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PROGRAMMABLE DISPLAY PUSHBUTTONS ON THE SPACE STATION'S TELEROBOT CONTROL PANEL

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INTRODUCTION

The Man-Systems Telerobotics Laboratory at NASA's Johnson Space Center and supported by Lockheed, is working to ensure that the Flight Telerobotic Servicer (FTS) to be used on the Space Shuttle (Orbiter) and the Space Station has a well designed user interface from a Human Factors perspective. The FTS, which is a project led by NASA's Goddard Space Flight Center, will be a telerobot used for Space Station construction, maintenance, and satellite repair. It will be directly controlled from workstations on the Orbiter and the Space Station and monitored from a ground workstation. The FTS will eventually evolve into a more autonomous system, but in the short-term the system will be manually operated (teleoperated) for many tasks. This emphasizes the importance of the human/ telerobot interface on this system.

The information driving the design of the FTS control panel is being provided by task analyses, workstation evaluations, and astronaut/FTS function allocations. Due to space constraints on the Orbiter and the Space Station, an overriding objective of the design of the FTS workstation is that it take up as little panel space as possible.

This phase of the FTS workstation evaluation covers a preliminary study of programmable display pushbuttons (PDPs). The PDP is constructed of a matrix of directly addressable electroluminescent (EL) pixels which can be used to form dot-matrix characters. PDPs can be used to display more than one message and to control more than one function. Since the PDPs have these features, then a single PDP may possibly replace the use of many single-function pushbuttons, rotary switches, and toggle switches, thus using less panel space. It is of interest to determine if PDPs can be used to adequately perform complex hierarchically structured task sequences.

Other investigators have reported on the feasibility of using PDPs in systems design (Hawkins, Reising, and Woodson, 1984; and Burns and Warren, 1985), but the present endeavor was deemed necessary so that a clearly defined set of guidelines concerning the advantages and disadvantages of PDP use in the FTS workstation could be established. This would ensure that PDP use was optimized in the FTS workstation.

The objective of this investigation was to compare the performance of experienced and inexperienced Remote Manipulator System (RMS) operators while performing an RMS-like task on simulated PDP and non-PDP computer prototypes so that guidelines governing the use of programmable display pushbuttons on the FTS workstation could be created. The functionality of the RMS on the Orbiter was used as a model for this evaluation since the functionality of the FTS at the time of this writing has not been solidified.

METHOD

APPARATUS

Computer prototyping was used as the means of evaluating the two different FTS control panel layouts. Hypercard was used as the prototyping package and it was run on an Apple Macintosh computer. Hypercard was also used as a data acquisition package once testing began. Total task time and the total number of commands activated were recorded.

The simulated task consisted of the operations to deploy a satellite on the Space Shuttle. This task required simulated RMS joint manipulations, camera manipulations, as well as other RMS-like activities, while using the computer prototypes.

The non-PDP control panel is depicted in Figure 1. The distinguishing feature of this configuration is that traditional single-function pushbuttons are used in conjunction with a simulated EL panel to activate commands. The EL panel was simulated in this evaluation by displaying single-function commands as they would appear on the EL panel in the upper right-hand corner of the prototyped screen. The simulated EL panel was used because the space constraints of the Macintosh computer would not allow the display of all of the functionality at one time. This then made it possible to study a task as complex as an RMS-like operation on this particular microcomputer.

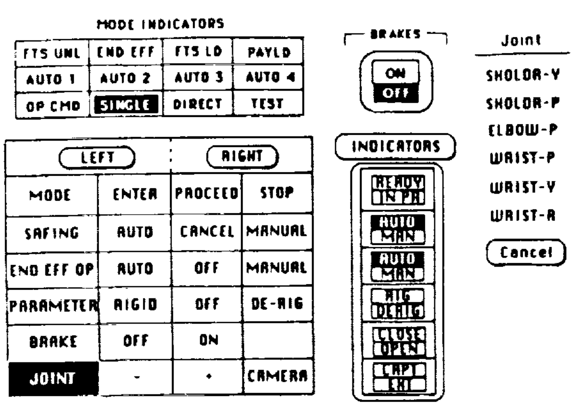

Figure 1. Non-PDP control panel prototype.

The PDP control panel is depicted in Figure 2. This control panel utilized simulated PDPs instead of single-function pushbuttons. In Figure 2, the PDPs are the twelve pushbuttons located in the lower-middle portion of the display. The portions to the left and top of the display are status indicators that were used to display various functional states.

When a PDP is selected, the name of that function is then displayed in a small simulated EL display located just above the PDP cluster and the options that follow within that functional category are then displayed by the PDPs. For example, when SINGLE is selected in Figure 2, the display changes to that depicted in Figure 3. In Figure 3, SINGLE is now displayed in the EL display and the PDPs have changed to list the options that follow under SINGLE. The small EL display was designed to serve as a navigational aid to help orient operators throughout performance of the hierarchically structured tasks. It was contended that the use of the navigational aid in the PDP hierarchy would be useful since a previous evaluation (Gray, 1986) found that navigational aids are helpful with hierarchical search tasks through menu structures on a computer.

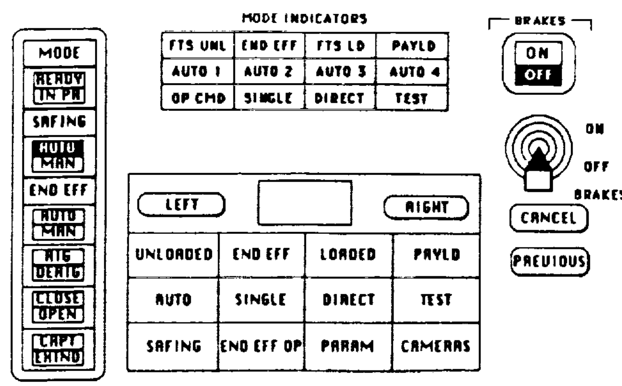

Figure 2. PDP control panel prototype.

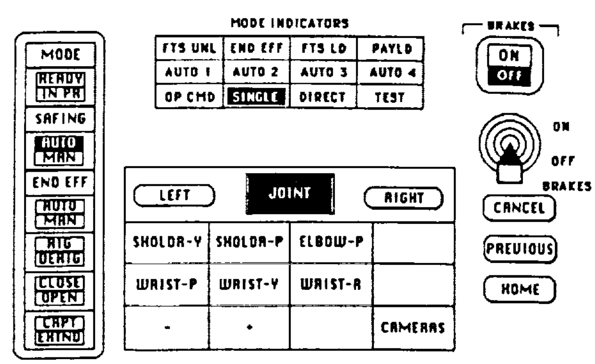

Figure 3. PDP control panel with PDP changes and navigational aid.

It was determined that there was a problem in maneuvering across functional modalities during the development of the PDP prototypes because it required many commands to do so. For example, when one was in the RMS joint manipulation mode, it would require several steps, including going back to the "Home" level of the task hierarchy first, to be able to make camera adjustments. Since the RMS operation requires much maneuvering across modalities during its use, this PDP arrangement would result in many circuitous movements and much wasted time. Therefore, a special PDP was developed for the present investigation which would readily allow operators to "jump" across functional modalities with a single command located within the PDP matrix.

EXPERIMENTAL VARIABLES

The independent variables in this investigation were the two different RMS operating experience levels of the subjects (experienced and novice) and the two different control panel prototypes (non-PDP and PDP). Since each subject was tested on each of the two control panel prototypes (in counterbalanced order), then a 2 x 2 repeated measures experimental design was used. Of specific interest was the comparison between PDP and non-PDP usage, the difference in the performance and subjective impressions of the two different subject groups, the use of navigational aids, and informational needs of operators while performing simulated FTS tasks.

The dependent variables were operator task completion times, number of commands required to complete the task for each control panel prototype, a question of preference between the two different control panel prototypes, questionnaire responses, and subjective impressions.

SUBJECTS

Volunteer subjects from both Johnson Space Center and Lockheed took part in this experiment. Four subjects who had no prior RMS training comprised the novice users group. Four subjects who had completed training on a high-fidelity simulator of the RMS comprised the experienced users group.

PROCEDURE

Performance of a simulated RMS-like task scenario was used for each of the control panel configurations. Each scenario covered simulated RMS-like manipulation activities and the testing took place on the Apple Macintosh SE computer. The task scenario was identical for both control panel configurations.

Before testing began, each subject had the basic functionality of each of the control panels explained to them. Subjects then completed a practice session on the first control panel configuration that they would be using. A subject would then perform the simulated tasks on the Macintosh. After the subject's first scenario was completed, the same procedure was followed using the other control panel prototype. Order effects were controlled by having an equal number of subjects begin the testing with the non-PDP control panel as those who began the testing with the PDP control panel within each of the two subject groups.

After performing the task scenarios on both of the control panel prototypes, each subject was asked to select which of the two control panel prototypes were preferred. Each subject was also asked to complete a questionnaire designed to garner subjective impressions concerning the control panels. Subjects rated five issues on a five-point Likert-scale where one point indicated "Least" and five points indicated "Most." These five issues were "Maneuver Across Modalities," "Maneuver Within Modalities," "Provides Task Structure," "Contributes to Task Structure," and "Ability to Make Commands." Subjects then answered open-ended questions concerning PDP use.

RESULTS AND DISCUSSION

Data were collected and analyzed with the objective of determining differences in user performance and preferences between the two different control panel configurations so that, ultimately, guidelines concerning the use of PDPs could be established. All numeric data were statistically analyzed with a repeated measures analysis of variance.

Analysis of the performance data revealed that subjects used significantly ($p = 0.001$) fewer commands when using the PDP control panel prototype than they did while using the non-PDP control panel. Interestingly, though, subjects did not significantly differ in the amount of time that it took for them to complete the two tasks. The average task time for the PDP prototype was 18:12 while it was 18:49 for the non-PDP condition. This finding provides some support for the PDP prototype in the sense that if more commands are required to perform the same task in virtually the same time frame then the condition which requires more commands to be activated may predispose operators to make more errors.

Analysis of the subjects' control panel preferences revealed that all eight of the subjects preferred the PDP control panel over the non-PDP control panel. As Table 1 indicates, the analysis of the five-point Likert-scale questionnaire responses also provided strong support for the PDP control panel since subjects rated two of the five questionnaire items significantly ($p < 0.05$) higher for the PDP prototypes. These two questionnaire items were "Maneuver Within Modalities" and "Ability to Make Commands." Subjects also rated the PDP prototype higher on the other three questionnaire items, although these differences were not statistically significant. There was also statistical significance ($p = 0.049$) due to the RMS experience level of the subjects where the novice users had a higher rating on the "Maneuver Across Modalities" question.

Subjective comments were also collected from each of the subjects. These are summarized in Table 2. The comments were categorized as either positive or negative with respect to PDP usage.

The subjective impressions indicate that PDPs can have very good as well as very bad features. It was observed by the subjects that the use of the PDPs can result in less panel space used and that they can provide task structure in the sense that they can clearly delineate what task options are available at specific times. On the negative side, subjects expressed that one loses "global perspective" with the use of PDPs and that this can contribute to task disorientation. It was also stated that PDPs should not be used in "exceedingly" complex systems.

Subjective impressions were also studied to determine if there was a difference between the two RMS-experience groups. Data analysis revealed that there were no differences since the comments were common across both groups.

TABLE 1.

Five-point Likert-scale responses for the non-PDP and PDP control panel prototypes

Questionnaire Item	Control Panel Non-PDP	PDP
Maneuver across modalities	3.12	3.87
Maneuver within modalities	2.87	4.25 *
Provides task structure	2.75	4.12
Contributes to task orientation	2.62	3.50
Ability to make commands	3.00	3.87 *

* Significant at $p < 0.05$

CONCLUSIONS

The ultimate objective of this investigation was to establish a set of guidelines concerning the use of PDPs for the FTS workstation. The data collected during this investigation were then used to create this set of guidelines. It is contended that the established set of guidelines will also be generalizable to other workstations as well. These guidelines are listed in Table 3.

It is clear from the previously mentioned experiment results and subjective comments that the use of PDPs does in fact present a trade-off — there is some good as well as some bad about them. It is for this reason then that PDPs should be used judiciously because improper usage can contribute to task complexity and user task-disorientation. It is contended that the previously mentioned set of guidelines will help to ensure that PDPs will be optimally designed and arranged.

TABLE 2.

Positive and negative subjective impressions concerning PDP usage

Positive
- Provide task structure
- Save panel space
- User attention is more localized
- Good when working within a functional modality (e. g., camera manipulation)
- Navigational aids provide user guidance
- Good for infrequently used sub-tasks
- Can result in reduced search time

Negative
- Processing time (option refresh rate) to perform next steps was too slow
- Bad if used in highly complex systems (e. g., large number of functional modalities within the overall task)
- Lose global perspective because fewer spatially redundant cues
- Not good for applications where few controls are used frequently
- Possibility of getting lost in complex task structures
- May result in more cognitive processing

Future research endeavors should examine the use of actual, hard-wired PDPs in full-scale mockups while performing high-fidelity simulated tasks. This would increase the external generalizability of the results. The development of an equation which would precisely determine how many PDPs should be used for a specific task may be possible. This equation would have to take into account variables such as the frequency that all of the commands are activated, as well as the depth and breadth of the task hierarchical structure.

TABLE 3.

Guidelines concerning PDP usage

- Use PDPs instead of other controls if PDP usage reduces the total number of commands to perform the task and doesn't significantly increase task completion time.
- A PDP or control capability should be provided that will allow "jumping" across functional modalities
- Navigational aids should be used to help orient users
- May be better for infrequently used sub-tasks
- May be better when working within a functional modality
- Should not be used for certain critical functions, such as brake control
- Should give an indication of the number of hierarchical steps the operator is away from the "Home" level

ACKNOWLEDGEMENTS

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