HUMAN-AUTOMATION INTERACTIONS AND PERFORMANCE ANALYSIS OF LUNAR LANDER SUPERVISORY CONTROL

K. R. Duda1, C. M. Oman2, A. Natapoff2, J. J. Marquez3, B. F. Gore3, H. Y. Wen1,2, C. J. Hainley, Jr.1,2, J. D. Kaderka1,2, A.W. Johnson1,2, M. Taula1 and J. J. West1

1The Charles Stark Draper Laboratory, Inc., 555 Technology Square, Cambridge, MA 02139, 2Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA, 02139, 3NASA Ames Research Center, Moffett Field, CA 94035, 4San Jose State University Research Foundation, San José, CA 95112

INTRODUCTION & RESEARCH AIMS

Safe and precise planetary landing requires complex interactions between the astronauts and the vehicle systems and automation. Although the tasks for the astronaut and the automation have yet to be specified, we can begin to define and quantify the complexities of this interaction. This project had four integrated specific aims to address the challenges of human-automation task allocation and performance in a complex space system using lunar landing as the case study: (1) Perform a critical analysis of human operator-automation interactions and task allocations, considering information requirements, decision making, and the selection of action, (2) Develop a closed-loop pilot-vehicle model, and parametrically analyze it to quantify system performance, (3) Conduct experiments in the Draper Laboratory fixed-base simulator to validate critical model parameters, and (4) Extend the model to include the effect of spatial orientation and conduct experiments on the NASA Ames Vertical Motion Simulator (VMS).

RESULTS SUMMARY

The hierarchical task analysis (HTA) included a critical analysis of the Apollo lunar landings as well as future lunar landing functions and capabilities (Aim 1) to generate sufficient detail for subsequent model development (Aim 2). This analysis also provided the basis for subsequent fixed-base (Aim 3) and motion-based (Aim 4) experiments. Our investigation motivated the identification of research gaps in dynamic task allocation, namely the definition of a “graceful transition” as “the ability of an operator of a complex system to change between levels of automation / levels of supervisory control (including automation modes) while maintaining control and awareness of the system without sacrificing system performance or mission objectives.” We quantified, for the first time, the magnitude of the decrement in flight performance, workload, and situation awareness as a result of 1) the planned transition to a lower level of automation, and 2) the pilot closing a greater number of control loops. In addition, a new metric and methodology – verbal callouts of key vehicle states – was developed to quantify real-time situation awareness.

A set of parameterized human performance models (HPM) were developed to represent the human and the system in a common modeling framework (i.e., MATLAB/Simulink HPM library). It is a research tool that enables the creation of integrated human-system simulations that quantify the sensitivity of system performance to critical model parameters while identifying intra-model interactions. The systems-level architecture includes a task network, HPMs, and vehicle dynamics (both the Apollo Lunar Module and Constellation Program Altair vehicles). The parameterized HPM modules include attention, perception, decision making, and action; and the task network allows the task to be allocated either to the human or to the automation.

In the human subject experiments, we quantified pilot performance, visual scan patterns, failure detection/diagnosis, and the effect of motion cues during several simulated lunar landings. The experiments further investigated our previous identification of the effect of mode transitions on workload and situation awareness by quantifying visual fixations on flight instruments as well as pilot performance during mode transitions. The active flight control mode had an effect on both the time required to detect failures (radar altimeter failure, stuck attitude control thruster, or fuel leak), as well as the visual dwell duration on required flight instruments. Surprisingly, we did not find an effect of motion cues on flight performance or failure detection latency. The data has been integrated into the human performance models to improve the robustness of the representation of performance during simulated lunar landings.

BENEFITS & RISK REDUCTION

The results of the investigations have provided metrics and methodologies for quantifying performance, workload and situation awareness that can be used to evaluate a system’s design and implementation (SHFE-TASK-01, SHFE-HCI-06) as well as improved the fidelity of model-based tools (SHFE-TASK-02). In addition, the underlying HTA for task allocations provides a framework for documenting tasks and information requirements (SHFE-HARI-01) and this HTA coupled with the modeling and experimental investigations provides a basis of metrics for quantitative comparison of human-automation task allocations (SHFE-HARI-03).

This work was supported by the National Space Biomedical Research Institute through NASA NCC 9-58.