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Abstract

A novel class of mobile, wearable computer systems designed and manufactured at Carnegie Mellon University is described. These wearable systems provide a variety of capabilities including head mounted display, speech recognition, wireless telecommunication, and global position sensing. The mobile computer emphasizes the integration of computer supplied information in the mobile workspace. Three generations of wearable computers representing an evolution in capabilities are described: VuMan 1, VuMan 2, and Navigator}

1 Introduction

Carnegie Melton University has designed and manufactured three generations of mobile computers: VuMan 1 [1], VuMan 2 [2], and Navigator [3]. The next two generations, VuMan 3 and Navigator 2, are under development. Mobile computers deal in information rather than programs, serving as tools in the user's environment much like a pencil or a reference book. Much like personal computers allow the accountants and bookkeepers to merge their information space with their workspace (i.e., a sheet of paper), mobile computers will allow mobile processing and the superimposition of information on the user's workspace. The mobile computer provides automatic, portable access to information. Sensors make the mobile computer an active part of the environment. Information can be automatically accumulated by the system as the user interacts with and modifies the environment, thereby eliminating the costly and error-prone process of information acquisition. Mobile computers are characterized by a modular architecture, which can be custom configured to a particular application. The modular design enables the system to be adaptable to the needs of the user.

2 Architecture of Mobile Computers

Mobile computers tightly integrate telecommunications, sensors, speech/gesturing/displays for the human/computer interface, real time software, and low power electronics housed in a conformable/light-weight package. A mobile computer consists of a number of modular, interconnected components, customized for the task being performed. Example *modules* include:

- Display, such as the head mounted Private Eye.
- Speech input (microphone) and Speech recognition, for interpreting user commands.
- Position sensing, which determine the user's location.
- Motion sensing, to recognize actions being performed by the user.
- Wireless telecommunication, for transmission of data to/from remote databases or computational servers.

Also, there may be a number of stationary devices for providing infrastructure, such as:

- Position sensing, for detecting the location of the user within a geographic area.
- Centralized databases, to maintain up-to-date information.

Table 1 illustrates sample applications and the associated modules. *Referential Systems* replace large volumes of printed materials such as maintenance manuals. *Manufacturing Systems* provide individualized and detailed work sequences in domains such as building and aircraft construction. *Information Sharing Systems* allow teams, such as firefighters, to coordinate activities.

CMU has developed architectures for Referential Systems (VuMan series) and Manufacturing/Information Sharing Systems (Navigator Series). Due to the human factor in mobile computers, these systems must be rapidly prototyped and evaluated by actual use. The next section briefly describes the first three wearable systems built by CMU.

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Applications	Display	Replaceable DataBase	Speech input	Position Sensing	Telecommunication
Referential Systems	•	•			
Manufacturing Systems	•	•	•	•	
Information Sharing Systems	•		•	•	•

Table 1. Mobile computer modules necessary for a selection of applications.

3 Three Generations of Wearable Computers

Over a 12-week period during the summer of 1991 four designers representing electronic, mechanical, industrial design, and software disciplines conceived, designed, and manufactured 30 copies of VuMan 1 in a total of 229 person days of effort VuMan 1, Figure la, was designed and implemented to be a small wearable computer weighing less than one kilogram for displaying construction blueprints. VuMan 1 allows the user to maneuver (scroll up/down, left/right; zoom in/out) through a set of blueprints using a simple, multi-button interface and a head mounted display, Reflection Technology's Private Eye [4].

VuMan 2, developed during the fall of 1992, required about half the effort but yielded a factor of four improvement in cost, power consumption, weight and functionality. Composed of only five chips, VuMan 2 provides a menu driven user interface for displaying a variety of information including maps, images, and text. VuMan 2 can display maintenance information, Figure lb, or, with the change of a PCMCIA card, allow a user to locate a person or a building on campus using limited information such as the person's names, the building's name, or general directions.

During the spring of 1993, 20 designers produced Navigator with 50% more effort than VuMan 1 but with over an order of magnitude more functionality.

4 The Navigator Mobile Computer

A modular "mix-and-match" architecture allows multiple configurations for Navigator, Figure lc. The display is driven by a 25 MHz Intel 386 processor running X Windows [S] on top of the Mach operating system [6]. Composed of a 16 MB main memory and a 85 MB disk, this processor also runs the Sphinx 1 speech recognition system [7]. A cellular phone provides wireless communications and a Global Position Sensing module provides position information.

The specifications for Navigator included:

- Dual mode of user input: speech and portable mouse
- Speaker independent, continuous speech recognition, with 200 words vocabulary, 90% accuracy
- Text and Graphics on 720x280 Private Eye display
- On board database of information and maps
- Differential Global Position Sensing (DGPS) to within 5 meters
- Modem/wireless communication with remote site
- Customized X server

The final Navigator system is based on a modular design in which each module performs a specific function, such as speech recognition, visual display with the customized X server, position sensing, and wireless telecommunication. The major modules are:

- Ampro LittleBoard/386SX processor, running Mach operating system, with the following main attachments:
    - Analog to digital converter board, 16 KHz
    - Two custom boards: on-set of speech detection, and power regulation
    - Head-worn microphone attached to the A/D board
    - Private Eye Display Card via an AT bus
    - 85 MB hard disk
    - Portable mouse
- Differential Global Position Sensing (DGPS) system, based on NavCore V GPS modules
- Wireless telecommunication, with base station and cellular phones connected to a modem.

An example of the Navigator screen showing the CMU

(a)

(b)

(c)

Figure 2:

(a) VuMan 1 with head mounted display used with construction blueprints.

(b) VuMan 2, a wearable computer with enhanced functionality, lower weight and lower power consumption, configured for an electronic maintenance application.

(c) Navigator, a modular wearable computer with speech recognition, global position sensing, and cellular phone. Mounted in the small of the back, Navigator can provide up to eight hours of hands free operation.

Table 2 Characteristics and attributes of the CMU mobile computers

a)

Artifact	Delivery date	Number of units	Embedded/ GP	Design Style	*ofc'!stPm. Boa s :hip Suit	#ofoff-the-shelf Boards	Lines of new code
VuMan 1	Aug91	30	embedded	semi-custom	1/24	1	1800
VuMan 2	Dec 92	7	embedded	fully-custom	1/5	0	4700
VuMan 3	Jun94	5	embedded	fully-custom	1/8	0	-
Navigator	Jun93	3	general purpose	design by composition	3/15	5	38000

b)

Artifact	Processor	RAM/ Nonvolatile storage	Input	Display resolutk)I1	Dimensions iinches)	Power m	Weight (Ibs)
VuMan 1	80188 8 MHz	8KB 512KB	3-button	720x280	2.5x5.5x12	3.8	3.3
VuMan 2	80C188 13 MHz	512KB 1MB	3-button	720x280	1.5x4x4.4	1.1	0.5
VuMan 3	80386SL 20 MHz	2MB 40MB	rotary multi-posit switch	720x280	2x4x5.8	2	0.7
Navigator	80386 25 MHz	16MB 85 MB	speech mouse	720x280	3x8x10	13	9

Campus map and a path between two locations is shown on Figure 2.

5 Comparison of the CMU Mobile Computers

Table 2 shows the characteristics and attributes of four generation of mobile computers. The implementation of VuMan 3 is currently in progress, and therefore some of its values are estimated. Table 3 depicts resource organization mechanisms for the four projects addressing the issues of personnel assignment, use of development platforms, and mechanisms of communication among the project participants. For example, Navigator software evolved ova: four platforms: workstation to verify algorithms, PC to verify functionality in target operating system, open air target system to verify operation on the final hardware platform, and

TaWe3 Resource Organization for the four generations of wearable computers.

Artifact	**Personnel**	**Platforms**	Communication
VuManl	Static Assignment	None	None
VuMan2	Static Assignment	PC	Weekly meetings
VuMan3	Static Assignment	PC	Weekly meetings, inter-group mechanisms
Navigator	Dynamic Assignment	workstation, PC, open air target system	Numerous intergroup mechanisms

Table 4 Distribution of Design Effort and Disciplines for four generations of wearable computers

Artifact	**Technology Assessment (Phase I, II, m)**	**Design Phase IV**	**Implementation Phase V, VI**	**Total Effort (Persondays)**
VuManl	**33%**	**50%**	**17%**	229
VuMan2	**17%**	**55%**	**28%**	138
VuMan3	**20%**	**45%**	**35%**	160
Navigator	**28%**	**38%**	**34%**	389

Artifact	**Electronics**	**Mechanical**	**Software**	**Total Number of** Designers
VuManl	55%	39%	7%	4
VuMan2	41%	28%	31%	6
VuMan3	37%	22%	41%	6
Navigator	34%	17%	49%	20

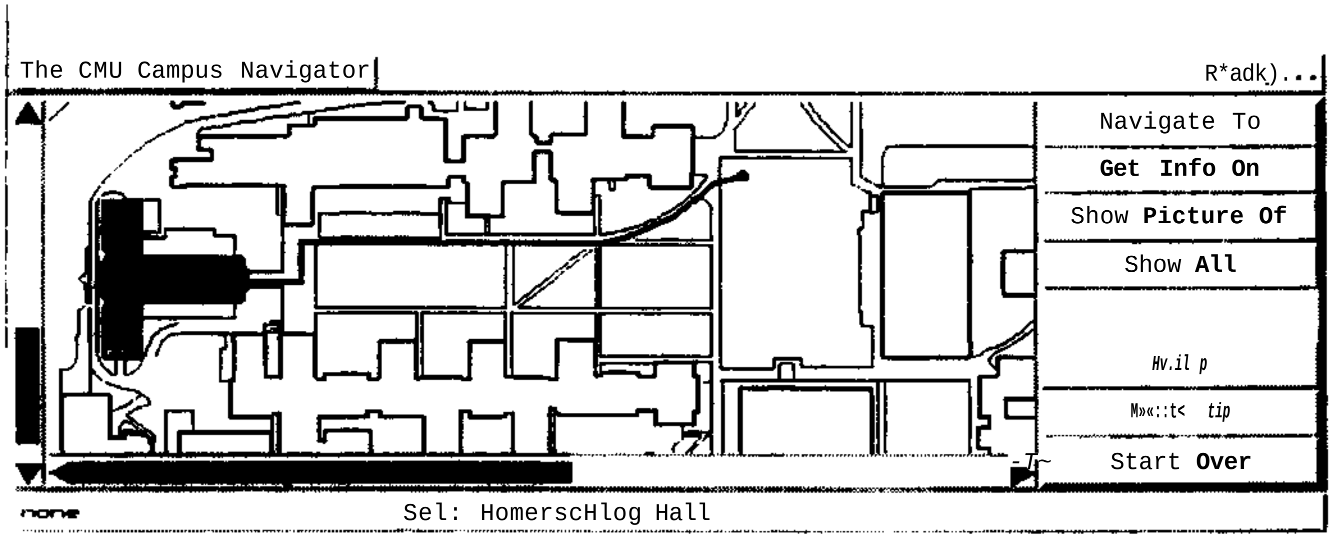

Figure 2: Navigator user screen, with the CMU Campus map and a path generated from the user to Hamerschlag Hall

the final wearable system.

Table 4 summarizes the design effort among phases in the design and between disciplines. Phases I, II, and III in the Technology Assessment column refer to the following phases: Technology Survey, System Architecture Specification, and Subsystem Specification. Since both VuMan 2 and VuMan 3 represent an evolution along the line of our embedded systems, initiated with VuMan 1, the Technology Assessment phases could be shortened. The implementation phase steadily increased in relative effort as the complexity of the systems increased.

6 Summary and Conclusions

In this paper we have described two classes of mobile, wearable computer systems designed and manufactured at CMU: VuMan and Navigator. VuMan-class computers provide referential access to information such as manuals. Navigator-class computers sense the user's position in the environment and provide information relative to that position.

Several classes of applications have been identified requiring different capabilities. The first class requires access to a large, relatively static data base for reference in completing a complex task. Typical referential applications include maintenance and operation procedures. A referential wearable computer which provides access to maintenance information while leaving hands free to perform the required physical operations could be an effective way to improve productivity. Several VuMan 2 and VuMan 3 units will be evaluated in a maintenance activity with the U.S. Marines.

The CMU Navigational computers include the ability lo register the position of the system in the environment so that information can be superimposed on the user's workspace with speech recognition for hands-off operation. Navigator 1 will be used by Boeing to access the effectiveness of mobile computers in aircraft manufacturing.

Mobile computer systems of future are going to be highly customized. A modular architecture can be custom configured to a particular application, as demonstrated by both VuMan and Navigator classes of mobile computers.

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