354

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THE USE OF GRAPHICS IN THE DESIGN OF THE HUMAN-TELEROBOT INTERFACE

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The Man-Systems Telerobotics Laboratory (MSTL) of NASA's Johnson Space Center employs computer graphics tools in their design and evaluation of the Flight Telerobotic Servicer (FTS) human/telerobot interface on the Shuttle and on the Space Station. It has been determined by the MSTL that the use of computer graphics can promote more expedient and less costly design endeavors. This paper describes in detail several specific examples of computer graphics applied to the FTS user interface by the MSTL.

INTRODUCTION

Computer graphics techniques, including software prototype development programs, can serve as an aide in the design, evaluation, and development of user interfaces of many types. These systems design tools can result in the development of ergonomically well-designed workstations in less time with lower costs when compared to the use of other systems design tools.

With the system development process becoming more complex and expensive, more emphasis is being placed on the evaluation of systems during early stages of the development cycle. The design of systems that include human operators is especially complex because determining overall systems performance is dependent upon the interaction of the human operator, hardware components and software components (ref. 1). Adequately evaluating the performance of a system during the design cycle is becoming increasing more difficult when using the static evaluation tools traditionally available to the Human Factors Engineer, such as job and task analyses and mockup development (ref. 2). It is becoming more common for systems developers to use computer graphics as a design tool instead of hardware models (ref. 3) and for Human Factors Engineers to use computer graphics to enhance the use of static design tools (ref. 4).

The Man-Systems Telerobotics Laboratory (MSTL) of NASA Johnson Space Center (JSC) with support from Lockheed has extensively used computer graphics tools in their design and evaluation of the Flight Telerobotic Servicer (FTS) user interface. It is the goal of the MSTL to help design, evaluate and develop requirements for the user interface of the FTS. Goddard Space Flight Center is the lead center in the development of the FTS with other NASA centers and industry playing various roles.

The FTS will be a dual-armed teleoperated robot used to help assemble, service, and maintain NASA's Space Station. There will be an FTS control panel on both the Shuttle and the Space Station. The design of the FTS control panel is especially challenging since it may be physically impossible to have identical control panels on both the Shuttle and the Space Station due to the physical constraints of the Shuttle. The ultimate objective in the design of the FTS control panel is that the human operator's capabilities and limitations have been best accommodated for while ensuring that overall systems goals and requirements are met. The use of computer graphics will enable NASA to iteratively design a good FTS control panel on the Space Station which does not radically differ from the FTS control panel included on the Shuttle. Radical departures from the control panel used on the Shuttle will increase the likelihood of negative transference or reversal errors. Therefore, design features which take advantage of population expectancies should be a constant feature across both control panels to ensure maximum performance.

This paper will discuss the MSTL's use of computer graphics tools that have been applied to the design and evaluation of the human-telerobot interface that will be a part of NASA's Shuttle and Space Station. Each example will begin with a statement of the objectives of the task and will then detail the approach taken by the MSTL for that particular application. The discussion of these applications will also include illustrations of the computer graphics used.

PROGRAMMABLE DISPLAY PUSHBUTTONS

The first example given will be an illustration of how computer graphics was used by the MSTL to establish a set of guidelines concerning the use of programmable display pushbuttons (PDPs) on the Space Station's FTS control panel (see ref. 5 for a detailed discussion concerning this study). The graphics tool used during this evaluation was Hypercard. Hypercard is an information management software package which allows the user to organize text, graphics and active "screen buttons" into cards. The cards can then be linked together in different user-definable stacks. The stacks can then be arranged so that high-fidelity control panel prototypes can be created with relative ease.

This phase of the FTS workstation evaluation covered a preliminary study of PDPs. Since the study of PDPs is now in the early phase of the design cycle, the focus on this evaluation was to use computer graphics as a means of testing the feasibility of using PDPs on the FTS control panel. 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. 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. 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 (refs. 6,7), 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 study the performance of subjects performing a simulated manipulator task on 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 manipulator on the Orbiter was used as a model for this evaluation since the functionality of the FTS at the time of this writing had not been solidified.

The graphics version of 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.

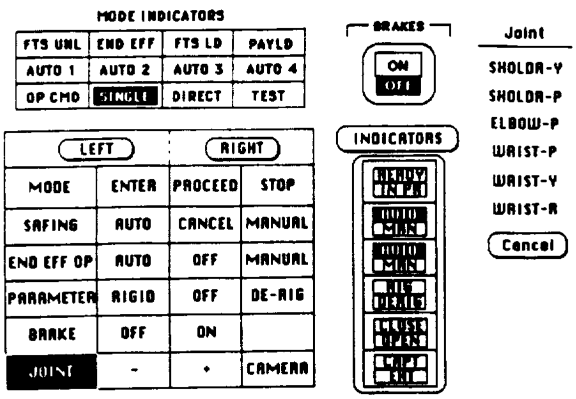

Figure 1 -- Non-PDP control panel prototype.

The graphics version of 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 dynamic status indicators that were used to display various functional states.

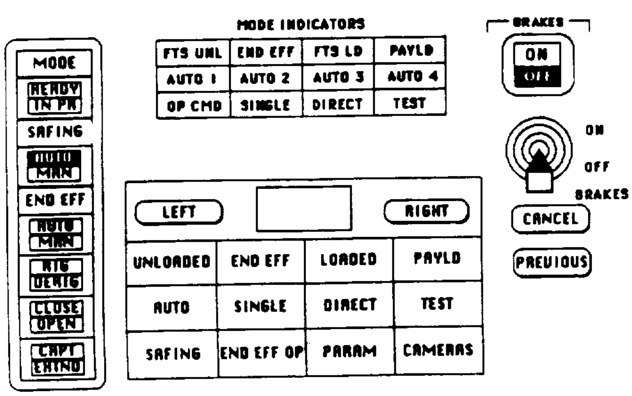

Figure 2 -- PDP control panel prototype.

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 (ref. 8) found that navigational aids are helpful with hierarchical search tasks through menu structures on a computer.

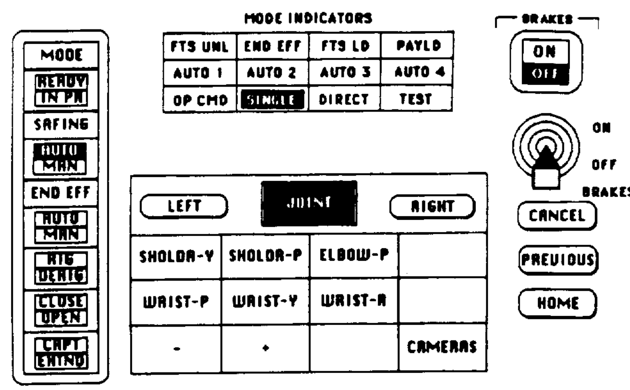

Figure 3 -- PDP control panel prototype with PDP changes and navigational aid.

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. Data were collected and analyzed with the objective of determining differences in user performance and preference 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.

The ultimate objective of this investigation was to use computer prototyping to establish a set of guidelines concerning the use of PDPs on the FTS workstation. The data collected during this investigation were used to create these guidelines. It is contended that the established set of guidelines will also be generalizable to other workstations as well.

For a complete list of these guidelines, please see ref. 5. It is contended that the use of this set of guidelines will help to ensure that PDPs will be optimally designed and arranged.

The use of computer graphics proved to be invaluable during this evaluation. Graphics allowed the experimenters to iteratively try out many different design configurations before testing actual, hard-wired PDPs. Without the use of computer prototyping, it is contended that the design process would have taken much more time and money to perform as efficiently. If computer prototyping was not used by the MSTL then it would have been necessary to have completely assembled the hardware components and electrical wiring of each of the design configurations evaluated with the computer prototyping method to iteratively evaluate different design possibilities so that an optimal solution could be derived. The hardware approach would have been much more expensive and involved.

HAND CONTROLLERS AND RESTRAINT SYSTEMS

The second example will be a discussion of how graphics was used to evaluate the placement of different types of hand controllers and different types of body restraint systems within various conceptual designs of the FTS workstation on the Shuttle. The tool used during this evaluation was the PLAID graphics package. PLAID is a graphics development package created by the Graphics Analysis Facility of NASA's Johnson Space Center. PLAID enables the creation of three-dimensional, color, graphical images with accompanying animation. The feature of animation enables the MSTL to evaluate different workstation configurations with the interaction of figures of human operators which are anthropometrically correct, thereby determining anthropometric reach limits and viewing angles. PLAID also makes it possible to evaluate how well operators of varying physical dimensions can interact with different workstations.

PLAID enabled the MSTL to iteratively evaluate FTS workstation layouts within the aft flight deck and the mid-deck of the Shuttle. Figure 4 illustrates a conceptual design of the placement of the FTS workstation on the aft flight deck. (PLAID drawings are produced in color, but, due to reproduction restrictions on this document, color prints could not be included in this article. Therefore, the PLAID renderings included in this paper are, out of necessity, line drawings.) If the FTS workstation is placed in this location, it will be in close proximity to the Remote Manipulator System (RMS) control panel. This particular figure gives an indication of how two 95th percentile male operators would work together simultaneously. The reader should notice that the PLAID drawing indicates that there will be some shared work space between the two operators. This important finding was made available to the MSTL without the necessity of fabricating full-scale mockups. Different sized operators other than the ones examined in this example could also have easily been put into the aft flight deck conceptualizations for evaluation.

Figure 5 illustrates how the FTS workstation might be laid out in the mid-deck of the Shuttle. In this figure, a 95th percentile male operator is using the workstation located within the bank of lockers in the mid-deck of the Shuttle. Figure 6 is a conceptualization of how well a 5th percentile female would be able to reach the controls of the mid-deck FTS workstation. The reader should notice that in each of these two figures a restraint system that attaches to the torso of the operators is included for evaluation. This particular restraint system concept was developed by Charles Willits of NASA-Reston.

CONTROL/DISPLAY LAYOUTS

The third example will be a discussion of the use of computer graphics in the consideration of the placement of the FTS control panel in the Shuttle. At the time of this writing, it had not been determined where the FTS control panel would be located in the Shuttle. As in the discussion of the use of PLAID in

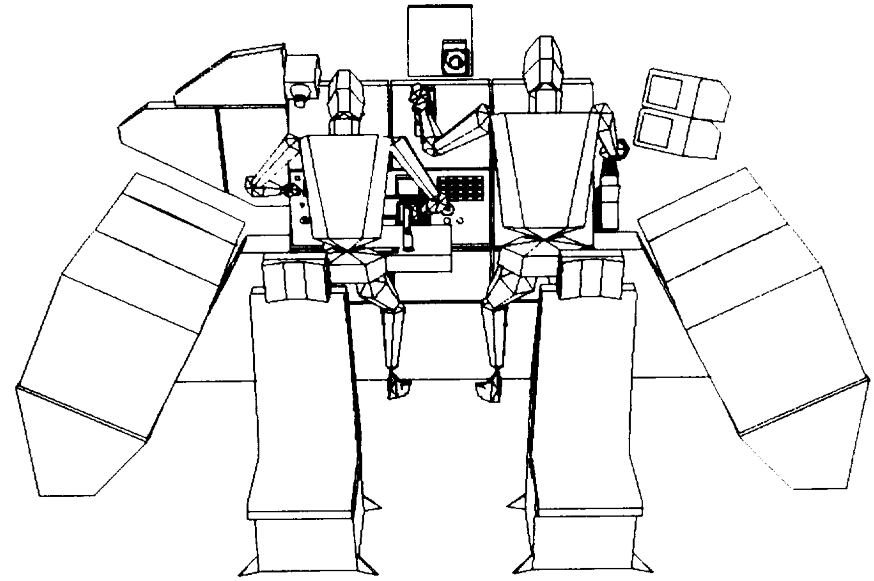

Figure 4 -- PLAID conceptualization of the placement of the FTS workstation in the aft flight deck of the Shuttle.

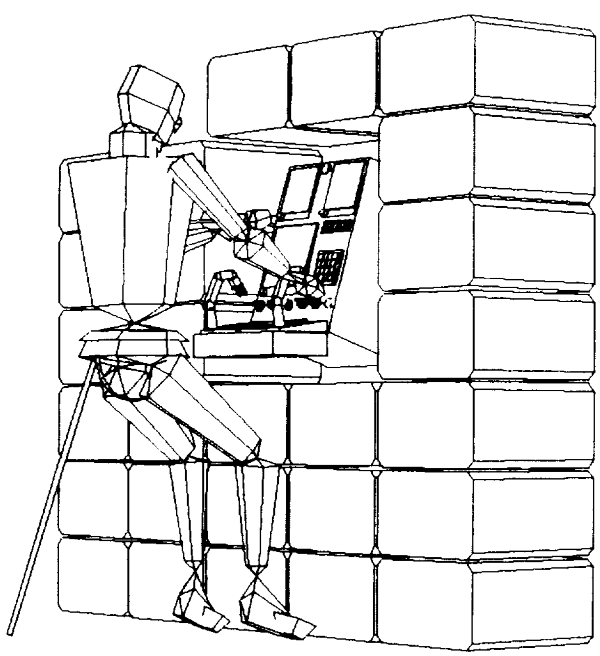

Figure 5 -- PLAID conceptualization of the placement of the FTS workstation in the mid-deck of the Shuttle with a 95th percentile male operator.

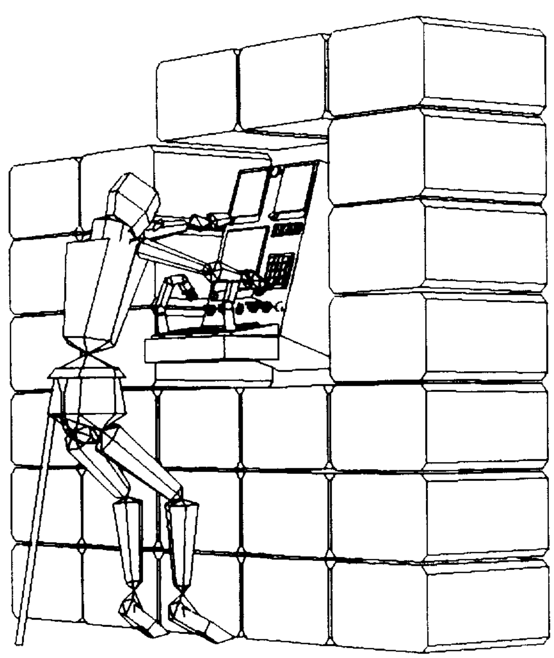

Figure 6 -- PLAID conceptualization of the placement of the FTS workstation in the mid-deck of the Shuttle with a 5th percentile female operator.

the previous section, two locations were being considered: the aft flight deck and the mid-deck. Many different design features were considered and computer graphics enabled the MSTL to quickly and inexpensively evaluate the preliminary placement of these features. Some of these features were the size and number of monitors to use, placement of control switches, the types of controls to use, and whether or not a detachable keyboard should be a part of the control panel. The graphics package used in this example was MacDraw. MacDraw is a graphics development package that is available on Apple Macintosh computer products.

The first examples given will be design considerations made concerning the placement of the FTS control panel in the aft flight deck. Figure 7 is a drawing made with MacDraw to illustrate a possible FTS control panel using aft flight deck panel A6-A2.

The second location within the Orbiter where the placement of the FTS control panel was considered was the mid-deck. There was more space available in the mid-deck for the FTS control panel, so the control panel layouts where slightly different. Figure 8 is an illustration of a control panel layout in the mid-deck.

The MSTL has determined that one advantage of the use of computer graphics is that it will allow a somewhat extensive analysis to take place before any physical mockups have been developed. After several design iterations using computer graphics, full-scale mockups with varying levels of fidelity can then be constructed.

OTHER COMPUTER GRAPHICS APPLICATIONS

The MSTL had other proposed uses for computer graphics at the time of this writing. Since these applications were still in the design stage, the drawings were not available for this publication. None the less, these applications also represent further uses of computer graphics within the field of Human Factors. For this reasons, then, these projects will be briefly described here.

One project which is currently underway is the use of Hypercard to create "pulldown" and "popup" menu-overlays on real-time video images that appear on cathode ray tube (CRT) screens. The video images will be fed from analog and digital cameras located at remote locations from test subject viewers. The video images will be the subjects' only view of remote work sites of interest. The menu-overlays will enable the MSTL to evaluate the utility of an operator using various input devices to control cameras while performing simulated FTS remote manipulation tasks.

Another project underway at the MSTL was the proposed use of computer-aided measurement tools to monitor and display various indicants of work physiology, especially mental workload. The objective here was to incorporate computer-aided data collection and display technologies so that the MSTL could evaluate the workload tradeoffs associated with various workstation components and configurations.

CONCLUSION

The consideration of the productivity, safety, and comfort of the astronaut crewmember is being incorporated into the design process of advanced NASA telerobots through the use of powerful computer-aided systems such as PLAID, Hypercard and MacDraw. The above mentioned examples serve to illustrate the invaluable role that computer-aided design technologies play in the design and development of the FTS workstation by NASA JSC's MSTL. The MSTL has determined that the use of computer graphics packages contributes to a more efficient and less costly systems design cycle. Graphics packages will continue to be used by the MSTL and should certainly exhibit increased usage throughout the field of Human Factors.

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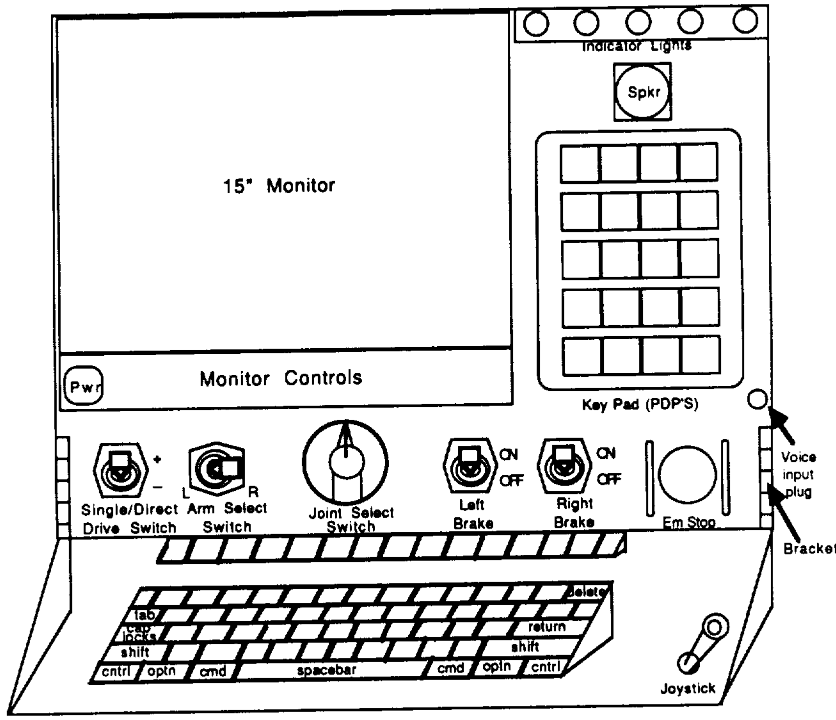

Figure 7 -- FTS control panel in aft flight deck panel A6-A2.

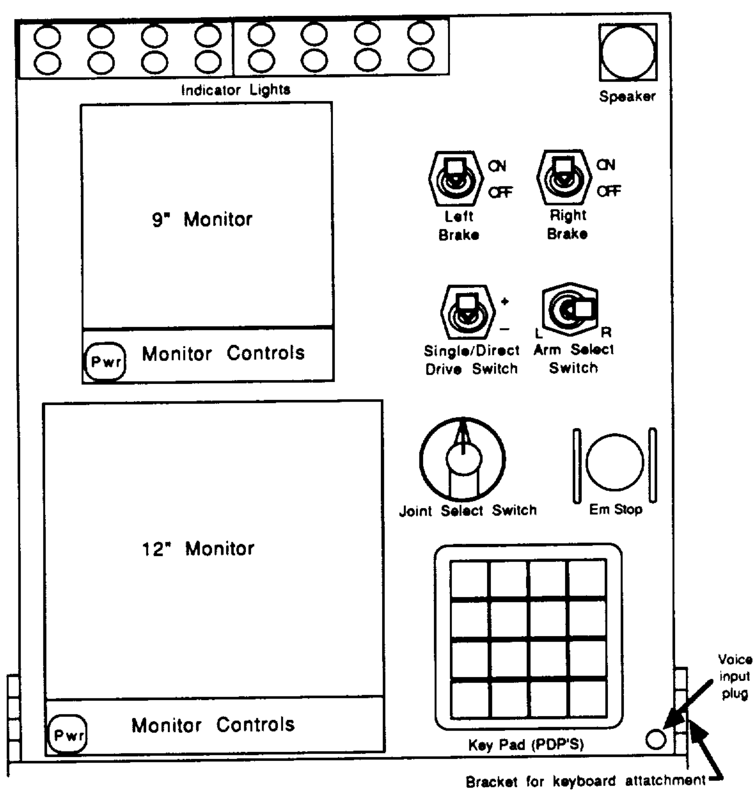

Figure 8 -- FTS control panel in mid-deck with nine-inch monitor and twelve-inch monitor.

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