Evaluation of Hands-Free Devices for Space Habitat Maintenance Procedures

Currently, International Space Station (ISS) crews use a laptop computer to display procedures for performing onboard maintenance tasks. This approach has been determined to be suboptimal. A heuristic evaluation and two studies have been completed to test commercial off-the-shelf (COTS) "near-eye" heads up displays (HUDs) for support of these types of maintenance tasks. In both studies, subjects worked through electronic procedures to perform simple maintenance tasks. As a result of the Phase I study, three HUDs were down-selected to one. In the Phase II study, the HUD was compared against two other electronic display devices - a laptop computer and an e-book reader. Results suggested that adjustability and stability of the HUD display were the most significant acceptability factors to consider for near-eye displays. The Phase II study uncovered a number of advantages and disadvantages of the HUD relative to the laptop and e-book reader for interacting with electronic procedures.

INTRODUCTION

Over the past year, NASA's focus has turned to manned long duration and exploration missions. On these journeys, crewmembers will be required to execute thousands of procedures to maintain life support systems, check out space suits, conduct science experiments, and perform medical exams. To support the many complex tasks crewmembers undertake in microgravity, NASA is interested in providing crewmembers a hands-free work environment to promote more efficient operations. The overarching objective is to allow crewmembers to use both of their hands for tasks related to their mission, versus holding a manual or controlling a display. The use of advanced, "hands-free" tools will undoubtedly make the crewmembers' task easier, but it can also add to overall task complexity if not properly designed [3].

The primary technology needed to support a "hands-free" environment is display technology. A Heads-up Display (HUD) is a natural fit for this need. Heads-up Display (HUD) is defined in Wikipedia as "any type of display that presents data without blocking the users view." Some will refer to a HUD as any display superimposed in the users work environment, such as a pilot's windshield. In fact, HUDs got their start in military applications such as windshield displays. Others will refer to HUDs that place a monocle or stereoscopic display over and near the eye of a user as Head Mounted Displays (HMD). The terms are used interchangeably in the commercial sector, and thus we will use the broader HUD term as not to limit our discussion.

Many human-computer interface (HCI) researchers have focused solely on traditional display issues. Although some work has been completed in the area of cockpit HUDs, additional research is required in order to produce concrete guidelines for the design of optimal, near-eye HUDs for hands-free tasks. It is also important to provide NASA with requirements for such advanced technologies for future implementation. These issues are of critical importance for the safety and productivity of future space missions. Thus, our evaluation method entails a holistic evaluation of COTS HUD technologies. The first step was to identify commercial products that appeared to meet the need to provide crewmembers a near-eye visual display for procedures and additional reference material. Previous work evaluated several HUDs for comfort and fit, as well as suitability for use in microgravity [1]. This early evaluation examined three different commercial products, and the testing of one of the commercial products in a microgravity environment. Overall, it was found that HUDs could be used in a microgravity environment. Further findings from this early evaluation included the identification of several requirements for NASA

HUDs including: (1) monocular or binocular see-through display; (2) padding for comfort; (3) easily adjustable display screen; (4) easily adjustable helmet; (5) minimization of wiring connections or a wireless connection; and (6) supporting text line drawings. For the current set of investigations, three COTS HUDs were selected, and the evaluations focused on maintenance procedures for the International Space Station (ISS).

METHODS

The studies were conducted in the Space Station Mockup and Trainer Facility (SSMTF) located at the NASA Johnson Space Center (building 9). The SSMTF is a full scale, high fidelity replica of the pressurized portions of the International Space Station. It supports crew training such as ingress and egress, habitability, and emergency procedures. The SSMTF is also used for mission support, engineering evaluations, and timeline and stowage assessments. One portion, the Payload Development Lab (PDL) II, was used for these evaluations. The PDL II encompasses a set of standalone racks. Two of the racks in the PDL II were used for the evaluations, and one additional rack was fabricated and brought in to the mockup for the evaluations. In addition, the PDL II was outfitted with cameras to record each participant's actions.

Before each evaluation began, the test participant was trained on the maintenance procedures tasks to be performed during the evaluation. They completed a thorough walkthrough of the PDL II for familiarization with rack location, rack markings, and the tasks associated with each rack. Each participant was tested for eye dominance, (the imagery from the eye that is preferred over the other eye). Normally a HUD is worn over the dominant eye. Although this elicits binocular rivalry and makes real-world imagery viewed with the other eye relatively more difficult to perceive, it was assumed that the procedure display would be seen more easily, more frequently, and for longer than the non-dominant eye [2].

Each device in Phase I (one of three HUDs) and in Phase II (best HUD from Phase I, laptop, and e-book) was used in performing two maintenance procedures (checking filters for contamination and rewiring associated circuits). The order of use of the devices was counterbalanced; two participants per each of six possible sequences. After the use of each device, the participant completed an evaluation questionnaire, and then a final comparison questionnaire after the third device. Task time was measured from the initial presentation of the maintenance procedures display until the participant completed both procedures. Errors were recorded for omissions and wrong sequences.

RESULTS

Phase I

The use of the MicroOptical SV-6 HUD was ranked the highest by participants in this design context.

- Display/Laptop Characteristics, Wearability, Work Environment, and Adaptability were used for ranking but did not differ significantly in ranking across participants
- Ability to view surrounding work area was identified as a critical operational requirement
- The biggest cluster of comments from open-ended questions was on adjustability/stability, display area, and focusing

Phase II

The use of the e-book reader was ranked over the laptop, and the laptop was ranked over the HUD by the participants for performing the maintenance procedures.

- Portability and information concentration were critical factors

[Full nonparametric statistical results and graphs will be included in the final paper.]

DISCUSSION

The maintenance procedures were selected to emphasize mobility, tool use, and multiple document sources during their performance. That is, the participant had to move from rack to rack, use a wrench, a camera, etc., replace components, and refer to diagrams to complete tasks. An additional constraint was imposed that the overall format of existing procedure documents was to be retained and not optimized for the electronic device (“plug and play” approach). This was based on the future plans to test with real procedures onboard NASA’s C-9 in a microgravity environment and then on ISS.

In the first study, a conflict surfaced between display size, visual surround, and stability. Although some participants preferred a larger and crisper display area for presentation of the procedures, a clear need surfaced for being able to see the visual surround (of the work environment) with the eye that was reading the text instructions. Overlapping images for both eyes were more of a problem when the near-eye display filled the field of view display for that eye [4]. In addition, the stability of the display was important for operational use.

In the second study, the best HUD from the first one (in terms of stability and size) was compared against the existing maintenance methodology, employing a fixed laptop. Another possible technology solution, the e-book reader, was included. Although portability was a characteristic of both the HUD and the e-book reader as compared to the laptop, the display of scrolling procedures in the HUD vs. a full page in the e-book reader seemed to be an overriding factor in the rankings by the participants. This was surprising since others have shown that the small monocular type of HUD display have minimal impact on visual fields, making them a reasonable choice to wear in non-immersive conditions with training [5]. Furthermore, the larger displays of both the e-book reader and the laptop, with a larger information concentration, apparently were influential in ranking the HUD below the other two electronic displays.

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