HUMAN FACTORS REQUIREMENTS FOR TELEROBITIC COMMAND AND CONTROL: THE EUROPEAN SPACE AGENCY EXPERIMENTAL PROGRAMME

Robert J. Stone
The National Advanced Robotics Research Centre
Salford, United Kingdom

Space Telerobotics research, performed under contract to the European Space Agency (ESA), concerning the execution of human factors experiments, and ultimately leading to the development of a telerobotics test bed, has been carried out since 1985 by a British Consortium consisting of British Aerospace, the United Kingdom Atomic Energy Authority and, more recently, the UK National Advanced Robotics Research Centre. The principal aim of the first study of the series was to derive preliminary requirements for a teleoperation servicing system, with reference to two mission model scenarios. The first scenario introduced the problem of communications time delays, and their likely effect on the ground-based operator in control of a manipulator system on board an unmanned servicing vehicle in Low Earth Orbit. In the second scenario, the operator was located on the NASA Orbiter aft flight deck, supervising the control of a prototype manipulator in the "servicing" of an experimental payload in the cargo bay area. Human factors analyses centred on defining the requirements for the teleoperator workstation, such as identifying basic ergonomic requirements for workstation and panel layouts, defining teleoperation strategies, developing alphanumeric and graphic screen formats for the supervision or direct control of the manipulator, and the potential applications of expert system technology.

The second study for ESA involved an experimental appraisal of some of the important issues highlighted in the first study, for which relevant human factors data did not exist. Of central importance during the second study was the issue of communications time delays and their effect on the manual control of a teleoperated manipulator from a ground-based command and control station. An experimental test bed, based around ASEA Irb6 and 60 robots was developed, incorporating a general purpose robot controller, a reconfigurable operator workstation and a modular task box. The programme was divided into a series of short pilot studies and two principal experiments. The aim of the pilot studies was to optimise the characteristics of hand controllers and visual feedback conditions prior to their more formal evaluation and comparison in the later experiments. The experiments were conducted using standard psychological paradigms, involving human performance comparisons over a range of 3 and 6 degree-of-freedom hand controllers, with TV and graphics displays in various configurations. Although a rigorous experimental approach was adopted during Teleoperation and Control Study 2, it was evident that this approach suffers a number of limitations. The most critical concerns the extent to which the data and conclusions from this study can be generalised to future scenarios. Also, it is recognised that the performance measures of time and accuracy alone were not satisfactory, as they each provided only an overall index of performance for a given trial, not an analytical index of performance within the trial. Clearly, more analytical techniques to analyse operator performance in detail are required, together with a methodological framework in which all techniques can be used to judge the effect of "cost" of a particular technology, not only on human

teleoperation performance, but also on the total telerobotic system, with the future aim of defining operational procedures.

Teleoperation and Control Study 3 is investigating a new technique - console or performance "logging"- for the measurement of teleoperation performance to complement those measures used in the second study, such as primitive and whole-task timings, handling errors, debriefing and subjective workload records (NASA TLX), video and audio recordings. Instrumenting the human-system interface to record and store both multiple gross actions and much finer keystroke-level parameters should provide a more detailed insight into the incidence, cause and effect of interactions between various control activities, and assist the experimenters in analyzing those control behaviours of too fine a nature to be extracted from video records alone (such as fine individual joystick motions). Such a keystroke level of analysis should provide data suitable for future performance modelling activities in the area of telerobotic command and control.

Included among the parameters to be recorded in Study 3 are all robot control joystick axes, all additional joystick-mounted controls (where used), all panel-mounted switches, all camera joystick controls, all direct voice input utterances (incidence of onset only), all robot motions, as resolved at the end effector (i.e., translation and rotation), elapsed time (pulse code modulated), and experimenter-induced event markers. Areas of interest for the analysis work include an appraisal of individual strategies and their relation to task success, across-condition comparisons of control characteristics (e.g., when stereo vision or predictor displays are used in the experimental designs), error history monitoring (i.e., analysis of "lead-up" events), analysis of discrete event changes (e.g., the effects of discrete time delay changes, or selections of new robot control frames), and possibly an appraisal of the effects of controller "physical" characteristics (e.g., axis cross-talk, deadband, breakout forces). Finally, there are a number of outstanding questions to be addressed with regard to the use and development of the data logging system described above. For instance, is it desirable and even possible to use the data to generate metrics of performance suitable for complementing experimental and subjective results? Do other forms of control data (other than onset, direction and duration of control inputs) exist that are appropriate for logging? How can the concept be extended to record performance-related parameters other than control inputs (such as visual search, attention, mental workload, etc.)? Can a data logging system provide a useful insight into the operational cost of remote space operations? Answers to these questions will become clearer, following the use of the logging system during the experimental phase of the third contract, scheduled for the Summer of 1990.