce all time delays below a second. (Indeed, our experiments showed that with time delays of about a half-second the current user interface worked well.) However, this solution could not be implemented for two reasons. First, the manufacturer, a small start-up, could not afford the cost of re-engineering the product with new components to reduce delays. Second, one intended use for the system was to provide a remotely operated microscope on the space station. Since current satellite links impose significant additional delays, an interface that could operate in the presence of time-delays was required.

Unlike the dynamic system we worked on, most current telepathology systems are static systems that allow a few selected images to be digitized, stored, and viewed remotely. They are mainly used for reference or training. Static systems are unsatisfactory for normal diagnosis. A complete diagnosis requires viewing several slides, and legally, a diagnosis cannot be rendered by looking at only part of a slide. Currently, digitizing the slides in sufficient detail to meet these requirements is impractical. In addition, static systems have limited use in training. Each branch of pathology has its own exploration techniques which cannot be learned on the static system. The first dynamic telepathology system was actually implemented between two teaching hospitals wanting to share their teams of specialists in order to train residents.

The dynamic telepathology system operates as follows. The transmitting workstation consists of a high-resolution camera mounted on a motorized microscope (Figure 1). The consulting pathologist sits at the receiving workstation, manipulates the microscope, and looks at the high resolution image of the magnified sample, which is transmitted via broad band satellite, microwave, or cable. A scanned global view of the whole slide is displayed on a control screen. The scanned image is black-and-white and at low resolution to avoid a diagnosis being made on this image instead of the high-resolution image.

Our goal was to simplify the user interface by using direct manipulation principles (Shneiderman, 1992). Unfortunately, several limiting factors exist in remote interfaces:

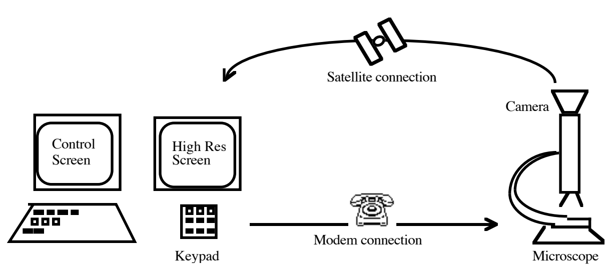

Figure 1 -- Simplified diagram of an existing telepathology system.

- Time Delays: The Corabi dynamic telepathology system delays about two seconds between user commands and microscope response.

- Incomplete Feedback: In our case, the controller is only able to report its current position when stopped. Thus, it is not possible to indicate the exact microscope position on the control screen.

- Unanticipated Interferences: For instance, the slide under the microscope may be accidentally moved by a local operator. As a result, the positions indicated may be incorrect. Or, a breakdown may occur during the execution of an operation without indicating this event properly to the remote site.

RELATED WORK

The telepathology system is an example of a supervisory control system. A supervisory control system is characterized by a human operator issuing instructions that are executed by the computer controls. In general, the feedback provided to the user is computer generated from sensors at the task end, and the operator does not receive any direct feedback. The telepathology system fits the multi-loop model of supervisory control (Sheridan, 1987 & 1988). This supervisory control model is characterized by a separate human interaction system (the pathologist's workstation) and a task interaction system (the microscope controller).

Ferrel and Sheridan (1967) studied a supervisory control system designed to command a robotic lunar vehicle from the earth. The Earth-Moon distance imposed a three-second round trip delay in command feedback. They found that the only control strategy that worked was to have the operator issue a command and wait for feedback as to the result of this command (move-and-wait strategy). Indeed, all other strategies resulted in an unstable system in which the errors of the operators were magnified by their attempts to correct them. In addition, they reported that "the operator can commit only to a small incremental movement". Ferrel and Sheridan noted that operators switched to a move-and-wait strategy as the system delay times increased over one second.

Lawrence Stark (1987) reported on a study of delays using a joystick to manipulate a remote robot. He found task times increased dramatically with delay as operators adopted a move-and-wait strategy. Next, a real-time computer simulation of the robot was added. This allowed operators to manipulate the simulation in real-time and then, the actual robot was commanded to duplicate the simulation's actions. In this case, task times were equal regardless of the actual delay. Both of the previous studies were designed for systems in space where high precision of movement was paramount. However, in telepathology real-time interaction is more important.

Funda, Lindsay, and Paul (1992) extended Stark's computer simulation to the concept of "teleprogramming". With teleprogramming the operator manipulates a computer simulation of a remote robot. However, instead of batching the commands they are sent in real-time. The robot responds to these commands when received. In the presence of significant time delays the operator does not adopt a move-and-wait strategy. If an error occurs, the simulation is backtracked to the point of the error and the operator must restart from that point. The principle difference between telepathology and teleprogramming is that it is impractical to construct a local simulation of the remote environment. The pathologist's task is to explore the remote image and render a diagnosis. The content of the sample drives the task and each sample completely changes the "navigation space". In order to construct an adequate simulation the image must be digitized. However, this is impractical at the required resolutions. Furthermore, if it were practical, there would be no need for a remotely controlled microscope. The pathologist could simply use the digital image for diagnosis.

Bejczy, Kim, and Venema (1990) experimented with force feedback control of a teleoperated Puma robot. To compensate for delays, they superimposed a wire-frame image of the robot over a video image of the robot in its operating environment. The wire-frame moved immediately in response to the operator's manipulation and force feedback was given in real-time. Delays of 0-5 seconds were introduced in the response of the robot. A preliminary experiment comparing operation with and without the wire-frame showed that the simulated position feedback dramatically decreased task time as delays increased. Time reductions of about 50% were reported for 5 second delays. Kim and Bejczy (1993) also report that a predictive display made possible high precision positioning in a robot for servicing in space. Sheridan (1993) provides a good summary of predictive display and other teleoperation experiments.

Hirzinger et. al. (1993) report on ROTEX a teleoperated robot experiment flown on space shuttle flight STS 55. ROTEX used a three-dimensional, stereographic, predictive display to compensate for 5-to-7 second delays in communication. The robot was able to perform the experimental tasks "without major problems".

The first "Medicine Meets Virtual Reality" conference (Aligned Management, 1992) reported on several teleoperated medical applications including radiology systems, and many miniaturized tools enabling physicians to perform procedures on a region of a patient's anatomy while minimizing the extent of surgical incisions.

Mercurio et al. (1992) describe an interactive visualization environment which allows physicians at remote sites to use a specialized high voltage electron microscope. In this case, it is the microscope itself which is the limited resource made available to others. Three-dimensional reconstruction and visualization tools are at the center of this project, while time delays and routine operations are not an issue.

INTERFACE REDESIGN

Our eventual solution was to blend real-time operation with computer simulation. We arrived at this solution by using successive prototypes followed by usability testing. Since the system already had the capability for digitizing the sample at low resolution in black and white, we elected to use this digitized image as a "map" or overview. The pathologist's workstation would show the position of the microscope on the map as it was reported by the remote microscope controller. We hoped this would provide sufficient contextual feedback and concentrated first on improving the movement controls.

Our first improvement was to let users specify the destination of the move. This was partially achieved by placing a red rectangle indicating the position of the microscope stage on the global view (Figure 2). The stage can then be moved by dragging the rectangle. Dragging eliminates the need to drive the microscope, and prevents overshooting. We expected this to improve the performance for long moves. Work on predictive displays and direct manipulation suggested that immediate feedback of a predicted final position would reduce operating times.

But when the specimen is viewed at very high magnification, the stage movements are too small to be specified on the global view. Therefore, additional controls are necessary. Those controls also must allow the pathologist to manipulate the movement and focus controls while looking at the high-resolution image. (Switching back-and-forth between the control display and the high-resolution image would interfere with the pathologist's task and slow performance.)

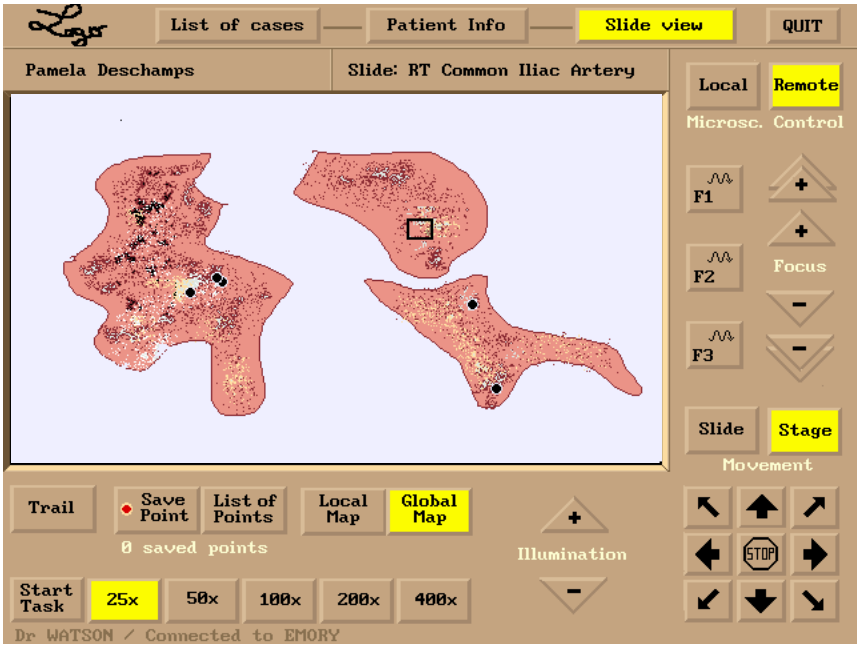

Figure 2 -- The proposed control screen of our simulator, equipped with a touchscreen.

We looked at other devices to let the user specify proportional commands (how far to go) instead of temporal commands (start-stop). Several input devices were considered.

- A "dummy" microscope, which was rejected for two reasons. First, it could not be easily produced by (or for) the small company commercializing the system. Second, it would create the false impression of responding as a conventional microscope. In fact, performance would be much worse and we expected users to quickly become very frustrated.

- A joystick, which was rejected by our sponsor for marketing reasons. (Early joystick-controlled microscopes have been rejected by pathologists as unusable and it was unlikely that many could be persuaded to use any joystick-operated microscope.)

- A mouse, which was rejected because pressing a button on a mouse also results in small movements. This would cause the microscope to move slightly on each focus adjustment unless special software was written to filter these movements.

- A 3-button track ball, which was chosen. The track ball like the mouse can be manipulated without looking at it. However, it does not have the movement problem of the mouse. Additionally, the track ball takes less working space. As we designed the microscope control, the rotation of the ball determines the distance and direction. The outside buttons were used for focusing. And, the middle button was used to issue a "stop now" command.

We built a simulator (Plaisant, Carr, & Hasegawa, 1993) of the diagnostic workstation and implemented two prototype interfaces in order to compare them at several time delays. The chief limitation of the simulator was that the samples consisted of colored rectangles instead of actual tissue samples. This limitation was imposed by the simulation hardware (2 IBM PC-ATs) which simply wasn't fast enough to animate actual tissue samples. For both prototypes, we implemented the control panel using a touchscreen. In addition, each interface had an alternate input device for operator control. The prototypes were:

1. The original interface (keypad, but dragging of the rectangle on the global view is not allowed).

2. A first track ball version (allowing the dragging of the rectangle on the overview, but not providing feedback as to the current position of the stage).

TESTING AND DESIGN ITERATIONS

Pilot Study

We then conducted a pilot study to test the efficiency of the prototype interfaces (Carr et al, 1992). Subjects were instructed to center the microscope field-of-view inside a specific rectangle on the simulated sample. Half used the original interface, and half used the first track ball version. Unfortunately, the experiment showed that the first track ball version was no better than the original interface at longer delays. In addition, the original interface was better with a half-second delay. The only tasks where the first track ball version was superior were those where the operators dragged the rectangle for coarse positioning of the microscope.

The major problem seemed to be that operators had a hard time determining how far to move the track ball to get the desired movement on the microscope. This led us to the conclusion that we needed to provide more feedback about the microscope's position. We decided improve the track ball interface by adding a limited simulation of the microscope position. This provided the user with real-time estimates of the actual microscope position and a prediction of the final stopping position of the microscope. This involved three modifications to the pathologist's workstation:

1. Adding predicted final position feedback for both the track ball motion and dragging of the position indicator on the "map" image. A predicted path was drawn between the microscope starting location and the predicted destination. This provided more user feedback for coarse positioning (Figure 3).

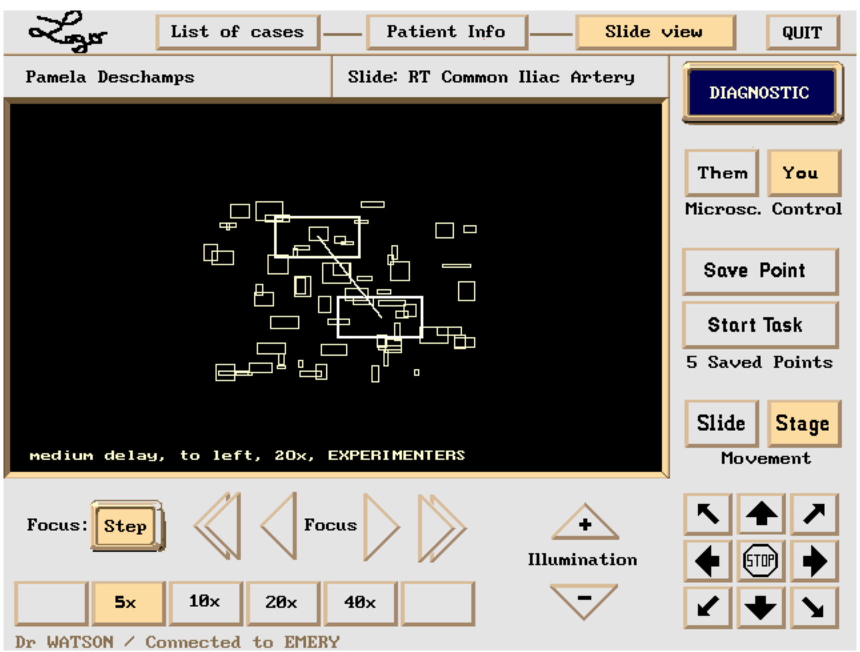

Figure 3 -- The redesigned control screen showing the predicted stopping position.

2. Adding a predicted stop position to the microscope display. A white cross would appear on the microscope display whenever the predicted stopping position was on the display. The cross was located at the predicted stopping position. When the predicted position was off of the

microscope display a yellow line would be displayed on the edge of the microscope display indicating the relative direction from the center of the microscope display to the predicted stopping position (Figure 4).

3. Adding intermediate position feedback to the "map" display. Since the microscope was not capable of reporting positions while moving, this display was a simulation of the microscope position.

Three experimenters then tested themselves with the new interface to see how it would affect the performance of pilot study tasks with experienced users. We did six repeats of the pilot study tasks with each interface. This test showed dramatic improvements in performance. The new interface was significantly faster than either earlier interface at all delays (Figure 5). The most encouraging result of the test was that not only was the new design faster, but times increased more slowly as delay increased (Figure 6).

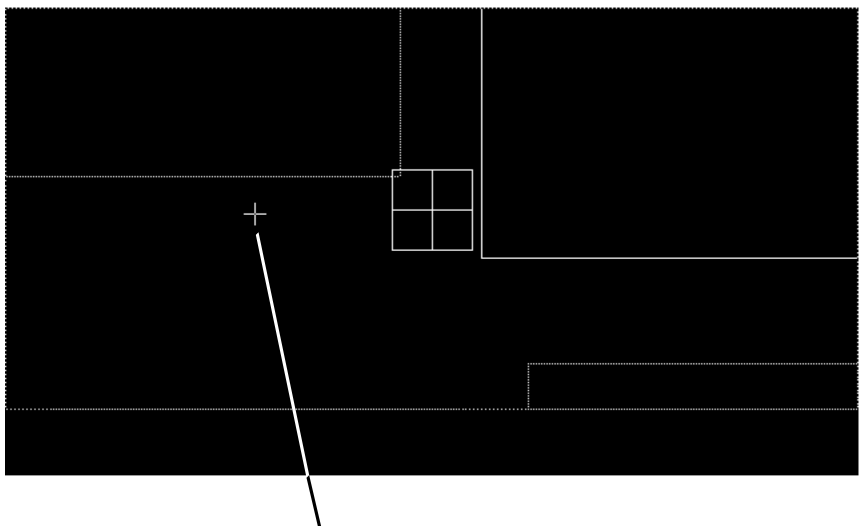

Figure 4 -- The redesigned microscope simulation screen with a white cross showing the predicted stopping position.

Interface version	0.5 Sec. Delay	2.5 Sec. Delay	4.5 Sec. Delay
Keyboard (KB)	73.17	107.22	142.06
Track ball (TB)	84.78	114.94	145.94
New track ball (TB2)	62.56	78.50	94.44
KB vs. TB difference	11.61^{**}	7.72	3.89
KB vs. TB2 difference	10.61^{**}	28.72^{**}	47.61^{**}
TB vs. TB2 difference	22.22^{**}	36.44^{**}	51.50^{**}

Figure 5 -- Mean total task time and differences in seconds for experienced users. (** significant at =.01 using Tukey's HSD.)

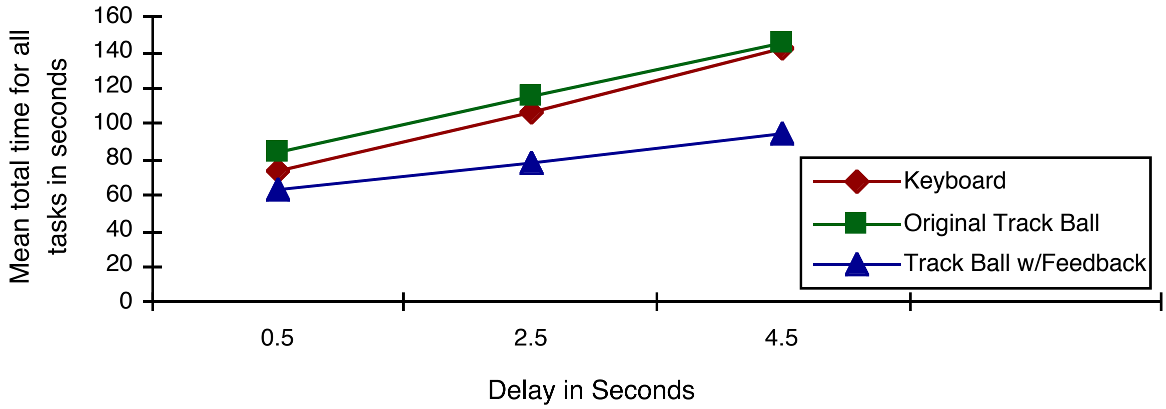

Figure 6 -- Experienced user performance with the three interface designs.

Comparing the Interface Versions

We next conducted a controlled experiment to test the three different interfaces with inexperienced users. Thirty-six volunteers were recruited on campus and paid $10 each for participation. In addition, there was a $5 bonus for the subject with the fastest time on each of the three interface versions. For this study we modified the tasks from the pilot study to make them more realistic. These modification consisted chiefly of adding more turns in the paths to reach the target rectangles. In addition, a set of "follow the trail" tasks was added. Volunteers were asked to operate one of the three interfaces (keyboard, original track ball, or improved track ball). They performed simulated microscope operations at three different control delays 0.5 seconds (short), 2.5 seconds (medium), and 4.5 seconds (long). The terms short, medium, and long were used in the experiment to prevent subjects from using any knowledge of exact delay lengths.

After a training session, experiment participants were asked to do sixteen tasks at each of the three delays. Each participant used only one interface version (keyboard, original track ball, or improved track ball). Each participant did the same sixteen tasks in the same order for each delay. However, delay task groups were presented in different orders to different participants to counterbalance learning effects. The first task in each group was considered an additional training task and not included for statistical analysis.

Each task group contained similar tasks which were divided into four types: on-screen, known-target, simple-path, and complex-path. In each task the goal was to position the target in the center of the microscope field-of-view. This was accomplished by putting a cross-hair which was always in the center of the field-of-view inside of the target rectangle. The participant pressed a button labeled "save point" on the control panel to signal that the task was completed. The simulator checked correct completion and acknowledged with a single beep. If the microscope was not within the target rectangle, the simulator emitted three beeps. Participants were required to correctly complete each task and the system measured time from the start of the task (signaled by pressing "start task") until the last time the microscope stopped.

For on-screen tasks, participants could see the target rectangle on the microscope display when the microscope was at its starting position. They simply had to move the microscope cross-hair into the target rectangle. For these tasks, the improved track ball version was the best (Figure 7). It was significantly faster than the original track ball version at all delays. It was also faster than the keyboard version at all delays, but only significantly so at medium delays. The primary reason for improved performance is that the user has only to place the predicted stopping position indicator inside of the target. Adding predicted stopping positions to the keyboard version would probably help its performance too. But, in order to be useful the microscope must be going slow enough for the indicator to remain on the display. In addition, the keyboard version only moves in cardinal compass directions. So, it would still be more complicated to position than the track ball for targets not in a cardinal direction.

Interface version	Short Delay	Medium Delay	Long Delay
Keyboard (KB)	5.33	9.00	11.63
Track ball (TB)	6.46	9.33	12.93
New track ball (TB2)	5.00	6.11	9.51
KB vs. TB difference	1.13	0.33	1.31
KB vs. TB2 difference	0.33	2.89**	2.11
TB vs. TB2 difference	1.46*	3.22**	3.42**

Figure 7 -- Mean time to complete and differences in seconds for on-screen tasks. (* significant at =.05 and ** significant at =.01 using Tukey's HSD.)

Known-target tasks were similar to on-screen tasks. However, the target was not visible on the microscope screen. The user was given the approximate location of the target on the sample overview and expected to position the microscope inside of the target. No significant differences were observed between interfaces for these tasks. In all task types except the on-screen tasks some users got lost on a task or two. This dramatically increased their times. It is clear that inexperienced users had trouble operating the microscope. We expect that pathologists unfamiliar with the system would have similar problems and that it would take more than a few minutes to learn to use the system.

Simple-path tasks required the experiment participant to follow a simple path such as "go right until you see the red rectangle and then go down to the target". Again there was no significant differences between interfaces.

Complex-path tasks required the user to follow a trail of rectangles in a manner similar to a pathologist examining the edge of a sample structure. Complex-path tasks had more turns than simple-path tasks. For complex-path tasks the improved track ball version of the interface was again faster for all delays. Figure 8 shows the timing data. Again, the most likely reason for better performance was the predicted stopping-point feedback on the microscope display.

Interface version	Short Delay	Medium Delay	Long Delay
Keyboard (KB)	31.42	49.86	69.92
Track ball (TB)	37.92	52.14	57.56
New track ball (TB2)	26.31	36.19	39.92
KB vs. TB difference	6.50	2.28	12.36
KB vs. TB2 difference	5.11	13.67**	30.00**
TB vs. TB2 difference	11.61*	15.94**	17.64

Figure 8 -- Mean time to complete and differences in seconds for complex-path tasks. (* significant at =.05 and ** significant at =.01 using Tukey's HSD.)

While the experiment did not show any version of the interface to be significantly faster than the others at all speeds, the track ball version with a predictive display (TB2) was significantly faster than the original keyboard based design (KB) with delays of 2.5 and 4.5 seconds for complex-path tasks. For these tasks, the TB2 version was also faster than the KB version with .5 second delays. However, this difference was not significant. We believe that these tasks were more representative of how the pathologist would actually use the microscope.

The inexperienced users did not have dramatic performance improvement on all tasks as the experimenters did. In particular, those tasks which required navigation on the overview did not show improvement for inexperienced users. This was probably due to inexperienced users not learning to use the overview as well as the microscope display. Since every task required some navigation on the microscope display, inexperienced users were more familiar with it. On the other hand, the experienced users had a much better idea of when to use the overview for navigation. One can hope that as inexperienced pathologists used the system their performance would approach that of experienced users.

Improving the Overview

As we developed and used our simulator, we noticed that when the magnification difference between the microscope display and the overview on the control display increased, the usefulness of the overview decreased. Movements which seemed large on the microscope display were not perceived on the overview. Indeed, we had to put "wings" on the field-of-view indicator so that it would be easy to locate when the magnification was large (and the indicator was correspondingly small). This lead us to ask "When would it be better to replace the overview of the entire slide with a magnified view showing a local area?"

We decided that it should be possible to add a frame grabber to capture the image on the microscope display. With this additional hardware the pathologist could capture an image at low magnification. We expanded the controls to allow such an image to replace the existing overview on the control screen. We called the captured image the "local map" and the overview of the entire slide the "global map". To use the new feature the pathologist would move to an area of interest at low magnification and press the local map button. The frame grabber would then capture the microscope image and replace the global map with the newly created local map. The pathologist would then increase the magnification and use the local map for navigation and orientation.

Once the new feature was implemented, we conducted an experiment (Plaisant, Carr, & Hasegawa, 1992) to determine when such a feature would be useful. We decided to simulate a blood counting task for our experiment. Participants would be required to move to a target area which was a large yellow rectangle. At the target, half of the participants would make a local map. Then, all participants would increase magnification and smaller rectangles would become visible within the large rectangle. They were asked to count the small yellow rectangles within the large yellow rectangle and use the same search strategy. The large rectangle was too big to fit entirely within the microscope field-of-view at the higher magnification. Therefore, the user would have to sweep the large rectangle in a back-and-forth pattern counting small yellow rectangles.

Twenty-four participants were recruited from the University community and paid $10 with a $10 bonus to the fastest error free participant. They were divided into two groups. The first group used the local map. The second group could not, as the feature was disabled for them. All participants performed three counting tasks at each of three magnifications, 100x, 200x, and 400x. The order in which the different magnifications were performed was permuted to counterbalance for learning effects. Both time to complete and accuracy of each task were recorded. We also asked participants to rate how confident they were that their answer was correct on a scale of 1 to 7 with 7 as certain.

At 100x there was no significant difference in either speed or accuracy between users with the local map and those without. However, users with a local map were significantly more confident of their answers (Figure 9). Since the global map represented a 5x magnification of the search space, 100x represents a 20:1 ratio between the global map and the microscope display. All local maps were constructed at 25x. Thus, users were more confident with a 4:1 ratio than a 20:1 ratio. However, their performance was not significantly different.

100x (20:1)	With local map	Without local map	t value
Errors per 3 tasks	.58 (.64)	.92 (1.04)	0.91
Time in sec. for 3 tasks	394.67 (62.56)	477.00 (128.94)	1.91
Confidence (1 to 7=high)	6.56 (.39)	5.92 (.93)	2.09*

Figure 9 -- Means and (standard deviations) for 100x (20:1). (* significant at =.05 using Tukey's HSD.)

At 200x the ratio increases to 40:1. At this ratio users without a local map began to have problems (Figure 10). They made significantly more errors than those with a local view. Even worse, they did not realize it. Non-local-map users had the same confidence as they did at 100x. For a pathology task where accuracy is important, this has very serious consequences. Watching the participants, we observed that non-local-map users still tried to use the global map for navigation. However, the level of detail had fallen so that they could not differentiate position finely enough to eliminate skipping or overlapping their search paths.

200x (40:1)	With local map	Without local map	t value
Errors per 3 tasks	.25 (.60)	.92 (.76)	2.29*
Time in sec. for 3 tasks	749.91 (191.41)	804.00 (246.52)	0.56
Confidence (1 to 7=high)	6.28 (.52)	5.94 (.83)	1.13

Figure 10 -- Means and (standard deviations) for 200x (40:1). (* significant at =.05 using Tukey's HSD.)

At 400x (80:1 ratio) the non-local-map users abandoned the global map as a navigational aid. They used the microscope screen exclusively. This improved their accuracy relative to local map users, but slowed them dramatically (Figure 11). Direct comparisons between magnifications were not made. While the tasks at all magnifications were similar, they were not the same. In addition, we reduced the size of the rectangles at 400x to speed up the experiment. The reduced size accounts for the shorter times at this magnification. It probably accounts for increased confidence of local-map users as well.

400x (80:1)	With local map	Without local map	t value
Errors per 3 tasks	.25 (.60)	.83 (.99)	1.68
Time in sec. for 3 tasks	364.33 (95.57)	493.50 (140.31)	2.52*
Confidence (1 to 7=high)	6.56 (.46)	5.92 (.82)	2.26*

Figure 11 -- Means and (standard deviations) for 400x (80:1). (* significant at =.05 using Tukey's HSD.)

IMPROVING THE WORKSTATION (FUTURE WORK)

Our efforts to improve the navigation interface by replacing the original keypad were successful in showing that improvements can be made. The most positive effects are the increased sense of control and likelihood of retaining users who are reluctant to use a new system. For our experienced users the revised interface was significantly faster, especially at longer delays.

Our experience clearly shows the advantages of using remote devices providing constant status feedback. This feature is still not adequately considered by manufacturers, but is essential to the design of interfaces by giving users a sense of control and confidence. The same problem arises in many applications. For example in the case of a home automation system (Plaisant & Shneiderman, 1992), devices in the home can be operated and scheduled remotely, but they typically do not send status feedback. When users start a CD player and do not hear anything they become confused and frustrated. They have no way to know if the volume has been turned way down by somebody else, if the CD player is off, or if it is malfunctioning.

On the other hand, our improvements to the interface had a relatively limited effect on the overall speed of operation. It is clear that remotely controlling a motorized stage will always be slower than the direct manual control of the slide. It only takes a few seconds to take a quick look at the slide with the naked eye and slide it under the objective at the desired place. When the slide is at a remote site, it must first be digitized to obtain a global view of the sample, then mounted tightly on the stage, and finally moved slowly to the appropriate coordinate. Innovative features like automated task functions might help compensate for the reduced interaction during the navigation process. Possible automated task functions include: saved points, trail following, automatic scanning, and slide annotation.

<u>Saved points</u>: Traditionally slides are "dotted" to mark a location that can be inspected again later. But "dotting" is not very easy to do, tends to be imprecise, and hides other parts of the slide. Automatically saving points is fast and will not interrupt the exploration of the slide. There can be as many points as desired. The points can be retrieved easily and set to the original magnification automatically. The only limitation is that mounting the slide has to be consistent between uses. Rapid return to saved points will speed the second opinion process and the review of a student's work.

<u>Trail following</u>: While glancing at the slide before putting it under the microscope the pathologist establishes an initial plan to explore the slide. In many cases this plan includes first following a trail or exploring a specific area, then rapidly checking the rest of the slide. Following a sinuous trail with the remote control is a demanding task. A possible way to simplify and accelerate the task is to allow the user to specify a trail on the overview and let the microscope trace it. Once the microscope is following the trail, the user can stop the microscope at any time, explore the neighborhood, and then resume following the trail.

<u>Automatic scanning</u>: Users could circle an area to be systematically scanned and indicate a preprogrammed scanning strategy. Potentially the system could automatically recognize the small part of the slide occupied by the specimen and reduce the scanned area to its minimum. Pathologists could stop, explore locally, and resume scanning.

<u>Slide annotation</u>: Another benefit of the computerized control environment is the possibility of simplifying the annotation and report making associated with the diagnosis. For example, a resident doing a pre-examination of the slide could link comments or questions to certain locations on the slide. Later, the pathologist can cycle through the questions and enter the final diagnosis.

We believe that the combination of such features will increase the usability of the workstation and allow pathologists to conduct remote work efficiently. To compensate for the inherently slower remote process, the workstation should also include access to bibliographic databases, image archives, and patient records.

CONCLUSION

Our efforts to improve the navigation interface by replacing the original keypad had a limited effect on the overall speed of operation for inexperienced users. However, for the few experienced users we tested (the experimenters), a predictive display produced dramatic improvements. Our hope is that with more experience the performance of inexperienced users would approach ours. Our second experiment showed that once the magnification ratio between the microscope image and a scanned image used for navigation reaches 40:1, inexperienced users have trouble using the scanned image . We recommend magnifying an image used as a navigational aid to keep that ratio about 20:1.

Our experience clearly shows the advantages of using remote devices which provide constant status feedback. This feature is still not adequately considered by manufacturers but is essential to the design of such interfaces to give users a sense of control and confidence.

Beside improving the direct remote control of the microscope, other techniques could be used to improve the microscope's functionality. These include:

- Drawing a trail on the slide overview and following it automatically.
- Saving the location of points of interest.
- Annotating the saved points.
- Automatic scanning.

We believe that our experience is a good example of a real world application for which added features and added hardware need to be justified. Company management heard our initial suggestions, but the prototypes and the results of our experiments were the most important factor when management made decisions about future versions of the system.

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