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The Effects of Time Delays on a Telepathology User Interface

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Abstract

Telepathology enables a pathologist to examine physically distant tissue samples by microscope operation over a communication link. Communication links can impose time delays which cause difficulties in controlling the remote device. Such difficulties were found in a microscope teleoperation system. Since the user interface is critical to pathologist's acceptance of telepathology, we redesigned the user interface for this system, built two different versions (a keypad whose movement commands operated by specifying a start command followed by a stop command and a trackball interface whose movement commands were incremental and directly proportional to the rotation of the trackball). We then conducted a pilot study to determine the effect of time delays on the new user interfaces. In our experiment, the keypad was the faster interface when the time delay is short. There was no evidence to favor either the keypad or trackball when the time delay was longer. Moving long distances over the microscope slide by

dragging the field-of-view indicator on the touchscreen control panel improved inexperienced user performance. Also, the experiment suggests that changes could be made to improve the trackball interface.

Introduction

Teleoperation enables a user to control a physically distant operation via commands sent over a communication link. As computer and communication costs drop and the cost of a human expert continues to increase, human experts may begin to routinely use remotely controlled equipment in order to perform their work. From his or her office, a pathologist sitting at a workstation could control a physically remote microscope in order to examine tissue samples of a patient who is across town, across the country, or even in space [8,9]. Thus, a pathologist can render a timely opinion for a patient who is physically remote. The expert's time is more productive since travel to the remote location is unnecessary. Also, timely opinions can reduce costs for patients in rural hospitals who typically must stay extra days until the expert arrives or for the tissue samples to be shipped to the pathologist. However, in order to be truly effective, control of the microscope must be simple and not interfere with examining the sample. Thus, the user interface is critical to the acceptance of a telepathology workstation for day to day use.

A teleoperated pathology system has been designed by Corabi Telemetrics International. It consists of two parts, a pathologist's workstation linked via telephone and satellite to a computer controlled microscope (see figure 1). A video camera attached to the microscope transmits a high definition TV image of the sample via satellite. Interaction between the pathologist's workstation and the microscope occurs in real-time. (Scanning the sample at high magnification and transmitting the entire image to the workstation for later review is impractical because of the storage volume required [10].) However, the communication link between the remote microscope and the workstation can impose time delays which cause difficulties in controlling the remote device. The Corabi system currently has about a 1.5 second delay between the pathologist issuing a motion command and the microscope beginning to move. Similarly, the system overshoots when a stop command is issued. The current system backtracks to the approximate position where the stop command was issued, but this takes additional time and can be imprecise and frustrating.

The pathologist uses a custom keypad to enter motion commands for microscope movement, magnification selection, focus, and illumination. The pathologist monitors the results of these commands on the high resolution display. Operation of the workstation is hindered by two major problems: 1) the lack of feedback as to global position on the slide and 2) the overshoot introduced by the time delay in any continuous operation such as moving. To position the microscope the pathologist presses a key to begin movement in one of the eight cardinal compass directions; when an interesting cell group is observed the pathologist presses a key to stop. Because the microscope controller and the communications link impose a delay, this results in an overshoot. The pathologist may have difficulty backtracking to the area of the slide that is of interest.

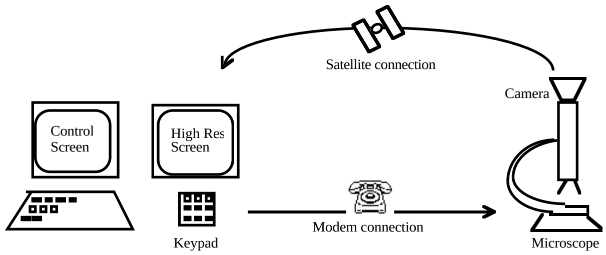

Figure 1 - Simplified diagram of an existing telepathology system.

One way to attack the time delay problem is to eliminate it. Indeed, the experiment shows that if the time delay were reduced to about one-half second an interface similar to the existing one works well. However, we wished to study the mitigating effects of alternate user interfaces. There are two reasons to explore alternate interfaces. First, one possible use for the Corabi system is to provide telepresence in space which imposes an inherent delay in the communications link. Second, was the belief that a well designed user interface could compensate for these delays. Since rapid response time hardware generally costs more than slower hardware, compensating for delays in the user interface could result in significant savings in the final cost of the system.

Previous Work

The telepathology system is an example of a supervisory control system. A supervisory control system is characterized by a human operator issuing instructions which 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 [5]. This supervisory control model is characterized by a separate human interaction system (the pathologist's workstation) and task interaction system (the microscope controller).

Ferrel and Sheridan [1] studied such a system which was designed to control 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 which 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 [7] reported on a study of time 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 is paramount. However, in telepathology real-time interaction is more important.

Keil-Slawik, Plaisant, and Shneiderman [2] studied supervisory control as an instance of remote direct manipulation. This study focused on the Corabi telepathology workstation and found that the remote environment introduced four complicating factors: time delays, incomplete feedback, feedback from multiple sources, and unanticipated interference, such as the microscope being manually adjusted at the remote site.

Interface Design Description

The telepathology system user interface was redesigned with attention being paid to compensating for time delays and limited feedback. Next, a prototype pathologist's workstation was implemented on an IBM AT. Two alternate versions of the redesigned user interface were implemented on the workstation: a keypad interface and a trackball interface. Both interfaces use a touchscreen for the control screen and are based on the principles of direct manipulation as described in [6]. Key features of these new interfaces are:

1. Placing the microscope controls on a touchscreen equipped computer display. This permits rapid prototyping of the microscope controls by changing the video image displayed on the monitor and the target map used to translate touchscreen actions into button presses [3,4].

2. Including a static black and white "slide overview" image on the control panel screen (see Figure 2). This image is obtained by digitizing the slide with a separate camera before installing it under the microscope.

3. Adding to each version an auxiliary input device which allowed the pathologist to operate the most frequently used controls (movement and focus adjustment) without moving his eyes from the high resolution microscope image to the microscope control screen. The first version used a keypad for the auxiliary control while the second used a three-button trackball.

For the trackball based interface the following additional changes were made:

1. Allowing coarse positioning of the microscope by dragging the field-of-view indicator from its current position on the "slide overview" to a new position. This

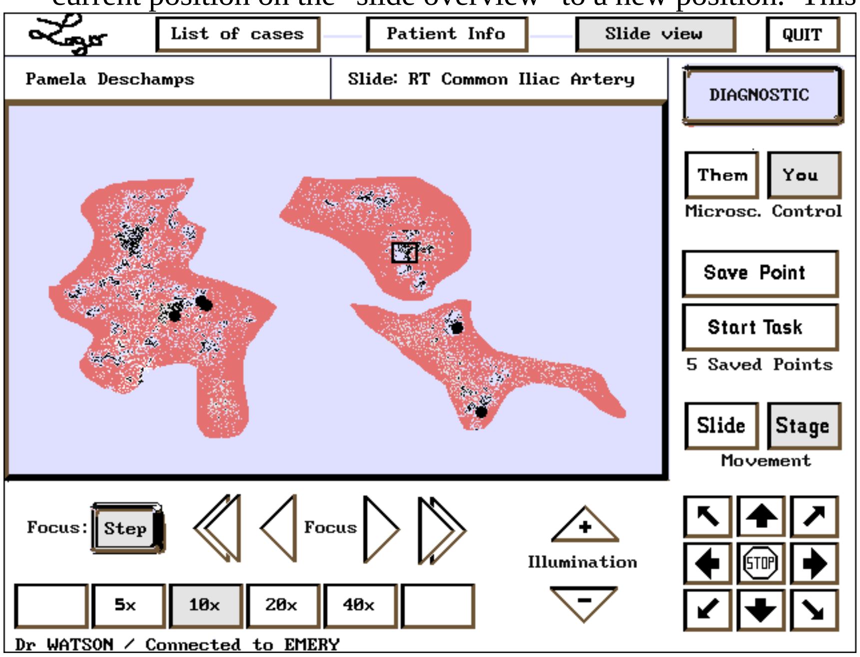

Figure 2 - Touchscreen Control Panel

allows long distance moves to be made with assured final position.

2. Replacing the start/stop keypad with a trackball for fine positioning. Moving the trackball issues a movement command which is proportional to the distance and in the direction that the trackball has been rotated. Small moves using the trackball are incremental in nature and easily reversible. We theorized that the trackball interface would allow faster operation at longer time delays by providing incremental distance based movement commands rather than time based movement commands. The keypad interface was expected to be fastest at the short delay because the final position of the microscope is very close to the current position for the combination of microscope speed and delay in the experiment. Thus, it is very easy for the user to anticipate the stopping position.

3. Assigning the two fine focus commands (in & out) and the "stop" command to the three buttons on the trackball interface in order to allow the pathologist to keep looking at the high resolution display while issuing these commands. Preliminary testing showed that the "stop" button was essential to limit overshoot.

Since the telepathology system was not easily accessible, a microscope simulator was implemented. It had programmable delays for all control commands allowing comparison of the two interfaces at different time delays. Since there was not enough computer power to animate a true tissue sample, the microscope simulator used colored rectangles to simulate cells. This decision allowed for real-time animation of the slide movement which was essential to the experiment.

Experiment Description

In order to investigate the effects of time delays on user interfaces for the telepathology system and gather data to refine our user interface design, we conducted an experiment which was between groups for two different user interface types (keypad & trackball) and with each participant operating the microscope at three different time delays: short (.5 sec.), medium (2.5 sec.), and long (4.5 sec.).

Twenty-four inexperienced University of Maryland students were randomly assigned to only one of the two interfaces. After a practice session, they performed five different tasks at each of the three time delays. Tasks were started by the participant pressing the "Start Task" button on the control screen. The participant then manipulated the microscope until the goal was met. Finally, the participant pressed "Save Point" to indicate task completion. The system automatically verified the goal conditions and signaled whether or not they had been met. Time to complete each task was measured by the microscope simulation computer. Tasks were not considered complete until the goal was met and the clock continued to run after a participant erroneously pressed the "Save Point" button. In each task the goal condition was to position a yellow target rectangle in the center of the microscope screen and then set a given magnification. Changes in magnification required refocusing the microscope. The center of the microscope display was marked by a crosshair. The crosshair indicated the microscope focus. When the microscope was in focus the crosshair was drawn with solid lines. If the microscope was out of focus, then the crosshair was drawn with dashed lines and the simulated microscope image was not displayed. The dashes were shorter as the microscope was farther out of focus. The five tasks were similar across all time delays and a detailed description of them follows:

Task 1 - The target rectangle appeared on screen in the upper right hand corner of the screen.

There was no magnification change or refocusing. (Short move to visible target.)

Task 2 - The target rectangle appeared on screen in the lower left hand corner. The magnification was decreased from 10x to 5x. (Short move with magnification change and focusing.)

Task 3 - The target was located just above the initial microscope field-of-view. Thus, a short distance move was required. No magnification change was required. (Short search for target.)

Task 4 - The target was located just below the initial microscope field-of-view (another short distance move). Magnification was changed from 10x to 20x. (Short search with magnification change and focusing.)

Task 5 - The microscope started in the center of the slide and the target was in the upper right hand corner. This required a long distance move and the trackball interface users were instructed to drag the field-of-view indicator. Magnification was changed from 10x to 20x. (Long search with magnification change and focusing.)

Two experiments were conducted. The first study was conducted with twenty-four inexperienced users to test their performance. All participants who volunteered for this experiment were University of Maryland students. The second study evaluated the performance of the three experimenters with 6 repeats of all the tasks using both interface versions. This was to see what the performance of experienced users would be.

Results

Since the individual tasks followed the trend of the mean total task time, mean total task time was analyzed with student-t tests. Table 1 shows means and standard deviations for the total time to complete the five tasks at each time delay for each interface version and Figure 3 is a graph of the mean total task time for inexperienced users. For the short time delay, the difference in the means is significant at alpha = .01. No significant difference was found for medium and long time delays. In addition, for the longest time delay the "long search" task was significantly faster with the trackball version. (Trackball mean = 67.75 seconds vs. Keypad mean = 84.58 seconds; t = 2.85; significant at alpha = .01).

	Trackball	Keypad	t value
Short Delay	122.25 (18.24)	100.67 (14.70)	3.06*
Medium Delay	194.75 (55.23)	158.67 (30.43)	1.90
Long Delay	222.33 (27.82)	231.25 (36.65)	0.64

Table 1. Inexperienced users mean total time and standard deviation for completing tasks in seconds.
*significant at alpha=.01

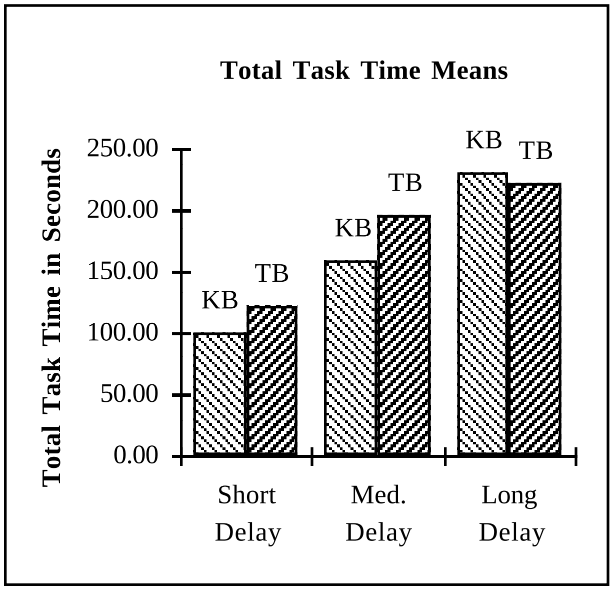

Figure 3 - Means for Both Interfaces at all Delays

Table 3 summarizes the total time means and standard deviations for the experienced users. As with the inexperienced users, the only significant difference for experienced users is for the short time delay. For both experienced and inexperienced users, the keypad interface facilitated faster task completion than the trackball interface when the time delay was short. Experienced users were able to complete the long search at the longest delay in the same time with either interface.

	Trackball	Keypad	t value
Short Delay	84.78 (12.09)	73.17 (8.71)	3.21*
Medium Delay	114.94 (15.12)	107.22 (15.16)	1.49
Long Delay	145.94 (24.61)	142.06 (21.34)	0.49

Table 3. Experienced users' mean total time and standard deviations.
*significant at alpha=.01

Discussion

Our experiment was designed to determine, in the presence of short, medium and long time delays, the effects of two different user interfaces -- trackball and keypad -- for teleoperating a microscope. We collected time-to-complete-task data for both inexperienced and experienced participants.

Our first hypothesis was that the keypad interface would be faster when time delays were short. The results of our experiment support this hypothesis since both inexperienced and experienced users showed significant "total task time" differences in favor of the keypad interface. Three observations of the participants while completing the tasks helps to explain why trackball users tended to take longer to complete tasks at short time delays.

1. A common participant remark was, "It is difficult to judge how far to move the trackball." This comment suggests that the cognitive thought processes with the trackball interface are more complex than that required for a keypad. The keypad only requires pressing the arrow key corresponding to the direction to move whereas the trackball involves thinking about not only which direction to move but also the more difficult process of estimating how far to rotate the trackball. We believe that this problem can be overcome by providing an estimated stop location indicator on the microscope display.

2. Trackball users sometimes did not use the stop key even though it would have been beneficial. They tended to overshoot targets because they did not use the stop key to cancel outstanding trackball movement commands; instead, they let the screen movement continue uninterrupted. Keypad users, on the other hand, always used the stop key when appropriate. Overshooting occurred for inexperienced users because they may not have learned when it was appropriate to use the trackball interface stop key. For experienced users, even though they knew how to use the stop key to prevent overshooting, they sometimes didn't use it because they thought the crosshair would stop on its own inside the target.

3. With short time delays, it was not as important to estimate when to press the stop key because of the quick command response. Therefore, trackball users tended to use the stop key less and, instead, guided the crosshair to the target. This resulted in more overshoots than keypad users.

Our second hypothesis was that the trackball interface would be faster when time delays were long. Our results did not support for this. We assumed that the trackball, compared to the keypad, would allow more accurate and faster positioning in the absence of feedback found in long time delay situations. However, the difficulty in judging trackball movement negated its potential benefit. In all task results, only task 5 (long search) for inexperienced users showed a significant difference in favor of the trackball interface. Since task 5 required the participant to move over a long distance on the microscope slide, task 5 results can be explained as factor of touchscreen dragging instead of trackball superiority. Trackball participants used the touchscreen control panel to drag the microscope field-of-view to the desired location without using the trackball, whereas the keypad participants used the arrow keys to move to the location. During movement to the desired location, the inexperienced keypad participants needed to stop two or three times in order to get their bearings because the interface did not provide continuous position feedback while the microscope was moving. In contrast, trackball users knew the final position of the microscope and did not need intermediate feedback. Therefore, task 5's difference was not a result of the trackball; instead, the touchscreen dragging eliminated the need for trackball users to stop to get their bearing whereas keypad still had to stop. This was supported by the fact that experienced users did not show a significant difference for task 5. Experienced users knew how to use the keypad interface to move to a desired location without stopping to get their bearings. They exploited the following facts: that there was no mechanical delay associating with stopping, that issuing a movement command while moving actually issued a stop command followed by the new movement command, and that the location of the field-of-view was updated with each stop command. These features combined to give an update of the microscope position with each movement key press.

After reflecting on the failure of the trackball interface we concluded that it could have been better implemented. The destination indicator on the field-of-view should have been displayed for trackball movement as well as when dragging the field-of-view indicator. As indicated above, a predicted stop location indicator should be visible on the microscope display whenever the expected destination is visible on the microscope screen. Both novices and experts would have benefitted from position feedback on the global view during movement. Even the dragging of the field-of-view would have been better with a touch target larger than the 10x field-of-view indicator.

It is interesting to note that experienced user times were approximately 2/3's of the novice user times. This was due to three factors. First, experienced users had a better idea of how the interfaces operated. They were able to use the stop key to limit overshoots and had a better idea of the ratio between trackball movement and microscope movement. Second, they required less feedback about the microscope's current position. This explains why dragging the field-of-view indicator was not faster for experienced users. Finally, experienced users knew how many focus increments were required for each magnification change and sent focus commands during the magnification change delay. In contrast, only a couple of novice users learned this during the experiment.

Conclusions

This study found evidence that the keypad interface using start/stop movement commands was preferable to the trackball interface using relative movement commands for teleoperating a microscope when time delays are short. For medium and long time delays, there is no evidence to favor one interface over the other. Inexperienced users moving long distances over the microscope slide in a long time delay situation may be assisted by having the ability to drag the microscope field-of-view indicator using a touchscreen; experienced users, however, did not seem to benefit from this feature.

After reflecting on the results of this experiment we decided that the key factor as to which interface worked best was feedback. The novices did well when they had short response time and when dragging the field-of-view indicator. In both of these instances, feedback to the user very closely predicted microscope behavior. This suggests that improved feedback on the trackball version could result in faster times. Specifically, we suggest two improvements to the trackball version. First, providing field-of-view destination feedback for all movement instead of only when dragging the indicator. Second, to provide a destination indicator on the microscope screen whenever the destination is visible. We are currently implementing a new trackball version with these improvements and will test it to see if these additions will improve trackball interface performance.

In summary, understanding the effects of time delays on teleoperation user interfaces may make it feasible in a number of different environments. The Corabi system described in this experiment is basically a remote control of an x-y stage and a television camera. Therefore, in addition to the telepathology, it could be adapted to allow experimenters and physicians access to environments such as space and deep sea which are currently inaccessible to most.

Acknowledgements

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