

# Applying a Wearable Voice-Activated Computer to Instructional Applications in Clean Room Environments

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## ABSTRACT

The use of wearable computing technology in restrictive environments related to space applications offers promise in a number of domains. The clean room environment is one such domain in which hands-free, heads-up, wearable computing is particularly attractive for education and training because of the nature of clean room work. We have developed and tested a Wearable Voice-Activated Computing (WEVAC) system based on clean room applications. Results of this initial proof-of-concept work indicate that there is a strong potential for WEVAC to enhance clean room activities.

## KEY WORDS

Wearable Computing, Pervasive Computing, Remote Learning, E-learning, Speech Recognition, Education Enhancement

## 1. Introduction

Over the past two decades, wearable computing technology has been applied in several areas including medicine, the military, industry, law enforcement, security, and education (particularly for the disabled and workers in restrictive environments) [4,5]. At Goddard Space Flight Center (GSFC), efforts in applying wearable computing to the NASA mission began in 2000, with the initiation of the WEVAC project in the Real-time Software Engineering Branch (Code 584) [2]. Three work environments relevant to NASA missions are being considered for use of WEVAC: (1) clean room, (2) launch pad, and (3) human space flight. Investigating clean room environments is a near-term priority because they are the most accessible of the three. This work will eventually expand research to include the launch pad and space environments. In this particular effort we seek to use the WEVAC system for speech recognition-driven multimedia in "embedded" instruction of tasks that require a high degree of hand-eye (or body-eye) coordination. Simply put, a person would be able to learn while doing, rather than viewing education material related to learning a physical task ahead of time, taking notes, and then referring to those notes while trying to

perform the task. Such an "embedded" learner scenario has been studied extensively by the authors in [1,2]. Two types of "embedded" instruction are of interest: (1) self-guided instruction and (2) remote instruction.

The goal of this research was to use the current WEVAC system to evaluate the practicality of self-guided instruction and remote instruction within the clean room environment. Efforts were also made to extend WEVAC functionality for instruction enhancement in an academic microelectronics clean room environment. Aside from the clean room being the most accessible of the three targeted environments, four other factors help to make a compelling case for applying wearable computing in this environment: (1) step-by-step procedures often need to be followed in the clean room, (2) tasks in a clean room usually require the hands free operation and coordination between the eyes and the rest of the body, (3) accessing and collecting data in many forms is required in the clean room, and (4) a computer worn under a clean room "bunny" suit (clean room suit) will cause less of a contamination concern than a laptop carried around outside of the bunny suit. The authors are not aware of any other studies geared toward using wearable computing in a clean room environment.

The remainder of this paper is organized as follows. Section II describes the state of the current WEVAC system. The three experiments conducted involving self-guided and remote instruction using common commercial software, are discussed in Section III. Finally, a summary of the work conducted is given in Section IV along with a perspective on possible future work.

## 2. Present WEVAC System

The following subsections describe the components of the current WEVAC system. This system was used to conduct all experiments subsequently discussed.

### 2.1 Wearable PC

Figure 1 depicts the actual wearable PC used, which is the Xybernaut MA V (Mobile Assistant 5). This unit is the

heart of the wearable system. It is designed to be belt-attachable, has dimensions of 5.9" x 3.5" x 2", and weighs approximately 1 lb. It is equipped with a 500 MHz Intel Mobile Celeron processor, 128 MB of RAM, and a 5 GB hard drive. Standard ports for interfacing include USB, FireWire, and Compact Flash.

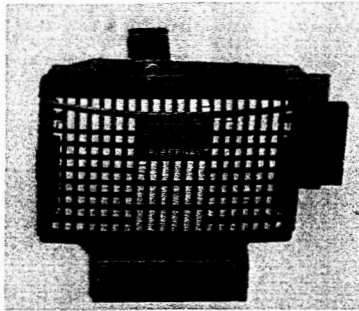


Figure 1: Xybernaut MA V Wearable PC

## 2.2 WEVAC Input Device

The WEVAC system allows four different modes of input. Two of the input modes require the use of at least one hand, and the other two modes are completely hands-free. As shown in Figures 2(a) and 2(b), the Off-Table Track Mouse and the Wrist-Worn mini-keyboard constitute the one-handed input devices. Figures 2(c) and 2(d) show the hands-free input devices, which are the Plantronics digital audio headset (microphone) and the IBOTpro web camera. All of these input devices interface with the MA V through the USB port except for the camera, which goes through the FireWire port.

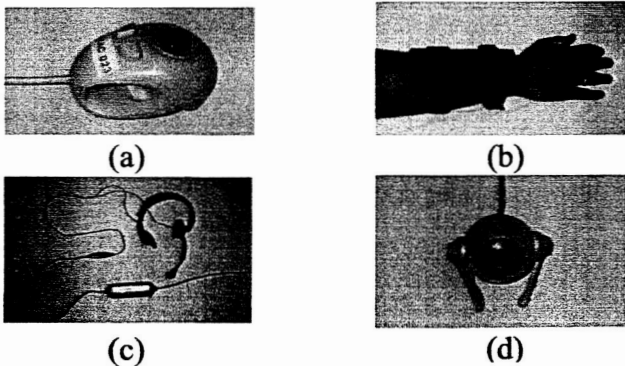


Figure 2: WEVAC Input Devices (a) Off-Table Track Mouse, (b) Xybernaut Wrist-Worn Mini-Keyboard, (c) Plantronics Digital Audio Headset, (d) iBOTpro Web Camera

## 2.3 WEVAC Output Devices

Like most traditional computer systems, the primary forms of user output provided by WEVAC are video and audio. Two video output devices are used. These are the

Xybernaut Flat Panel Display (FPD) and the MicroOptical clip-on viewer (Head Mounted Display), shown in Figures 3(a) and 3(b). The small FPD is typically attached to a user such that it can be accessed on an as-needed basis (usually for application setup purposes). The MicroOptical clip-on display is intended to be the primary source of video output for the system since it allows heads-up viewing. The clip-on display outputs VGA resolution video and covers only one of the user's eyes (monocular display). Thus, when the clip-on display is viewed with both eyes open, a see-through effect is perceived. The earphones of the Plantronics audio headset are used for audio output.

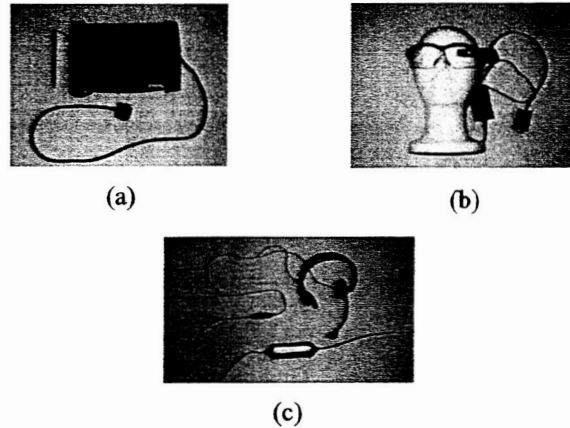


Figure 3: WEVAC Output Devices (a) Xybernaut Flat Panel Display, (b) MicroOptical SV-9 PC Viewer, (c) Plantronics Digital Audio Headset

## 2.4 WEVAC Wireless Communication

An essential feature for WEVAC is the ability to send and receive data via a wireless network. Networking is needed for sharing multimedia data with other computers as well as for general access to the Internet. Wireless communication is needed because the users of WEVAC are expected to be highly mobile and actively performing physical tasks. This means that they cannot afford to be restricted by network cabling. The current system is able to interface with 802.11b-based wireless local area networks (WLANs). The WLAN card currently used is manufactured by Orinoco, and inserted into the wearable computer in Figure 1.

## 2.5 WEVAC Specific Software

The WEVAC system currently is running the Windows 2000 operating system. Although there are many programs stored on the computer, those specifically used in initial experiments presented here include (1) Dragon NaturallySpeaking for speech recognition, (2) Macromedia Authorware Web Player for slide show presentations, (3) Microsoft Windows Media Player for

video playback, and (4) Microsoft Windows NetMeeting for multimedia sharing.

## 2.6 System Integration

All hardware components of the WEVAC system and the appropriate interconnecting cables are attached to a vest which the user can put on and take off conveniently, without having to attach or remove each wearable component to or from the body each time the system is used. The integrative vest is shown in Figure 4.

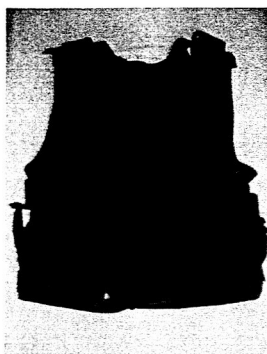


Figure 4: Vest to Integrate the Wearable Components

## 3. Experiments Conducted

With the hardware and software described in the previous section, three voice-driven experiments were set up. Two of these experiments involved self-guided instruction and the third involved remote instruction. Self-guided instruction experiments included one that utilized static multimedia (images and text) and one that utilized dynamic multimedia (video and audio).

### 3.1 Experiment #1: Static Multimedia for Self-Guided Instruction

#### *Experimental Setup*

The first experiment involved accessing static multimedia for self-guided instruction purposes. The term “static multimedia instruction” is used to refer to a set of instructions given as a collection of text and images. A traditional slide presentation is an example of this. This experiment was developed based on a NASA GSFC online tutorial showing how to put on a bunny suit prior to entering the clean room—which was intended primarily to demonstrate the concept of enhanced training. This tutorial was generated as a web-based slide presentation using the Authorware Web Player by Macromedia. Each slide in the presentation represents a distinct step in the process of putting on the bunny suit. Two non-consecutive example slides from the bunny suit tutorial are shown in Figure 5. The slide in Figure 5(a) shows a step early in the process in which the garments are retrieved. The slide in Figure 5(b) represents a step

sometime later in the process where the user is about to put on the gown. Note the corresponding text at the bottom of each slide.

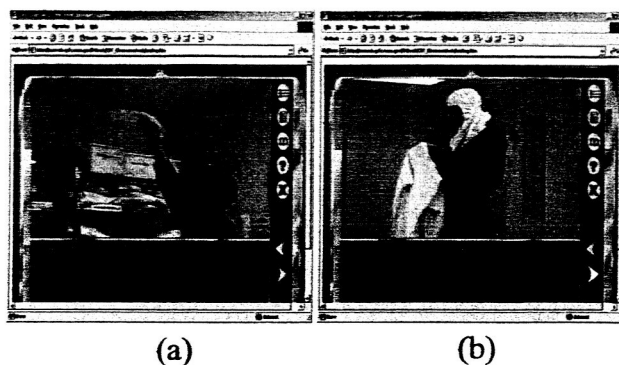


Figure 5: Static Multimedia Example

Now imagine that the person in Figure 5 is equipped with an internet-connected wearable computing system such as WEVAC and can view this tutorial presentation while he is actually in the process of gowning. Alternatives to this would be to either (1) view this tutorial online some time prior to entering the clean room gowning area while taking notes (mental or written), and then taking these notes into the clean room gowning area to refer to while putting on the bunny suit, or (2) carrying an internet-connected laptop computer into the gowning area and referring to the presentation in that way. We believe that the wearable approach would be a more effective and efficient option for learning the bunny suit gowning procedure (given a comfortably attached wearable system) because it would cause minimal distraction to the user, as well as requiring the user to remember fewer steps. The concept for enhancing this simple gowning procedure using wearable computing and static multimedia can be applied to more complicated clean room procedural tasks.

#### *Vocabulary for Static Multimedia Instruction*

In the WEVAC system, the above tutorial was setup to be viewed via voice commands. In this and all other experiments, the user always has the ability to use the built-in Windows navigation vocabulary in the Dragon software (i.e., mouse manipulation, window swapping, etc.). Additionally, each experiment required the creation of a custom vocabulary. For the case of static multimedia access, only two custom vocabulary words were created. These words are shown below, along with a description of the action taken when the words are recognized.

1. **Next** - Progress to the next slide.
2. **Previous** - Go back to the previous slide

#### *WEVAC Custom Command Protocol*

Each custom WEVAC command in this and other experiments follow the same activation protocol. Prior to

the initiation of any custom WEVAC voice command, we assume that the system is in the *Asleep* state, where the only word that will be recognized is the "WEVAC" wake up command. The protocol is as follows:

1. From the *Asleep* state, say "WEVAC" to get the system's attention.
2. Once the beep sound is heard (indicating that you have the systems attention), then say the custom WEVAC command (e.g. "next").
3. Specialized computer instructions will execute based on the custom command recognized.
4. The system goes back into the *Asleep* state and beeps as an indication of this.

The *Dragon NaturallySpeaking* scripting language is used for voice command programming. Programs are stored in *Dragon* voice command files (with the .dvc extension).

#### *Results of Experiment #1*

For this experiment there is a very small custom vocabulary and each of the commands lead to a simple keystroke sequence being sent to the system. Thus, no problems arose related to recognizing and executing the custom commands. The only significant limitation observed while conducting *Experiment #1*, was that the Authorware output didn't fit completely on the VGA screen of the WEVAC system. One solution to this problem would be to utilize a higher resolution wearable display. Drawbacks of this solution would be bulkier (and heavier) display electronics, as well as a large, more obstructive computer screen, floating in front of the user. A more feasible solution to the problem would be to create the static multimedia presentation with a software tool that allows the size of the presentation slides to scale according to the size of the application window (e.g. MS PowerPoint).

### **3.2 Experiment #2: Dynamic Multimedia for Self-guided Instruction**

#### *Experimental Setup*

"Dynamic multimedia instruction" refers to instructions given in video form (with accompanying audio). Additionally, static multimedia may be included as part of dynamic multimedia presentations. For example, it may be useful to overlay a segment of instructional video with bulleted text information. Also, most traditional presentation tools, such as PowerPoint, are capable of including video and audio clips within a presentation. For this experiment, we used Windows Media Player as the instruction delivery tool. We used professionally produced clean room instructional MPEG encoded videos that pertain specifically to microelectronics clean rooms. These videos can serve as a model for other institutions and organizations that want to produce such instructional material. Again, we feel that it would be beneficial for

clean room personnel to view these instructional videos using a wearable computer while in the actual environment working on specialized equipment.

It is important to note that an intermediate process needs to be performed before the videos can be used effectively in the WEVAC system. This process involves segmenting a long video clip into many small clips and is essential for allowing easier voice-activated navigation because the single stream of video (for a particular tutorial) is segmented into clips representing distinct steps in the process. For example, in this experiment an equipment tutorial video was segmented into 24 separate video clips using a video-editing tool. Jumping between major steps in the equipment tutorial only requires skipping from one clip to another (either forward or backward), rather than fast-forwarding or rewinding and visually trying to determine when to stop at boundaries separating major steps of the procedure. The user, however, is still allowed to use fast forward, rewind, and stop commands within a video clip (major step) if needed.

#### *Vocabulary for Dynamic Multimedia Instruction*

Again, the built-in vocabulary for *Dragon Naturally speaking* is used. The customized WEVAC vocabulary for this experiment is given below.

1. **Proceed** – Play video clip from current position.
2. **Freeze** – Pause clip at the current position.
3. **Full Screen** – Display full-screen version of the current video clip being played.
4. **Fast Forward** – Move forward through the current video clip at a high speed.
5. **Rewind** – Move backward through the current video clip at a high speed.
6. **Next** – Jump to the start of the next video clip (next step) and begin playing.
7. **Previous** – Jump to the start of the previous video clip (previous step) and begin playing.
8. **Repeat** – Return to the beginning of current video clip (current step) and begin playing.
9. **Stop It** – Return the clip position to the beginning of the current clip (current step) and stop playing the video.
10. **Volume Up** – Adjust volume upward by one increment.
11. **Volume Down** – Adjust volume downward by one increment.
12. **Volume Mute** – Toggle between muted and non-muted audio.

#### *Results of Experiment #2*

The cited limitations and associated recommendations resulting from conducting dynamic multimedia, self-guided instruction with WEVAC are compiled in Table 1.

Where feasible, the recommendations were implemented on the current WEVAC system, as indicated in the table.

**Table 1: Summary of Experiment #2 Results**

Limitations	Recommendations
Some voice commands associated with long keystroke sequences are not always executed properly on first attempt.	Inserting "wait" commands between individual commands in the voice command script helps. Repeating the commands several times works.
The video output from the Media Player is not seen in the wearable Head Mounted Display	Reducing the graphic acceleration setting to about half of the maximum setting solves this problem.
Speech recognition software performance is greatly reduced by playing video at the same time.	Obtaining a higher performance wearable computer will improve poor performance.

### 3.3 Multimedia Sharing for Remote Instruction

#### *Experimental Setup*

The final experiment was based on the idea of two users, an instructor and a student, being able to share multimedia information through a wireless network. The instructor is envisioned as being stationary in her office during the instruction session, while the student is moving freely in a lab-like learning environment, such as a clean room, while wearing a wearable computer such as WEVAC. The idea is that the instructor and the student may not be able to occupy the learning environment at the same time. For example, the instructor may need to be in her office to conduct office hours, while at the same time one of her graduate students needs assistance from her to perform a very specialized task in the laboratory. In the case of clean room instruction, an instructor may not find it to be useful or efficient to "suit up" in the bunny suit and enter the clean room to help with a minor task.

In this experiment, "sharing of multimedia data" refers to each party (the instructor and the student) being able to observe and control the multimedia information of concern for instructional purposes. Windows NetMeeting fit our needs for this experiment. It was originally intended for teleconferencing purposes over long distances. The key feature of NetMeeting that is useful for remote instruction is the *desktop sharing* feature, which allows either of the users to observe and control the other user's desktop upon request.

A student working alone in a lab may require the assistance of a remote instructor. WEVAC should allow the student to initiate a remote instruction session and communicate verbally and visually with the instructor. In many cases it may be useful for the student to transmit video (using the wearable camera) to his own desktop, and then share his desktop with the instructor. In this way, the instructor and the student will not only be able to see the same view, but if needed, the instructor can take control of the student's cursor in order to point out

specific items of interest in the lab environment in which the instructor is not located. Note that this works ideally when the person sharing their desktop is operating with a lower display resolution than the other person. The person with the wearable system (student) will likely be working with a lower resolution display than the other person (instructor) who will likely be working with very high resolutions offered by modern desktop and laptop machines. In the opposite case where the instructor would be sharing her desktop with the student, her higher resolution screen would not show up completely on the student's lower resolution screen. Thus, the student would have to do some window scrolling in order to access the entire content of the instructor's desktop. This would be inconvenient, but not prohibitive. Fortunately, the first situation of a student sharing his desktop is the more likely scenario. A low resolution display is a short-coming of wearable computer systems, but the technology for these displays is evolving.

#### *Vocabulary for Remote Instruction*

Below is the custom vocabulary developed for Experiment #3.

1. **Send Video** – Start transmitting video frames from the WEVAC camera.
2. **Snap Shot** – Hold the current video frame.
3. **Hang Up** – Disconnect from current remote session with instructor.
4. **Single Size** – Return the selected video window to its original size.
5. **Double Size** – Make the selected video window twice its original size.
6. **Triple Size** – Make the selected video window three times its original size.
7. **Quadruple Size** – Make the selected video window four times its original size.
8. **Share Desktop** – Share WEVAC desktop with remotely connected user and automatically allow control of desktop when requested.
9. **Accept Calls** – Accept incoming calls automatically.
10. **Unshare** – Disable sharing of the WEVAC desktop.
11. **Do Not Disturb** – Prevent incoming calls from being seen or heard.

#### *Results of Experiment #3*

The cited limitations and associated recommendations resulting from experimenting with remote instruction using WEVAC are shown in Table 2. Again, where feasible, the recommendations were implemented on the current WEVAC system.

**Table 2: Summary of Experiment #3 Results**

Limitations	Recommendations
With a single microphone, only the speech recognition or the remote audio communication can be implemented at any given time, but not both.	Using two microphones, one for speech recognition and the other for remote audio communications corrects this. (USB technology makes this possible)
USB-based video and USB-based audio connected simultaneously cause overload on USB resources	Replacing the USB-based camera with a FireWire-based camera corrects this.
Communication lag for all types of data.	Ensure high bandwidth network availability.

#### 4. Conclusions

In summary, we believe the WEVAC system is useful in clean room environments for the following reasons:

- 1) The clean room is a manual work-intensive environment that could benefit from hands-free computer use.
- 2) Higher fidelity training is possible because the actual environment is used for training, leading to better overall performance of tasks.
- 3) More efficient training is possible, which requires less time, less people, and less paper documentation.
- 4) Contamination of the clean room environment with wearable computer systems is less of a concern than with traditional systems because the wearable computer can potentially be concealed within the bunny suit.

We were successful in demonstrating the possibility of using a wearable computer system for instructional enhancement in both the NASA and academic clean room environments. Self-guided and remote instruction experiments were conducted using NASA's WEVAC system. At the time of these experiments, commercial wearable computing devices were still too bulky to be concealed within a clean room bunny suit comfortably. Thus, a usability analysis in practical clean room situations was not feasible. Our experiments with the WEVAC system lead us to recommend that wireless technology be used as much as possible for interconnection between the wearable computer and peripheral devices in the future. This is due to the problems encountered when trying to conceal the system cables while attaching devices to the integrative vest. The next generation of WEVAC is expected to take advantage of the latest advances in computing and communication technology. The next WEVAC system can expect to have a smaller more powerful CPU, with many of the input/output devices connected wirelessly by way of Bluetooth or Ultra Wideband (UWB) technology.

Future research will compare the performance of a fully wearable system (like the current WEVAC system) to that of a system where only the I/O is wearable. In a *wearable I/O only* system the Head Mounted Display,

audio headset, mouse and keyboard will be interfaced to a non-wearable computer via wireless connections. Another wearable computer system variation to be examined is one in which a lighter-weight, less power-hungry Palm PC-type device (perhaps Windows CE-based) could be incorporated as a wearable, wireless, remote terminal for a high-performance desktop machine. It will be interesting to assess the pros and cons of these three systems across a wide range of educational enhancement related applications. Factors that will be of interest in the evaluations would include (but not be limited to) power consumption, heat dissipation, I/O and computational latency, bulkiness, and reliability [4,5].

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