

APPLICATIONS OF WEARABLE COMPUTING TO EXPLORATION IN EXTREME ENVIRONMENTS

Christopher E. Carr and Dava J. Newman^{*}

ABSTRACT

Wearable computing technologies have the potential to enhance human exploration in extreme environments by serving as multifunctional tools, including serving as cognitive aids, communications tools, research assistants, and real-time health and performance monitors. Future planetary explorers may also use wearable systems to provide "just in time" training or to serve as an entertainment device or virtual abode of privacy while living in cramped quarters. This paper discusses potential uses of wearable computing technologies for planetary exploration on Earth and Mars, as well as potential uses in weightlessness. A wearable computer-based biomedical monitoring and cognitive aid experiment, tested via ground studies and in simulated weightlessness on the NASA KC-135 aircraft, demonstrates some potential uses for wearable computing by astronauts, and indicates necessary areas of improvement for wearable computing technologies. Lessons learned and future opportunities are also briefly discussed.

INTRODUCTION

During exploration in extreme environments, lowered performance can have ultimate consequences such as mission failure or loss of life. Lack of awareness or knowledge about the environment can lead to disaster. Minor health problems can become seriously debilitating. Cognition can be impaired due to environmental conditions or health. Group communication and coordination may suffer. Task proficiency may become degraded due to lack of practice. Skills outside of previous training may be needed. Finally, psychological needs may go unmet: contact with family or friends may be impossible, creative or entertainment outlets may not be available, and privacy may be difficult or impossible.

Many of these problems can be mitigated through timely access to information, including information relating to the state of the explorer. Wearable computers have the potential to mitigate some of these problems by serving as multifunctional tools that function as both monitoring devices and information delivery devices. Wearable computing technologies can enhance self-sufficiency, autonomy, and human/machine teaming by enhancing local human performance and mediating outside interactions.

^{*} Department of Aeronautics and Astronautics, Massachusetts Institute of Technology
Emails: {chrisc, dnewman}@mit.edu

BACKGROUND

A wearable computer can be roughly characterized as a computing device that is portable while operational, capable of hands free use, able to sense characteristics of its environment, is "always on," and is capable of augmenting human capabilities [Rhodes, 1997].

In a more abstract fashion, a wearable computer can be thought of as a human-centric device that performs information processing for or in cooperation with a user. Using this definition, one might consider as relevant the first mention of the eyeglasses in 1268 or the following expression of Robert Cooke in 1665 [Wearables, 2000]:

The next care to be taken, in respect of the Senses, is a supplying of their infirmities with Instruments, and as it were, the adding of artificial Organs to the natural... and as Glasses have highly promoted our seeing, so 'tis not improbable, but that there may be found many mechanical inventions to improve our other senses of hearing, smelling, tasting, and touching.

Other important events in the history of wearable computing include (adapted from [Wearables, 2000]):

- ♣ Invention of the pocket watch by John Harrison (1762).
- ♣ Development of the first wrist watch by Louis Cartier (1907).
- ♣ Proposal of the idea of augmented memory by Vannevar Bush (1945).
- ♣ First stereoscopic head-mounted display (HMD) produced (1960).
- ♣ First wearable computer (built to predict results of a spinning roulette wheel) built by Thorp and Shannon (1966)
- ♣ First computer-based HMD developed by Sutherland (1966).
- ♣ S. Mann develops backpack-mounted computer for photography (1981).
- ♣ Student Electronic Notebook demonstrated by G. Maguire and J. Ioannidis (1990).
- ♣ T. Starner starts constantly wearing his computer (1993).
- ♣ Rapid advances in wearables research and technology; commercially produced wearable computers; strong interest in military and aerospace markets (1994-2000).

WEARABLES AND EXPLORATION

Wearable computers can enhance human exploration in extreme environments by serving as multifunctional tools. A wearable computer may function as an information capture tool, a health and performance monitor, a cognitive aid, a communication and coordination tool, a tool for education, training, or retraining, or as a tool to provide psychological support.

A wearable computer can serve as an information capture tool via automated information capture or by directed (user-initiated) information capture. The wearable computer may act as a recorder, binding context to information (such as position or time information, or other relevant data related to user activity) so the user can focus on the task at hand. The wearable computer

may also have the capability to share that information over a network to other users or machines. Directed information capture might be enabled using multiple interfaces such as haptic input devices, gestures, voice commands, or direct manipulation interfaces (ex: for visual input, a camera is a direct manipulation interface). Recording of audio, images, video, or text might be appropriate for a large number of applications.

Wearable computers can also serve as biomedical monitors. A wearable computer may non-invasively monitor a series of physiological parameters such as heart rate (or a full electrocardiogram), blood oxygen saturation, blood sugar, blood nitrogen, respiration rate, or walking gait. The wearable computer might contain a physiological model, potentially tailored to the individual user, and might be able to provide real time physiological feedback or intervention or suggest a remote consultation with medical personnel. Measurements could be made during normal daily activities of an explorer in an attempt to reduce the number of perceived extraneous medical tests required in some environments (such as during long-duration spaceflight). In addition, wearable computers might provide environmental safety assurance by using wearable sensors to monitor atmospheric gasses such as O₂, CO₂, CO, NO, or potential airborne toxic chemicals. Temperature or pressure monitoring might also be appropriate in some environments. Biomedical monitoring using wearable computers raises important privacy issues that must be considered in conjunction with the technical advantages that might be achieved by such monitoring.

Wearable computers might serve as cognitive aids by functioning as information gatherers and presenters, providing users with procedural checklists or technical references ("interactive electronic technical manuals"), or functioning as "expert systems" for troubleshooting of equipment or other problems. A wearable computer might also serve as a signal processing system with data visualization or enhancement capabilities. Past wearable computing systems have been used as visual information processing platforms with features such as spatial and tonal enhancement [Mann, 1998]. These cognitive aids might function as decision aids or planning tools, and may have personalized interfaces tailored to an individual.

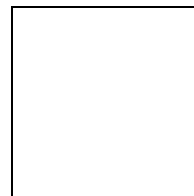
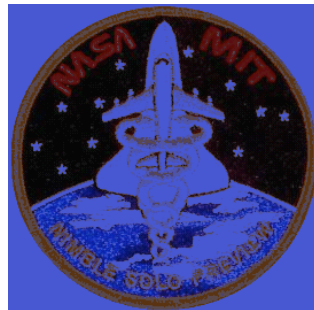
Using a wearable computer as a mediation tool might enhance communication and coordination between users or machines. The wearable computer might function as an attention access regulator, or as an interface to experiments or equipment (thereby reducing the need for experiment-specific or equipment-specific displays except as desired for redundancy). This mediation tool might provide information about other users or machines to the user (such as position, status, conditions, or plans), and could be used to coordinate group activities. Communications could also be stored for later review or reference, and translation between communications formats (synchronous/asynchronous, or audio/text conversion) could be performed.

Wearable computers could support continuing education and training, or just-in-time learning. For example, during a long-duration space flight, a doctor might need to perform a surgical operation not covered in previous training, or not recently practiced. Wearable computers could be used to provide access to domain specific databases (ex: a soldier hiding out behind enemy lines uses his wearable computer to confirm what plants in the area are edible). With the right interfaces, wearable computers can provide augmented reality or virtual reality for

training and simulation. Retraining or simulation capabilities are especially important during long-duration space flight: the complexity of space missions requires the crew to be proficient in the use of a huge number of complex systems. For example, on-orbit astronauts may need to re-familiarize themselves with a particular piece of equipment through simulation due to a long period of time between their original training and operation of the equipment during a critical phase of a mission. One of the factors involved in the crash of a Progress supply vehicle into the MIR Space Station in 1997 may have been the significant procedural changes made prior to the attempted rendezvous and a lack of recent training with the rendezvous systems.

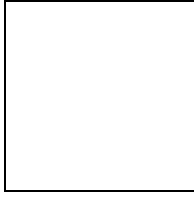
Many of the serious challenges encountered during exploration in extreme environments are psychological in nature [Stuster, 1996]. Wearable computers have the capacity to provide psychological support by serving as a creative outlet: explorers might use a wearable computer as a tool for music composition, writing, drawing, imaging, photography, or video capture. A wearable computer might also function as a game playing machine or a multimedia display device (for private or shared displays of movies or music, for example). This may help users cope with the boredom that is often encountered in extreme environments during periods of inactivity. Such a device could also serve as a virtual private space, customized to an individual. Explorers might use such a device to communicate with family or friends in privacy, or to store personal documents or keep a personal journal.

A Case Study: Wearable Computing in Simulated Weightlessness



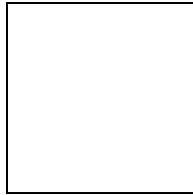
The authors began a project in 1998 to build and test a flexible wearable computer system for astronauts that serves as a biomedical monitoring device and multipurpose tool. The specific aim of project NIMBLE (a Non-Invasive Microgravity Biomedical Life-sciences Experiment) was to measure the effects of micro-gravity and hyper-gravity environments using pulse-oximetry and electrocardiography, while providing a cognitive aid for the user (the use of the wearable computer as a checklist was compared with the use of a paper checklist).

The wearable computer system was based upon a commercially available wearable computer from Xybernaut Corporation, the Mobile Assistant IV, and included a wearable central processing unit (CPU), a head-mounted display, and a wrist worn keyboard. The wearable computer performed data collection for an electrocardiography system, and for a serial-port-based pulse-oximeter sensor. A general block diagram of the experimental setup and analysis approach is shown below:

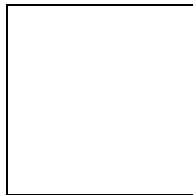


Data Collection and Analysis Block Diagram

The system was built, ground tested, and later flown on the NASA KC-135 aircraft as part of the NASA Reduced Gravity Student Flight Opportunities Program in March 1999. Two flights on the KC-135 with four sets of 10 parabolas per flight yielded a total of 80 parabolas for testing of the system in simulated weightlessness. About 20-25 seconds of simulated weightlessness was available during each parabola, and while continuous biomedical monitoring was being performed, checklist evaluation sessions (each 15 seconds long) were performed. Tight choreography of activities during the experiment was made possible only by experiment management and data collection software that had been written and developed for the wearable computer. Two flight-crew members (acting as subjects) flew on the KC-135 per flight, each with a wearable computer system. The author is shown below wearing the wearable computer system during flight:

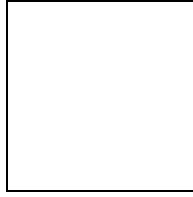


Heart rate recordings obtained during repeated parabolas clearly demonstrated the dynamic response of the cardiovascular system to repetitive exposure to simulated weightlessness and 2-g conditions:



Further analysis of the biomedical data illustrated the important of reducing the effect of outside disturbances (such as movement artifacts or drug effects on biomedical sensors).

In addition to successfully demonstrating wearable computer-based biomedical monitoring, the system also allowed subjects to simultaneously perform a series of simple tasks (such as pushing buttons, turning dials, etc.) with guidance from either a paper checklist or the wearable computer. Biomedical monitoring and cognitive aiding functions could therefore be performed by the system in a simultaneous fashion. The chart below illustrates checklist completion times for subjects using the wearable computer checklist or the paper checklist under all experimental conditions including pre-flight, simulated weightlessness (0-g), 2-g, and post-flight testing.



While the task completion times were lower for the wearable computer than for the paper checklist, the differences in task completion times were not statistically significant. Post-flight results also indicated that a significant learning effect was at play. Subjects' subjective ratings suggested that the wearable computer checklist was easier to use in the simulated weightlessness and 2-g environments.

Overall, the system demonstrated the need for lower-mass, lower-profile, and lower-power wearable computers. The commercially available Xybernaut system was quite bulky, and on one occasion tangled wires resulted in a hard landing on the padded floor of the KC-135 aircraft by two of the subjects at the end of a parabola. In order to provide future astronauts with wearable computing platforms that do not interfere with their mobility, future wearable systems must be significantly less encumbering and more body conformal.

FUTURE WEARABLE COMPUTING TECHNOLOGIES

Wearable computing technologies are undergoing rapid advances. Conductive fabrics, sensor mesh fabrics, and washable wearable computers have been designed or demonstrated [Post, 1997a]. Smaller, lighter wearable computers have been developed, such as a 360 gram prototype, developed by IBM (see figure). Micro-Electro-Mechanical-Systems (MEMS) sensors have been developed for noninvasive biomedical monitoring, and wireless sensors are under development. The MIT Media Laboratory has demonstrated data and power distribution using the body electric field [Post, 1997b]. Human-based power generation for wearable computing has been demonstrated using piezoelectric materials embedded in shoes, and other power generation mechanisms for human-powered wearable computing have been proposed [Starnier, 1996]. See-through micro-displays, or micro-displays embedded in glasses have also been developed.



A VISION FOR THE FUTURE

Wearable computers have the potential to evolve into systems about as encumbering as clothing, and ultimately may be partially or completely human powered. Wearable computers will be used in extreme environments here on Earth and in microgravity. Researchers may use wearable computers to support science activities and operations research at Mars analog sites such as Devon Island or the McMurdo Dry Valleys in Antarctica: wearable computers may be used to study and support the exploration process, to coordinate research activities or observations, and to support distributed collaboration during real or simulated extravehicular

activities between a field team and "base camp." Wearable computers will help take humans to Mars, and will ultimately be in everyday use, in one form or another, by many people on Earth.

Wearable computers have the potential to improve the everyday lives of people around the planet, and those people fortunate enough to journey off the planet. In extreme environments, wearable computing technologies have the potential to make the difference between mission success and failure – because they help empower the strongest link in the chain: the humans.

ACKNOWLEDGEMENT

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