Maintenance Activities with Wearable Computers as Training and Performance Aids

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Abstract

Engineers refer to technical manuals when performing maintenance on complex mechanical equipment, often located in difficult environments. Wearable computers provide their users access to information at any time or place. It is hypothesised that accessing technical manuals on a wearable computer would allow maintenance engineers to perform their tasks faster and more accurately. A planned case study involving Mechanical Engineering students is described in this paper, including the expected outcomes and their possible implications.

Keywords

wearable computers, head-mounted displays, performance aiding, interactive electronic technical manuals

INTRODUCTION

Wearable computers often run continuously and are available for user interaction at any time. In the past, they were large and unwieldy but with technological improvements in recent years, they have shrunk to more practical sizes. One of the key functions of wearable computers is augmenting the user's memory, making them ideal for presenting technical documentation to maintenance engineers. Engineers traditionally referred to paper-based manuals but they are being increasingly replaced with electronic formats called Interactive Electronic Technical Manuals (IETMs). This paper details the plans for a case study comparing wearable computer-based IETMs to desktop-based systems, focusing on the fit between the user and the work environment.

BACKGROUND

Technical manuals contain information that helps engineers with their maintenance tasks, for example parts catalogues, disassembly procedures, wiring diagrams and inspection checklists. Bass et al (2001) states that technical manuals for small aircraft often contain up to 100,000 pages and over 600 individual items in an inspection checklist. The primary advantage of using IETMs over paper is its significantly lower distribution cost.

Many difficult maintenance engineering environments have been documented in literature. Bass et al (2001) stated that environments with dirt, grease and temperature and light extremes are difficult for computers. Sunkpho et al (1998) argued that bridge inspectors need to be highly mobile and cannot focus all of their attention searching for information on a computer for safety reasons. Military engineers often work in harsh conditions for example deserts, ships, and aircraft (Bapst et al 2001). Crane inspectors need the full use of both hands and feet to climb and inspect cranes (Boronowsky et al 2001). Paper manuals in these scenarios may be too heavy and bulky to carry, cannot be set down and may have pages flapping in the wind (Siegel et al 2001). It also may be impossible to carry or use laptops in these environments. Traditional IETM systems are unsuitable as they are designed for stationary users whose attention is fully focused on interacting with the computer.

Engineers needing to refer to technical manuals during their work have at least two options. First, they may guess the solution or ignore the problem, for example when a step in an inspection has been forgotten. Second, they can stop what they are doing, go to the workbench, refer to the documentation and return to the equipment to continue working. These interruptions may reduce their productivity or even introduce mistakes (McFarlane 2002).

Review of Past Studies

Wearable computers appear to be ideal for the scenarios described above their use has been investigated in many studies. The following studies have mostly used head-mounted displays for output but the range of input devices varied between speech, data gloves, and rotary dials.

Wearable IETM systems may be effective on-the-job training tools as new engineers are guided through unfamiliar tasks without having to refer back to manuals on the workbench. Baudhuin (1996) described an early training and technical documentation system for wearable computers. Thompson et al (1997) investigated using wearable computers to train military equipment operators and maintainers and conducted a performance study with a simple mechanical task. Siegel et al (2001) performed a case study with military aircraft maintainers using a wearable computer for task guidance and found that they have the potential to be effective training tools.

Many studies have looked into using wearable IETM systems as performance aids for maintenance work. For example, Siewiorek et al (1998) created and tested a fault diagnosis and preventative maintenance system for a train network. Ockerman et al (1998), Sunkpho et al (1998) and Boronowsky (2001) developed wearable computer-based performance aids for aircraft, bridge and crane inspectors. These systems aimed at reducing the time spent performing inspections and reducing errors in the inspection process. This was achieved by allowing the inspectors to record their observations immediately, with access to technical manuals where necessary.

Usability problems with wearable computers may affect their usefulness with IETMs. For example, Kotulak et al (1995) and Laramee et al (2002) documented issues with head-mounted displays. Wearable computers have battery lives in the range of four to six hours (Bapst et al 2001), too short for an entire work day. They may also generate too much heat for comfortable use. Few commercial systems can withstand harsh environments, for example extreme temperatures, high moisture levels or excessive amounts of sand and dust (Bapst et al 2001).

The studies listed above have two characteristics in common. First, these studies developed completely new wearable IETM systems with little or no pre-existing content available. Boronowsky et al (2001) notes that reproducing technical content for a wearable IETM system is an expensive exercise. It is therefore desirable for a wearable IETM system to be able to display existing technical manuals with little or no modification. However, Siegel et al (2001) found that many existing technical manuals may be ineffective for on-the-job training. Second, the baseline condition in all of the studies was the use of paper-based (or no) manuals. As stated earlier, paper-based manuals are increasingly being replaced by IETMs. There is a need for wearable IETM studies to contrast their use with standard desktop or laptop-based IETMs to ensure that any identified benefits are specifically due to the use of a wearable computer.

METHOD

During a preliminary study a prototype wearable computer-based IETM system will be developed and evaluated. The study differs from previous work in two key areas. First, the prototype to be developed will allow any existing technical manual in the Mincom LinkOne format to be viewed without modification. Second, the control condition in the experiment will be the use of a desktop-based version of the prototype instead of paper-based or no support as in past studies.

This study will be performed in five phases:

(i) Contextual inquiries will be performed by visiting worksites where maintenance activities occur. The aim of this is to examine how wearable computers may fit into the engineers' work environments.

(ii) A user interface building on past studies and using a head-mounted display, jog dial and voice recognition will be designed.

(iii) A prototype IETM system extending Mincom's existing LinkOne software will be developed.

(iv) Usability testing will be performed with the prototype system as detailed in the following section.

(v) The data collected from the tests will be analysed to determine the outcomes of the study, and areas where additional research is needed.

EXPERIMENTAL DESIGN

Participants

Eight Mechanical Engineering students from the University of Queensland's Formula SAE-Australasia (Student Division) team will participate in the usability test. Each year, this team designs, develops and tests a Formula-style race car that is entered into the national competition. Although the team focuses on building the car instead of maintaining it, the team members have significant experience with its assembly, disassembly, and repairs.

Apparatus

The experimental group will be using the developed prototype IETM system on a Xybernaut Mobile Assistant® V wearable computer. For output, a MicroOptical SV-6 head-mounted display will be used with a Logitech Stereo USB Headset and Contour Design ShuttleXpress rotary dial for input. The control group will use the prototype on a desktop computer with the same input devices except for an additional mouse. The participants will perform the tasks on the front corner assemblies (that attach the wheels to the chassis) of the team's 2003 competition car.

Design

The participants will perform four maintenance tasks: assembling the front right and then front left corner assemblies and then disassembling them. For students who have not performed the procedures before, the total time required to complete the tasks varies from one hour to three hours depending upon experience levels.

The experiment will have two independent variables: the type of computer support and the level of the participant's maintenance experience. Two levels of computer support will be used: a traditional desktop computer on a workbench and a wearable computer worn by the participant for the duration of the test. There will be two experience levels: novice, students who have not had significant experience with mechanical maintenance activities and expert, students who have worked extensively with the SAE car. None of the participants have previously performed the tasks as the tasks are simple enough that students should need support once they have performed the procedures. The experimental and control groups will each have four members. Each of these groups will have two novice and two expert participants.

The dependent variables in the study are task time and learning rate. The task time is the amount of time required to perform each of the four maintenance tasks. The learning rate will be measured by the reduction in task time between the right and left corner assemblies and the assembly and disassembly tasks. In a similar vein to the missing checklist items in the study by Ockerman et al (1998), there will be intentionally incorrect steps in the maintenance manual that the students will be expected to detect and perform correctly based on prior experience.

Procedure

In usability tests to be conducted in the University of Queensland's Usability Laboratory, the participants will initially be given training on the use of the wearable computer and prototype software. They will practice using the system with a simple task, folding a paper crane. The entire training process will require one hour.

After training, the students will use the prototype technical manual system to guide them through the four maintenance tasks. The test process, from the initial training to performing the tasks, will be videotaped for later review. The participants will also complete questionnaires and interviews before training, after training and at the conclusion of the tests. This will establish their demographic details, confidence levels after training and usability concerns with the wearable IETM system. Comfort assessments of the wearable computer will be made using questionnaires similar to the model described by Knight et al (2003).

DISCUSSION

Preliminary testing has shown that wearable computer-based IETMs can be highly beneficial despite numerous usability issues with the equipment. The initial participants noted that looking up technical manuals on the wearable is far less tedious than having to constantly refer back to a desktop computer. The inexperienced users found the step-by-step guiding very helpful as training aids, especially photographic illustrations for each step. Voice recognition was the preferred input interface over the jog dial as it allowed both hands to be free for the task and learning how to operate it was intuitive. The main issues with the system were the excessive size and weight of the MA V unit and the difficulty of keeping the head-mounted display comfortably in place.

Expected Outcomes

Three possible high-level outcomes are expected from this study. First, the tests may show significant performance improvements using the wearable computer. In this scenario, less time would be required to perform the tasks and the participants' learning rate would equal or exceed the learning rate with the desktop. Second, the tests may show that using and navigating the wearable IETM system is slower or less effective than referring back to a desktop computer. Further research would be needed to find the bottlenecks and identify solutions. Third, major usability problems may prevent IETMs on wearable computers from being used at all. Some issues (short battery lives) may be solved with future technological improvements but others will be more fundamental (such as rivalry and interference with head-mounted displays).

External Factors

The two dependent variables in the study (time and learning rate) may be affected by factors relating to the test process and not the usability of wearable computers in general. The experimental group will have had years of experience with desktop computers but only a few hours with the wearable computer. They may focus too much of their attention on using the wearable and end up taking more time than otherwise to complete the tasks as in the study by Thompson et al (1997). The differences between the desktop and wearable groups' learning rate may not be an accurate indication given the relative simplicity of the tasks.

Even if the usability test shows significant performance improvements using a wearable IETM system, there are external factors that may prevent them from being used in the workplace. Wearable computers are significantly more expensive than desktop computers and require additional training for staff. Wearable computers (especially head-mounted displays) can feel very invasive and face workplace resistance to their introduction. Wearable IETM systems would need to be integrated with existing work management systems for them to be truly effective (Bapst et al 2001). Finally, work interruptions may actually be beneficial since it gives the engineers opportunities to take breaks.

Future Work

In the future, the video data collected from this study may be coded for statistical analysis. There are many aspects of wearable computer-based IETM systems that also deserve further study. Other wearable computers can be trialled to determine if they resolve any of the usability issues identified in the study. Testing with maintenance engineers from a diverse range of backgrounds and experience levels would be more representative. Finally, field tests in difficult work environments would determine whether wearable computers would be more effective for electronic technical manual access than traditional desktops and laptops.

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