Improving the Capture and Re-use of Data with Wearable Computers[1]

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Abstract

At the Goddard Space Flight Center, members of the Real-Time Software Engineering Branch are developing a wearable, wireless, voice-activated computer for use in a wide range of crosscutting space applications that would benefit from having instant Internet, network, and computer access with complete mobility and hands-free operations. These applications can be applied across many fields and disciplines including spacecraft fabrication, integration and testing (including environmental testing), and astronaut on-orbit control and monitoring of experiments with ground based experimenters. To satisfy the needs of NASA customers, this wearable computer needs to be connected to a wireless network, to transmit and receive real-time video over the network, and to receive updated documents via the Internet or NASA servers. The voice-activated computer, with a unique vocabulary, will allow the users to access documentation in a hands free environment and interact in real-time with remote users. We will discuss wearable computer development, hardware and software issues, wireless network limitations, video/audio solutions and difficulties in language development.

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1. INTRODUCTION

The world is becoming more and more dependent on computers. Many applications can be found which would benefit from the development of smaller, faster computers, and video and audio products capable of being worn by the user. The era of the next generation of personal and business computers is rapidly approaching. This allows for mobile computing not only in a lab setting, but also in the real world tasks. These smaller, more powerful computers, coupled with cameras and microphone technology, allow communication and collaboration with others while working on a task. The benefits are evident in areas such as clean rooms, space shuttle engine checkout, pre-launch checkout and on-orbit activities. Wearable computers will become strategically important to NASA for many uses including collaboration. A single technician could provide a live video stream of her activities via the web while performing tasks that require the use of her hands. Experts could share their knowledge with her from anywhere in the world. This would contribute toward the goal of reducing the number of people required in a clean room, around a thermal-vacuum chamber and in other situations requiring video/voice conferencing using on-self computing resources and hands free operations. A single expert could monitor (and instruct) multiple technicians even when they are deployed to different areas, all via video streams over the web. This would integrate computers and humans working in diverse geographical areas. The voice-activated computer would allow the technician to annotate the steps completed on a list of activity procedures, document any changes, and send those changes to others participating in the activity. Also if a new procedure is available, it could be accessed via the voice-activated computer over the wireless network. Astronauts could use small, light wearable computers to reference procedures and manuals, while keeping their hands free to perform their work. They could also communicate with experts on the ground with this device, alleviating the need to find/grab an off-body microphone. In many cases, the electronic drawing board (which all parties could see) could be used for communicating detailed descriptions. Specialized languages to aid a speech interface to the computer will pave the way for these activities to happen much more quickly.

Kennedy Space Center representatives have expressed interest in this project and the possibility of using wearable computers during space shuttle main engine checkouts. Currently, technicians use a digital camera to take pictures, then, when finished, email them to experts. Once the expert receives the pictures, it may be too late to see other angles. A technician with a wearable computer could be guided to the best views by remotely located experts. The experts could pick out damaged spots more reliably than could the technicians. The video and still shots would be seen in real-time while better views could still be requested. Better safety and design related decisions could then be made. The video and still shots could be archived for future reference.

With all these applications in mind, the Wearable Voice Activated Computer (WEVAC) Project was initiated, with minimal funding and with part-time efforts of the personnel involved, to develop and test out a wearable computer. The initial system needed two software components. First, speech recognition software was needed in order to free the user's hands as much as possible while using the computer. Also, collaboration software was needed to enable conferencing and collaboration amongst users. For hardware, the system needed a CPU, a camera, a microphone, and a display system. All of these components had to operate using batteries.

The focus of this project is to investigate the current state-of -the-art in both complete wearable systems and systems integrated from individual components. We want to see which elements of the systems are ready for use and which elements need to evolve. We hope to drive or at least encourage the manufacturers of these components to create the devices with the features NASA needs. We want to see what we can do with language and collaboration software to improve functionality as well. At Goddard Space Flight Center, there are several environments where a hands-free, wearable, wireless, and voice-activated personal computer would be a desirable device to have. By working with engineers here at Goddard and also with Kennedy Space Center and Johnson Space Center personnel, the goal is to implement a WEVAC into some of the work that goes on at Goddard and NASA as a whole. The goals for the future are to use NASA applications on a WEVAC and test how a prototypical WEVAC would perform in spacecraft testing, inspections, and collaboration environments.

2. WORK ACCOMPLISHED

The first things we considered were complete systems, including the Xybernaut Mobile Assistant IV, the Microvision Wearable Display System, The Computex Taipei 2000, and the SyVox Speech Data Terminals. We saw demonstrations of the Xybernaut systems in particular. These are very good systems, and they fired up our enthusiasm and convinced us that this technology will transition from the research lab to mainstream use within a matter of years. Since our research (Gartner Group, other visionary groups) has shown that this architecture will replace a majority of desktop and laptop systems, we expect that NASA will be buying systems from these companies or similar ones in the future. For our research effort, however, we did not choose to buy a complete system for two primary reasons. First, the CPUs clock speeds in the complete systems were only about 200MHz – we needed more CPU power for video applications. Secondly, we thought we'd learn more about each component by researching the individual markets, buying the best we could find, and integrating them ourselves.

So, the work accomplished on the WEVAC project entailed researching, procuring, and testing available software and hardware components. We first researched the different speech recognition and collaborative software available. Once the best packages were identified, we began to research the hardware. This involved researching the specifications of different units, price, and other factors. Once different components had been purchased, they were put together as prototype units. We then tested how well these units performed in work-like conditions. One sizeable task was to create a grammar set that the speech recognition software could recognize and execute successfully. This was accomplished through research in the programmable portion of the software and through the employment of a software development kit. Another task was employing wireless networking into the units, thus making the unit mobile. This coupled with having to fashion a battery in-house for one of the units, proved to be another challenging task. To make the battery, two smaller commercial batteries were linked together from a suitable power source. The prototype unit had shortcomings, but provided useful insight to the future of wearable personal computers.

Our initial goals for the first prototype were:

1) Assemble a wearable, wireless, voice-activated computer.
2) Implement collaborative and speech recognition software into this unit.
3) Demonstrate the operability of a WEVAC.
4) Study the human interface factors from using such a unit.

To accomplish these goals, we performed many tasks including:

1) Installing, testing, and analyzing collaborative and speech recognition software packages
2) Researching the components that would comprise a prototypical WEVAC
3) Ordering, testing, and analyzing the WEVAC.
4) Document progress and the advances of the project overall

3. SPEECH RECOGNITION SOFTWARE

As stated above, in order to achieve a completely wearable device with hands-free operation, the system must have a robust speech recognition capability. Therefore, several speech recognition packages were tested. The goal for this type of testing was to find a package that could be used to work with our prototype unit. The packages that we considered were chosen based on the ability to recognize the user's voice with minimal error and enable the user to manipulate the desktop in a customary manner. Based on this, three packages were chosen to be tested: Dragon Naturally Speaking, L&H Voice Express, and IBM ViaVoice. Several members of the WEVAC team tested these packages and tabulated their findings.

The evaluation factors were as follows:

1. Installation Time
2. Impact to overall speed of machine
3. Amount/Frequency of Disk Access Required
4. Installation difficulty
5. Installation instruction clarity
6. Training process time
7. Training process difficulty
8. Ease of Use
9. Free speech accuracy in quiet conditions
10. Free speech accuracy in more noisy conditions
11. Use of menus in a package (like MS Word)
12. Ability to work with varying voice volume
13. Ability to work with Windows directly

The following phrases were spoken to the package to test comprehension:

1. Undo the last step
2. Go to Page 53
3. Find annex A
4. Step 46 completed
5. Sheet 21, move to right
6. Next page
7. Drawing 10 zoom in
8. Close book
9. Undo the last step, go to page 53 and find annex A.
10. Step 46 completed, move sheet 21 to the right.
11. Next page, open drawing 10 zoom in and close book.

Overall, L&H Voice Xpress received the highest ratings using the evaluation factors. Thus, it was chosen as the speech recognition software to be used in conjunction with the wearable computer. However, it should be noted that none of the speech packages provided the accuracy needed to enable a user to be completely hands free. The basic vocabulary set provided in the speech packages was too large and did not provide the capability of going to a particular spot in the document and annotating. All of the testers 'trained' the voice recognition software before exercising the test phrases. The two general problems with the training programs were inability to keep up with the speaker's natural speaking speed, and inadequate word recognition. These were very frustrating to the testers. The age and gender of the tester made a difference in the training results, however a pattern could not be validated without a much larger group of testers.

All three packages were sensitive to varied background noise. The pitch of the background noise also made a difference. The general office and facility noises, except a loud air conditioner, did not seem to impact any of the software packages. One of the portable computers had a fan that seemed noisy, which influenced the initial noise checks and caused more failures than the software exhibited on a different computer.

All users reported that free speech accuracy was poor to unusable. Most users also reported that the mouse and keyboard would be preferred at all times over the voice recognition software. In free speech mode all users reported accuracy problems from an 80 to 30 percent failure rate. The failures included misspelled words, missing words, or additional words. Also varying the tester's voice changed the accuracy rate. Individuals normally do not talk in a monotone voice in a real world environment.

Each package performed fairly well for the limited word sets used to navigate the computer file system and application windows. These word sets include file, open, close, exit, etc. However the testers reported quicker responses by using keyboard or mouse.

Some examples of the free speech mode are below:

Tester spoke: select automatic inventory
Computer: so let ought to manage in the Tory

Tester spoke: select automatic inventory
Computer: feather that I had a inventory

Tester spoke: select fantastic
Computer: slow lack didn't have that

Tester spoke: select fantastic success
Computer: The lack and passed the success

Tester spoke: Accuracy of representing dictation was, at best 50%, and most sentences made absolutely no sense.
Computer: Act receivers presenting dictation was, at best 50%, and most centers is made absolute nonsense.

The next step is to develop a limited language set with specific functions. This not only would make the language software more accurate, but also quicker in accomplishing the desired task. The WEVAC would contain several of these language sets which could be applied to specific applications and environments.

4. Collaborative Software

Another type of software that is essential to the successful operation of a WEVAC is collaborative software. Many of the envisioned applications for this unit involve the user having conferencing capabilities with another person. A similar process was used to choose a collaborative software package. This time, four packages were tested: Microsoft NetMeeting, I-Visit, CU-SeeMe, and Clearphone. The factors for the evaluation of these packages were:

1. Installation Time
2. Installation Difficulty
3. Installation Instruction Clarity
4. Video Picture Quality
5. Video Speed
6. Audio Clarity
7. Ability of Package to slow down machine
8. Ease of Use
9. Easy of program sharing with other applications
10. Ease of Chat Box use
11. Ease of File Transfer/Display
12. Ability of PC users to collaborate with Mac Users
13. Overall Satisfaction

NetMeeting was the clear choice, based on the evaluation factors, for our collaborative software. The audio/video capabilities added features, and ease-of-use made NetMeeting the preferred choice for collaborative software on the WEVAC.

5. Hardware

After the software had been chosen for the WEVAC, hardware had to be procured and assembled to create the prototype unit.

5.1 *System Unit*

For the actual system unit, we had several specifications to consider. We wanted a processor with a speed of at least 400 MHz and 64 MB RAM. This may seem a bit powerful, but when one considers the kind of video and voice capabilities along with the software that must be installed, these specs become minimal, especially for the RAM. We also knew that we would need a USB port for a mouse/trackball, a PCMCIA port for a wireless LAN connection, and a large enough hard drive to handle all of our applications comfortably. After much research and deliberation, two units were chosen: the Sony Picturebook and the SaintSong Pocket PC.

The Sony Picturebook offers all of the features that we wanted for our unit. It is lightweight, has a 400 MHz processor, 128 MB of RAM (upgraded), a USB port, a PCMCIA slot, and a 6 GB hard drive. The only drawback is that it is a notebook and thus has its own display; the WEVAC team had envisioned a unit with a heads-up display for the user interface. This unit had a price tag of around $2000.

The second unit, the Saintsong Pocket PC, boasts a 533 MHz processor, 64 MB of RAM, a 4 GB hard drive, and two USB ports. This unit is also very lightweight (2.2 lbs.) and lacks a visual display of its own. This makes it a good fit for our wearable computer. There are two main drawbacks with the SaintSong unit however. First of all, there is no battery currently available for this unit and that hinders its ability to be part of a completely mobile system. Secondly, it lacks a PCMCIA slot, so we have no means of accessing the wireless network with the SaintSong unit. Still, this unit's size and functionality make it an intriguing piece of equipment. Combined with some of the Picturebook's features, this unit could be the future of WEVAC.

5.2 *Displays*

The second main portion of hardware that had to be considered was the heads-up display. The WEVAC team wanted to find a lightweight, VGA-compliant unit that would give a readable display without impairing the peripheral vision of the user. The team felt that 640 x 480 pixel resolution was the lowest level resolution that would yield positive results. With these factors considered, two displays were chosen: the Micro-optical clip-on display and the Olympus Eye-trek. The Micro-optical unit has only 320 x 240 pixel (QVGA) resolution, but offers superior peripheral vision for the user, optimizing the ability to see the work environment while using the display. It is extremely lightweight and can be used in conjunction with everyday eyeglasses.

The Eye-trek has a great resolution (800 x 600 pixel) but has two drawbacks. First, the unit inhibits some of the vision, covering a good portion of one of the user's eyes. Secondly, this piece of equipment does not re-create the user's display as one would see on a regular PC. Instead this eyepiece creates a blank screen that is an extension of the regular PC screen. This means that Windows have to be dragged into the extension to be seen, making this unit less easy to use. However the resolution of this unit is impressive.

In the future, the WEVAC team envisions a heads-up display, which has both the weight and visual freedom of the clip-on display and the superior resolution of the

Olympus display.

5.3 *Wireless Communication*

The WEVAC group decided to use the 802.11 standard for wireless local area networking. The IEEE 802.11 standard supports transmission in infrared light and two types of radio transmission within the unlicensed 2.4GHz frequency band. This allows for a range of 200 to 600 feet in real world applications, without the interference experienced with the 900 MHz range.

The use of wireless networking presents possible concerns with unauthorized access, data integrity, password interception, and session hijacking. We settled on the Cisco and Lucent products utilizing spread spectrum technology that was designed to be resistant to unauthorized access or interference. The Lucent WaveLan product offers two levels of data encryption, 64-bit and 128-bit keys. However, using encryption reduced data throughput. Cisco products require a service set identifier (SSID) code with over 16 million possible values; no wireless client can access the RF wireless network unless they have the correct SSID security codes. In addition, wired equivalency privacy (WEP) is used to ensure that captured RF waves cannot be intercepted for content or potential modification. To ensure the integrity of the data, 128-bit key encryption is used to encrypt the data before it is transmitted through the airwaves. Any packets received by the wireless network that is not encrypted with a valid key will be discarded.

The future of wireless technology in increasing the data rate from the current 11 MBps looks promising. The increase is needed to provide better quality video and audio in a collaborative environment. Firewire wireless appears to be the next step at this point .The WEVAC project will test this capability when it becomes available.

5.4 *Video cameras*

The last area, which is still being explored, is the video camera that would allow the wearable computer to share what the user is seeing with other collaborators. The fixed focal length cameras, which are small, light weight, and use little power, do not present a true picture. There is a bowing effect that at times can misrepresent the activity occurring. The zoom cameras are much better, but weigh over four ounces and use a lot of power that, on a wearable computer, is a limiting factor. At this time the WEVAC engineers are communicating our form factor and weight concerns to the vendors of these cameras and encouraging them to improve their current models.

6. SUMMARY/FUTURE ENDEAVORS

We have assembled a prototype unit linking the Picturebook and the Micro-optical clip-on display. Figure 1 shows the architecture of this system. This unit was demonstrated by the project's two summer students, Daniel Green and Becky Williams. This WEVAC had full wireless capability and enabled the user to operate relatively easy within the Windows 98 operating system.

However, many challenges lie ahead for this project. Speech recognition development will be a large area of study for the future. It will be necessary to develop specific vocabularies for the speech package to recognize. These vocabularies will more than likely come from NASA applications and limit the amount of error in recognition for the speech recognition package. We have proposed a research project to develop a process to reduce the time to create custom vocabularies. To speed up development, our language development process will involve tools for language generalization so that similar environments can share a generalized description of a language (macro language) and this can be used to quickly generate other similar verbal languages. Also, it will be critical to find ways to minimize the space taken up by wearing the WEVAC. Another area still to be explored at length is battery life. Private industry is working on several different solutions for commercial users and WEVAC hopes to leverage this into a 6 to 8 hour life of the WEVAC before recharging or replacing batteries is needed. Currently, the prototype is relatively large, but once prototype models are available for testing, the human factor engineering effort will dictate the changes in its current form most important to the users. Obviously, one area of effort will be to gain more funding for future prototypes and more equipment. Also, the WEVAC team hopes to find other environments here at Goddard and other NASA sites to test the capabilities of our units. This is the only way that the unit will be truly tested.

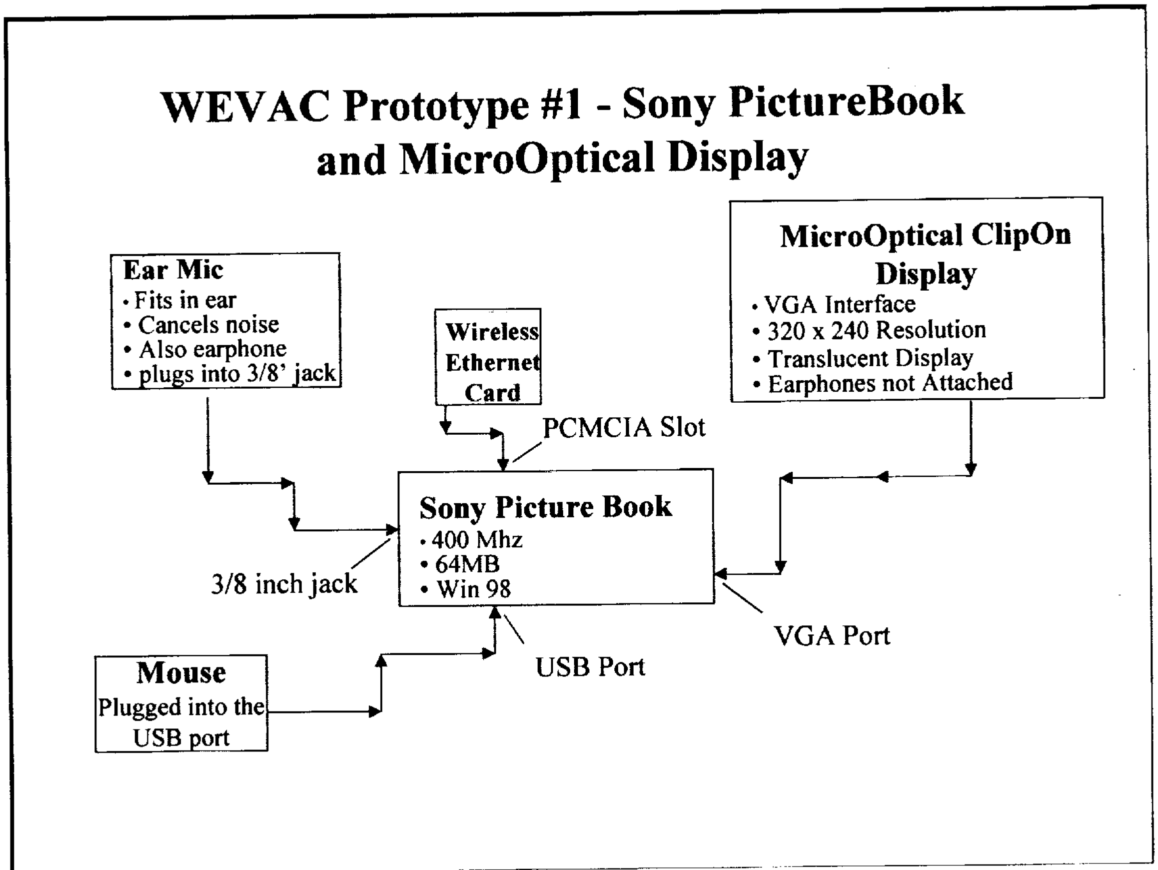

Figure 1 – WEVAC Prototype #1

7. REFERENCES

The summary report for the collaborative software testing evaluations. This can be viewed at the following URL:

http://www.wff.nasa.gov/~WEVAC/Documents/collaborative_test_report.htm

The report justifying the choice in hardware can be viewed at the following URL:

http://www.wff.nasa.gov/~WEVAC/Documents/Justification_hw.htm

These along with other documentation can be viewed from the website, which includes links to corporate sites for all hardware and software used for the WEVAC project and all products mentioned in this paper. This URL is:

http://www.wff.nasa.gov/~WEVAC/index.html

9. BIOGRAPHIES

Barbara Pfarr is the Head of Goddard Space Flight Center's Real-Time Software Engineering Branch, which develops Command and Control systems for integration and test and on-orbit operations of Earth and space science missions. This branch includes approximately 55 people working at both Wallops Flight Facility and Greenbelt on a large variety of projects and systems, including the Hubble Space Telescope, the Small and Medium Explorer Missions, Landsat 7, Triana, Terra and Aqua, EO-1, Sounding Rockets, and Ultra-long Duration Balloons. She received Goddard's Outstanding Management Award in 1999. Prior to this, she was the Hubble Space Telescope Observatory Management Systems (HSTOMS) Manager, responsible for development and maintenance support of the Hubble ground systems at Goddard. She received NASA's Spaceflight Awareness Award and Goddard's Exceptional Achievement Award for these efforts. She received a B.A. in mathematics and astronomy from Smith College in 1981 and a M.S. in Computer Science (concentration: Artificial Intelligence) from Johns Hopkins in 1991, and a M.S. in Computer Science (concentration: Graphics) from George Washington University in 1998.

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Daniel Green is a student at the Georgia Institute of Technology, majoring in electrical engineering. He attended Morehouse College from 1997 until Fall of 2000. He worked at Goddard Space Flight Center in the summer of 2000 as a Morehouse College Project Space Intern. Daniel is demonstrating WEVAC Prototype #1 in this photo.